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Synergy Between AI and Robotics: A Comprehensive Integration

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The emergence of artificial intelligence is mostly linked to software-driven robotic systems, including mobile robots, unmanned aerial aircraft, and, to a growing extent, semi-autonomous automobiles. Nevertheless, the significant disparity between the algorithmic realm and the physical realm hinders current systems from achieving the desired outcome of creating intelligent and user-friendly robots that can effectively engage with and manipulate our human-centric environment. The nascent field of machine intelligence (MI), which combines robotics and artificial intelligence, strives to develop reliable and embodiment-aware artificial intelligence systems. These systems possess self-awareness and an understanding of their environment, enabling them to adapt to the interacting body they are operating. The incorporation of artificial intelligence (AI) and robotics into control, perception, and machine-learning systems is necessary for the realization of fully autonomous intelligent systems in our everyday existence. This review provides an overview of the historical development of machine intelligence, tracing its origins to the twelfth century. It then proceeds to examine the present state of robotics and artificial intelligence (AI), discussing

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significant systems and contemporary research directions. Additionally, the article outlines the remaining challenges in these fields and speculates on the potential future of human-machine interactions that has yet to be realized.

Keywords: Synergy; AI; robotic systems.

1. INTRODUCTION

The convergence of robots and artificial intelligence (AI) is rapidly emerging as a catalyst for the development of novel industries, state-of-the-art technology, and enhanced productivity and efficiency across established sectors [1]. The ongoing development of artificial intelligence (AI) in the field of robotics is leading to a growing recognition of its practical applicability in various real-world contexts [2]. Artificial intelligence (AI) is significantly contributing to the transformation of various industries and enhancing the quality of everyday life. It applications ranges from self-driving automobiles, customer service and healthcare to industrial and service robots [3]. Despite apprehensions around the potential displacement of human labor by AI and robotics, the World Economic Forum (WEF) forecasts a net increase of 12 million employment resulting from the use of this technology by the year 2025 [4]. The current expansion offers a favorable circumstance for the retraining and acquisition of new skills among the workforce, as well as the allocation of resources towards knowledge development that is in line with the most recent technological advancements [5].

The integration of artificial intelligence (AI) and robotics holds significant promise for transforming work responsibilities in many sectors. This includes the automation of repetitive operations within manufacturing facilities, as well as the introduction of adaptability and cognitive capabilities into monotonous applications. The potential applications of artificial intelligence (AI) in the realm of robotics are many and diverse, rendering it a captivating area of study and comprehension. Continue reading to get further knowledge about robots and artificial intelligence, as well as discover ways in which you may actively contribute to the future development of this significant sector [6,7].

1.1 Robotics

Robotics is a multidisciplinary field that encompasses the design, construction, operation, and use of robots. Robotics is a discipline within the fields of engineering and computer science, encompassing the conceptualization, fabrication, and utilization of robots endowed with the ability to execute predetermined actions autonomously, hence obviating the need for human intervention [8]. Fundamentally, the field of robotics revolves around the utilization of technological advancements to streamline and enhance the efficiency and safety of various jobs through automation. Throughout history, robots have been employed to carry out tasks that are deemed arduous or hazardous for human beings, such as the lifting of heavy machinery. Additionally, they have been utilized for activities characterized by high levels of repetition, such as the assembly of automobiles. Through the automation of these jobs, robotics solutions have the potential to augment productivity and boost safety, so allowing human workers to allocate their efforts towards more intricate and innovative pursuits. It is noteworthy to mention that robots are not bound by the same constraints as human beings. As an illustration, it is observed that a human engaged in repetitive tasks may experience fatigue, ennui, or disinterest, whereas a robot will persist in executing the same activity with a consistent degree of effectiveness and accuracy. Robotics solutions have already demonstrated significant influence in various industries, encompassing tasks such as precise crop harvesting, efficient delivery services, and streamlined automobile assembly processes [9].

1.2 Machine Learning

Machine learning has emerged as a potent instrument for enabling robots to perform complex tasks. Robots can enhance their understanding of the world, devise strategies to navigate barriers, and optimize problem-solving techniques to enhance task completion efficiency through the process of exploring their surroundings. Machine learning is playing a crucial role in enhancing the intelligence and adaptability of robots across various domains, ranging from household robots such as vacuum cleaners to industrial robots employed in manufacturing facilities. These aforementioned

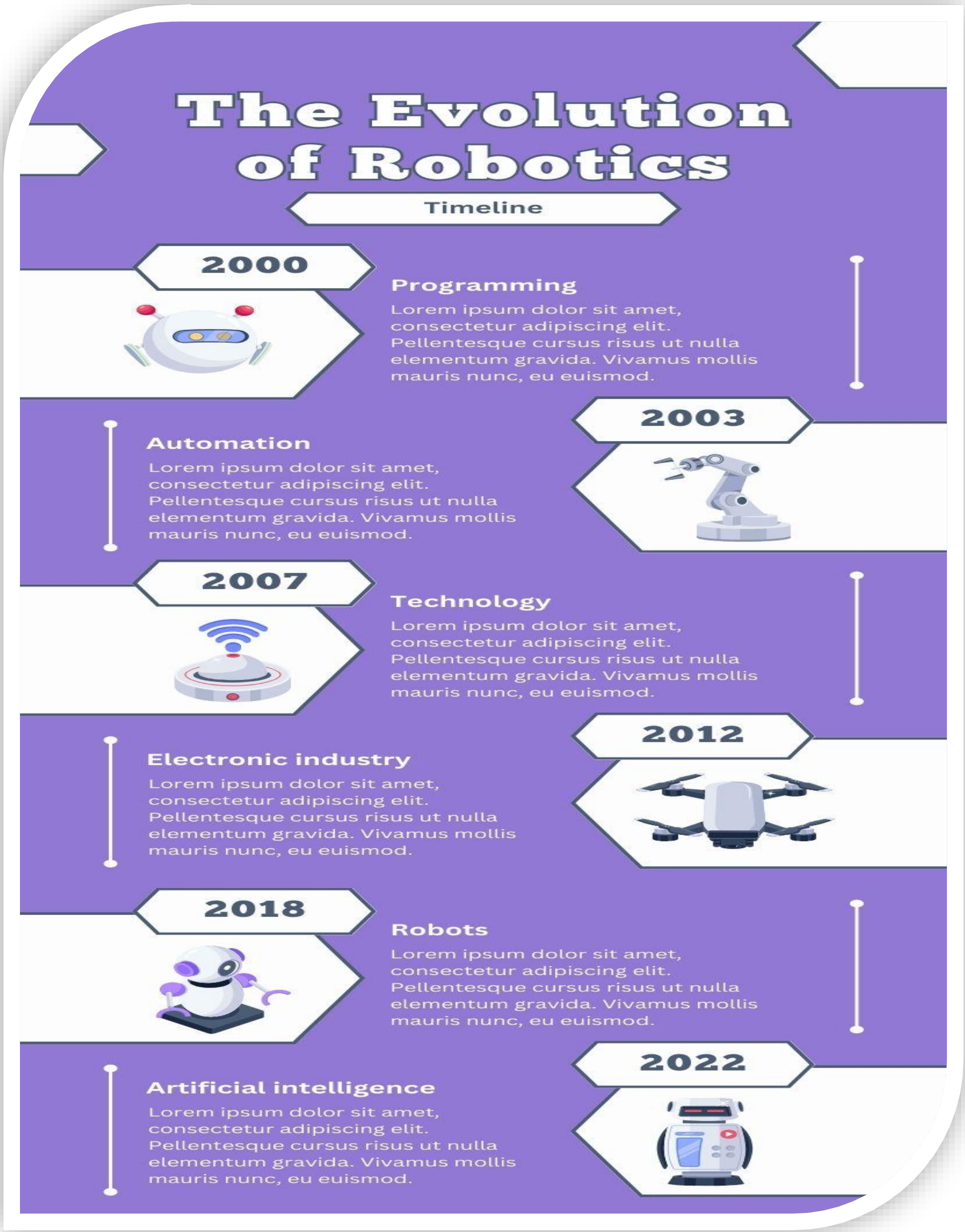

Fig. 1. History of robotics

examples represent a mere fraction of the myriad uses of artificial intelligence within the realm of robotics in contemporary times. With the ongoing expansion and increasing sophistication of these technologies, it is certain that a plethora of further inventive uses will emerge in the foreseeable future [10-12].

A robotics engineer is a someone who specializes in the field of robotics, which involves the design, development, and operation of robotic systems. The field of robotics has had a significant impact on a wide range of industries, and within this context, the work of a robotics engineer is of utmost importance. A robotics engineer is responsible for crucial tasks such as designing, maintaining, and ensuring the optimal performance of robotic systems. A robotics engineer is a highly skilled professional that is tasked with the construction, installation, and upkeep of machinery utilized in several industries, including manufacturing, security, aerospace, and healthcare [13,14].

1.3 Is There a Distinction between AI and Robotics?

While AI and robotics are occasionally utilized synonymously, they are, in fact, separate yet interconnected disciplines. Artificial intelligence (AI) and robotics possess the ability to exert substantial influence on diverse businesses and facets of human existence. However, it is crucial to recognize that these two fields serve distinct purposes and function through distinct mechanisms. In essence, AI neural network models exhibit resemblances to biological brain networks, whereas robotics can be likened to the anatomical structure of the human body. Artificial Intelligence (AI) encompasses the advancement of systems capable of executing tasks that conventionally necessitate human intelligence, including but not limited to learning, problem-solving, and decision-making. These systems have the capability to operate autonomously, without requiring continuous instructions, as they are designed to acquire knowledge and adjust their behavior independently [15-17].

In contrast, robotics pertains to the advancement of robots capable of executing designated physical activities. These robots have the capability to be programmed in order to execute uncomplicated and repetitive tasks, such as the categorization of objects or the assembly of extremely small components. Although the integration of artificial intelligence (AI) into robotics has the potential to augment the capabilities of robots and optimize their decision-making processes, it is important to note that such integration is not always indispensable. Certain applications in the field of robotics necessitate robots to perform predetermined behaviors without the inclusion of supplementary cognitive functionalities. Although AI and robots are distinct concepts, they possess a synergistic relationship that enables them to collaborate effectively, resulting in a diverse array of advantages and progress across numerous domains [18-21].

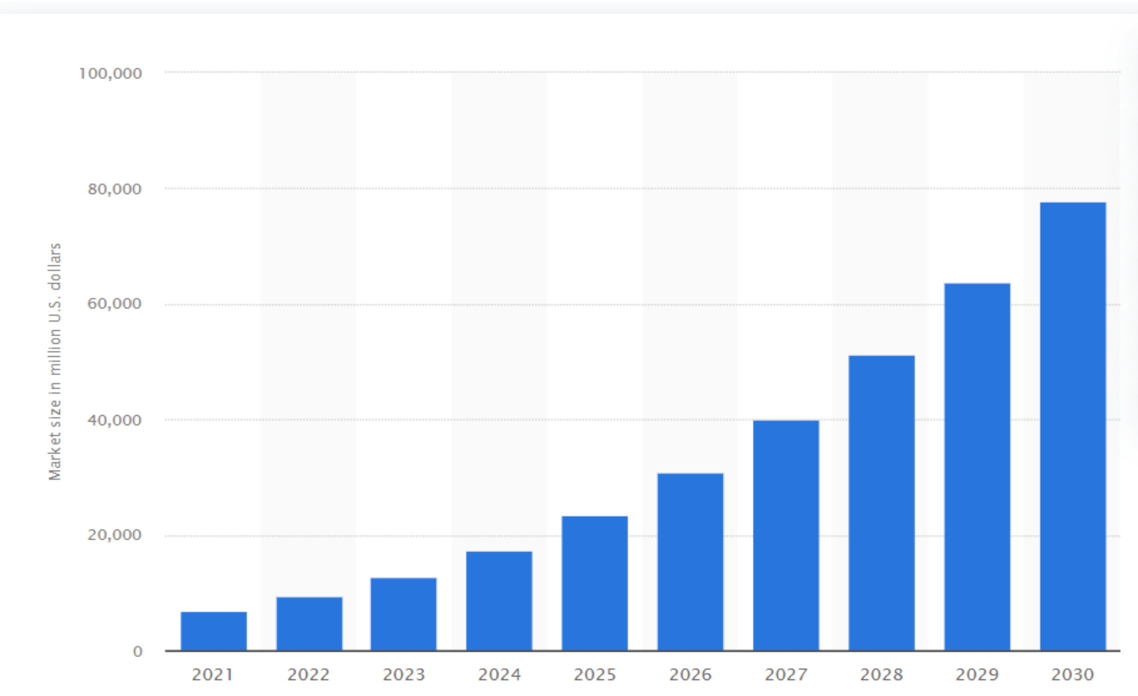

Fig. 2. Artificial intelligence (AI) driven robots market size worldwide in 2021 with a forecast until 2030

2. THE UTILIZATION OF ARTIFICIAL INTELLIGENCE IN THE FIELD OF ROBOTICS

Significant advancements have been achieved in the field of artificial intelligence (AI) in recent years, leading to its seamless integration with robotics, which may be seen as a logical and organic evolution. Although the prevalence of AI in robotics is not yet extensive, its adoption is swiftly accelerating due to the increasing sophistication of AI systems. The integration of artificial intelligence (AI) with robotics presents significant opportunities, resulting in enhanced production and efficiency, heightened safety measures, and enhanced adaptability for individuals across various occupational domains [22,23].

Machine learning is a prominent method by which artificial intelligence (AI) is employed in the field of robotics. This methodology facilitates the acquisition and execution of particular tasks by robots through the process of monitoring and imitating human activities. Artificial intelligence (AI) provides robots with the capability of computer vision, which allows them to effectively traverse their surroundings, recognize objects, and make appropriate responses based on their observations. This facilitates their transition from mere execution of repetitive duties to assuming the role of genuine "cognitive collaborators [24,25]."

Edge computing is an additional method by which artificial intelligence (AI) is employed in the field of robotics. The utilization of artificial intelligence (AI) in the field of robotics necessitates the processing of substantial volumes of data acquired by sensors integrated within robots. This data is promptly examined in close proximity to the robot itself, as opposed to being transmitted to remote cloud servers for computational purposes. This methodology facilitates the provision of real-time awareness to machines, hence empowering robots to make judgments and take actions at a significantly faster pace than what is achievable by humans [26]. Artificial intelligence (AI) also facilitates the acquisition of task-specific skills by robots through the utilization of diverse sensory inputs, which may encompass:

- Time-of-flight optical sensors are a type of optical sensor that measure the time it takes for light to travel from a source to a target and back to the sensor.
- Temperature and humidity sensors are devices used to measure and monitor the levels of temperature and humidity in a given environment. These sensors are commonly employed in various fields such as meteorology, agriculture, and indoor climate control systems
- Ultrasonic sensors are electronic devices that utilize ultrasonic waves to detect and measure distances to objects.
- Vibration sensors are devices used to detect and measure mechanical vibrations in various systems and structures. These sensors are designed to convert mechanical energy
- Millimeter-wave sensors are a type of sensing technology that operates in the millimeter-wave frequency range. These sensors utilize electromagnetic waves with
- These sensors facilitate the acquisition and adjustment of knowledge by robots, thereby enhancing their cognitive capabilities and enabling them to effectively respond and adapt to various situations.

3. THE UTILIZATION OF ARTIFICIAL INTELLIGENCE IN CONJUNCTION WITH ROBOTICS ENCOMPASSES A VARIETY OF APPLICATIONS

The utilization of artificial intelligence (AI) in the field of robotics has garnered significant attention and interest in recent years. This emerging area of research and development explores the various ways in which AI can be integrated into robotic systems to enhance their capabilities and performance. Within the realm of robotics, artificial intelligence (AI) has demonstrated its significant use across a diverse range of applications. AI has significantly impacted various sectors, including customer service and manufacturing, leading to a paradigm shift in our perception and engagement with robotic systems. In the present era, it is necessary to examine the prominent domains in which artificial intelligence (AI) is employed in conjunction with robots. The utilization of AI-powered chatbots in customer support applications is experiencing a growing prevalence. Automated service agents possess the capability to address uncomplicated and repetitive inquiries devoid of human intervention. As the level of interaction between these systems and humans increases, their capacity for learning also expands. With the increasing advancement of AI systems, it is anticipated that there will be a growing utilization of robots in customer support across various platforms, including online and physical establishments [27,28].

The utilization of artificial intelligence (AI) has demonstrated its immense value as a tool in the realm of robotic assembly, particularly within intricate manufacturing sectors like aerospace. The utilization of improved visual systems in conjunction with artificial intelligence (AI) facilitates the ability to make immediate adjustments and corrections in real-time. This capability can be leveraged to assist a robot in autonomously acquiring optimal pathways for certain operations throughout its active functioning. The packaging business use artificial intelligence (AI) to enhance operational efficiency, enhance precision, and optimize cost-efficiency. The utilization of artificial intelligence (AI) facilitates the simplification of the installation and relocation processes of robotic equipment through the iterative refinement and preservation of specific motions executed by robotic systems [29,30].

Imaging plays a critical role in various industries, encompassing assembly and logistics, where precision is of utmost importance. With the aid of artificial intelligence, robots can attain improved visual acuity and image recognition capabilities, hence enhancing their ability to accurately perceive even the minutest details [31,32].

3.1 The Daily Duties of a Robotics Engineer

The tasks encompassed in this domain involve the installation, repair, and testing of various equipment and components [33].

- The execution of predictive maintenance
- Integrating pertinent technical material with one's comprehension of system operations
- The task at hand involves the identification of novel sources of data.
- Establishing Effective Working Relationships
- The objective of guaranteeing that software solutions align with consumer requirements
- The objective of this endeavor is to establish and execute an AI governance framework that effectively oversees the continuing execution of AI plans.
- The ongoing assessment and conceptualization of procedures to integrate conversational AI.
- Ensuring familiarity with safety norms and laws pertaining to the secure functioning of a system.

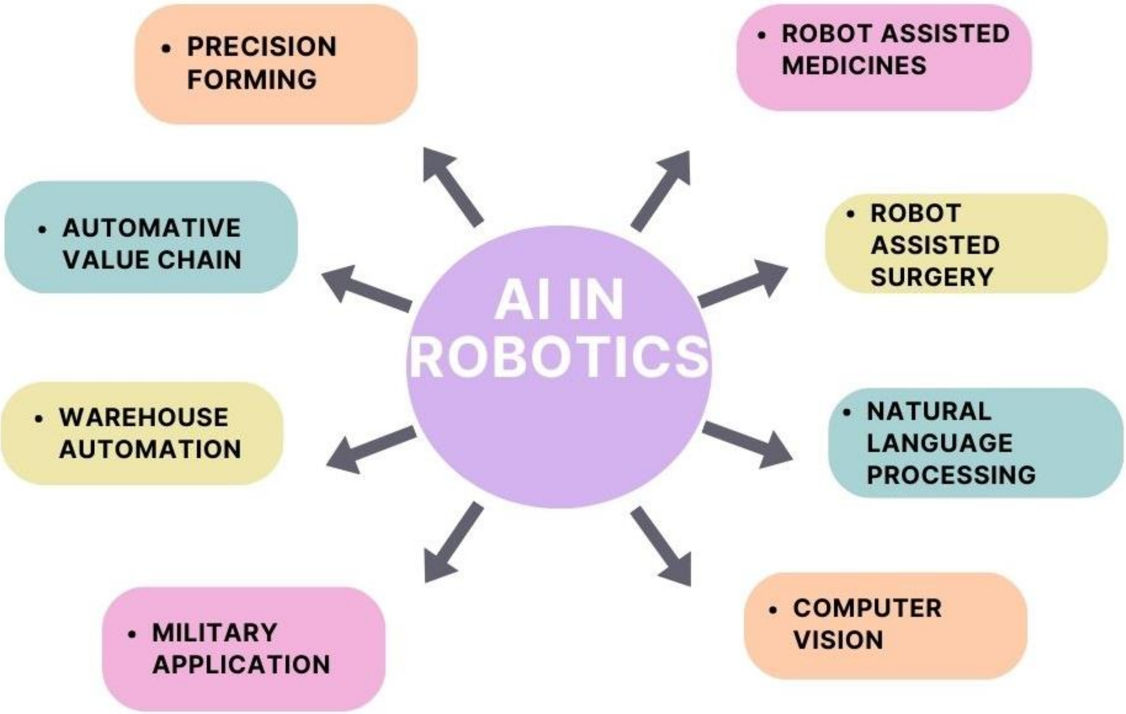

Fig. 3. AI in robotics

In order to pursue a career as a robotics engineer, it is important to possess a bachelor's or master's degree in computer engineering, computer science, electrical engineering, or a closely related discipline. Proficiency in numerous programming languages and expertise in algorithm design and debugging are also crucial qualifications. A proficient robotics engineer exhibits a proclivity for perpetual learning, possesses inherent problem-solving abilities, and demonstrates an unwavering commitment to continued enhancement [34].

4. THE MODERN ERA OF ROBOTICS AND AI

The contemporary epoch of robotics and artificial intelligence is distinguished by the progressive reduction in size of electrical and mechatronic components, as well as a substantial augmentation in computational capabilities. These advancements have resulted in the emergence of increasingly feasible and functional robotic systems [35,36]. In 1973, a research team from Waseda University in Japan introduced the WaBot, which was the inaugural humanoid robot designed to replicate human motion. WaBot possessed rudimentary functionalities for locomotion, object manipulation, and transportation between different locations. The year 1978 witnessed the introduction of a technologically advanced iteration of the Unimate by Unimation, known as the Programmable Universal Machine for Assembly (PUMA). PUMA has gained significant traction across both industry and academics, becoming as a prominent exemplar for anthropomorphic robots. The system continues to be extensively utilized in contemporary academic robotics literature and publications as a prominent reference and benchmark. The establishment of the contemporary discipline of reinforcement learning occurred during the 1980s through the integration of diverse methodologies from multiple academic domains. The initial premise originated from the concept of trial-and-error learning, which was drawn from psychological research on animal behavior dating back to the early 18th century [37,38]. Reinforcement refers to the manifestation of a specific behavioral pattern resulting from the interaction between an animal and its surrounding environment. The animal is exposed to various stimuli that are temporally correlated with its behavior, resulting in the persistence of specific behavioral patterns even after the stimuli have ceased. From a technical perspective, this process can be characterized as an optimization problem that has stochastic elements due to limited knowledge of the entire system. An extended iteration of the optimal control framework previously discussed can be employed to characterize and address the aforementioned system. One of the pioneers in implementing this concept was Witten, who employed an adaptive optimum control methodology [39,40]. Temporal-difference (TD) learning, which has its roots in animal learning psychology, constitutes a significant element in the development of the contemporary theory of reinforcement learning. The concept in question might be interpreted as either a subclass or an extension of the broader notion of reinforcement learning [41]. In contrast to the conventional reinforcement approach, TD learning involves the adjustment of the learner's behavior or strategy not only after the receipt of a reward, but also after each action prior to its receipt. This adjustment is made by utilizing an estimate of the anticipated reward, facilitated by a state value function. The method is governed by the disparity between consecutive approximations. The implementation of this strategy was initially demonstrated by Arthur Samuel in 1959, within his program designed for playing checkers [42]. The application of the actor-critic architecture, an advancement of the reinforcement learning method, was employed in 1983 to address the control problem of pole balancing. The year 1989 [43] witnessed the complete integration of optimum control approaches with online learning, marking a significant milestone in the field. In the present year, the integration of time difference and optimal control approaches has been accomplished by the pioneering work of Chris Watkin [44], who devised the Q-Learning algorithm. In addition to the development of reinforcement learning, the 1980s witnessed significant advancements in the field of robot manipulator control. In the early years of the decade, a novel hybrid control technique for manipulators was introduced by John J. Craig and Marc Raibert. The implemented approach facilitated the concurrent fulfillment of both position and force limitations in trajectories, hence permitting compliant motions of robot manipulators.

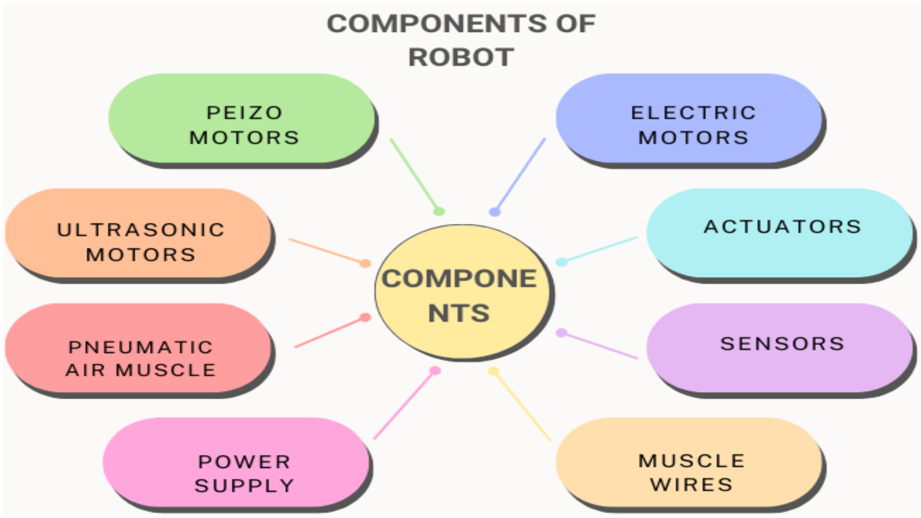

Fig. 4. Components of robot

During the mid-1980s, Neville Hogan [45] made significant advancements in the field of physical interaction by introducing impedance control. This development played a crucial role in facilitating the establishment of safe human–robot interactions that are prevalent in contemporary times. The year 1986 marked the publication of Oussama Khatib's [46] seminal work on the topic of real-time obstacle avoidance for manipulators and mobile robots. This work served as the foundation for the development of time-varying artificial potential fields specifically designed for collision avoidance purposes. This idea has facilitated the realization of real-time robot operations in dynamic and complicated situations. One year later, Khatib [47] devised a novel operational space framework that integrates both motion and force control into a unified system. The introduction of this novel mathematical framework for robotic manipulators has significantly facilitated the comprehension of modeling and control principles pertaining to these complex nonlinear dynamic systems. Honda ventured into the realm of humanoid research and development during the early 1990s with the debut of its P1 system. Participant 1 (P1) exhibited a height of 191.5 cm, a weight of 175 kg, and demonstrated the ability to ambulate at a maximum velocity of 2 km/h. Additionally, P1's battery endurance was estimated to be approximately 15 minutes. The success of the Rotex mission in 1993 [48,49] can be attributed to the advancements made in the field of telerobotics. During this trip, a team of researchers led by Gerd Hirzinger achieved a significant milestone by developing the first space robot that could be operated from Earth. In 1995 [50], Ernst Dickmanns and his colleagues were at the forefront of the development of autonomous driving. They successfully undertook a drive from Munich, Germany to Odense, Denmark and returned, covering a distance of approximately 1,758 kilometers. This significant achievement was accomplished as part of the PROMETHEUS project. The researchers employed a Mercedes-Benz S-Class automobile that had been modified to enable autonomous driving capabilities. Approximately 95% of the total distance may be traversed entirely using automated means, marking a significant achievement in the field of autonomous driving. During subsequent years, IBM undertook the development of the Deep Blue system. Deep Blue was a sophisticated computer software specifically developed for the purpose of engaging in chess gameplay [51]. This computer system holds the distinction of being the first to achieve victory in a game of chess against the reigning world champion, Garry Kasparov, utilizing the assistance of a human operator to physically perform the moves, all within the confines of standard time regulations. Building upon the groundbreaking contributions made by RC Smith and P Cheeseman in 1986 [52], as well as the research conducted by Hugh F Durrant-Whyte's group in the early 1990s, further advancements towards the development of autonomous propulsion systems were made at the onset of the twenty-first century. These advancements laid the groundwork for contemporary simultaneous localization and mapping (SLAM) algorithms, which are utilized in the navigation of vehicles or robots. In 1998, Wolfram Burgard and his colleagues introduced a novel software architecture for an autonomous tour-guide robot employed at the Deutsche Museum in Bonn, as a component of their research and development efforts [53].

5. MAN AND MACHINE IN THE AGE OF MACHINE INTELLIGENCE

In this section, we will examine existing intelligent systems in further detail. On one side, there is a growing prevalence of AI systems that are solely reliant on software. In the optimal scenario, these services, predominantly accessible through the internet and smart devices, furnish us with valuable knowledge [54]. However, in less favorable circumstances, they inundate us with copious quantities of unorganized and potentially unreliable information and data. In contrast, the private sector encompasses several categories of robotic systems, including mobile robots like lawn mowers, vacuum-cleaning systems, unmanned aerial aircraft, and, notably, semi-autonomous autos [55]. Articulated robots are currently limited to the industrial sector due to safety concerns associated with human interaction and the intricate and specialized nature of their programming processes. It is evident that the development of sophisticated, intricate, and user-friendly robotic systems capable of effectively engaging with and controlling our human-centric environment is still a considerable distance away. To address this disparity, it is imperative to establish a more efficient integration between the realms of algorithms and the physical world. The nascent field of machine intelligence (MI) offers a comprehensive framework to tackle this concern [56]. The integration of perception (sensing), AI (planning), and robotics (acting) with pervasive control and machine-learning functions is a crucial field of study. Its significance lies in its ability to facilitate the development of fully autonomous AI robots, autonomous vehicles, aerial taxis, networked cyber-physical systems, molecular robots for drug delivery, and other intelligent systems. These advancements have the potential to transform various domains such as our homes, workplaces, and healthcare facilities. The overarching objective of the field of machine intelligence (MI) is to develop a reliable and perceptive artificial intelligence (AI) that possesses self-awareness and environmental awareness. This advanced AI not only governs its actions, but also adjusts its control mechanisms to suit the intelligent entity it is intended to oversee. This technological innovation has the potential to fundamentally transform the manner in which individuals utilize and engage with robotic systems in their everyday activities. The implementation of a development method that prioritizes human-centered principles, along with a significant emphasis on maintaining the trustworthiness of AI systems that are becoming more powerful, will be of utmost importance. However, it is important to determine the first stage and subsequent actions required for these systems to achieve the specified long-term objective [57-59]. The subsequent sections aim to provide insights into these inquiries from a systems perspective.

5.1 Flying Robots

Unmanned Aerial Vehicles (UAVs), sometimes known as flying robots, are autonomous or remotely controlled aircraft that The continuous advancements in computer hardware, characterized by increased affordability and enhanced capabilities, coupled with the miniaturization of devices, have significantly contributed to the remarkable advancements observed in the domain of aerial robotics. These advancements have been further augmented by the development of sophisticated sensors and real-time signal-processing algorithms, resulting in substantial progress in the field. These small unmanned aircraft vehicles (UAVs) possess an extended airborne endurance compared to earlier systems, and have experienced a significant enhancement in their autonomy capabilities. In the domain of aerial robotics, autonomy refers to the capability of flying robots to operate and make decisions independently, without direct human intervention. Autonomy in the field of robotics refers to the capacity of robots to operate in unfamiliar, hazardous, and uncertain settings without requiring human intervention. Numerous elements pertaining to navigation, as previously discussed in the section addressing essential technologies, are relevant in this context. These tasks encompass the estimation of the robot's position, the mapping of the surrounding environment, the generation of trajectories, and the determination or interpretation of the generated maps. In the domain of aerial robotics, computational algorithms pertaining to aerodynamic modeling and wind estimation hold significant importance. The implementation of novel sensor systems is of utmost importance in order to facilitate the real-time utilization of these algorithms by the aerial robot. The primary objective of this study is to examine the integration of exteroceptive sensors, such as cameras and laser rangefinders, with proprioceptive sensors, such as an inertial measurement unit, in order to establish a comprehensive multimodal sensor system. Contemporary unmanned aerial vehicles (UAVs) possess the capacity to use six stereo cameras concurrently in real-time, alongside a range of additional sensors, to execute tasks such as occupancy grid mapping, motion planning, visual odometry, state estimation, and human tracking. These operations are facilitated through the utilization of deep learning algorithms. The aforementioned advanced systems are equipped with actuators, sensors, and computer systems that are seamlessly integrated into a lightweight structure, weighing approximately one kilogram. These systems are capable of sustaining a flight duration of approximately 16 minutes. The cost of acquiring these systems is approximately €2,500. Flying robots with lower levels of intelligence, characterized by weak or nonexistent obstacle avoidance capabilities, are typically priced between €200–1,000. These robots have a weight ranging in the several hundred grams and an average flight duration of 10–30 minutes. The utilization of validated models could potentially streamline the development process and decrease the associated costs of such systems. Another challenge involves identifying a sophisticated and ideally entirely model-based method for differentiating aerodynamic forces from forces resulting from collisions and interactions. Extensive study is necessary before a secure physical interface for human-flying-robot interaction can be commercially introduced. In order to achieve a degree of practicality for everyday use, it would be necessary to lengthen the flight time. One potential method to accomplish this objective is by the implementation of novel materials or structural techniques, which would result in a reduction in the overall weight. This advancement would additionally enhance the safety of human-robot contact by reducing the amount of energy transferred to the human body in the case of a collision. Based on an analysis of these many criteria, it is evident that there is a considerable distance to be traversed prior to the widespread use of small and cost-effective fully autonomous aerial robots [60-64].

5.2 Mobile Ground Robots

The topic of discussion pertains to mobile ground robots. The Shakey system holds significance in the annals of mobile robotics as it stands as the first mobile robotic system to have been employed in practical applications [65]. The aforementioned system established the fundamental principles for the development of technologies such as hierarchical control architecture about four decades ago. Subsequent to this, a substantial body of research has been conducted in the domain of mobile robot platforms, leading to the emergence of diverse methodologies tailored to a wide array of applications [66]. These applications span from industrial contexts to hazardous situations, including disaster zones, where human presence is perilous. For the successful integration of mobile robots into everyday life applications, it is imperative that research and development efforts prioritize the enhancement of safe human-robot interaction skills exhibited by these systems. Rollin'Justin is an example of a robot that has been specifically designed to provide safe interaction between humans and robots [67]. The present system has considerable potency; yet, its developmental trajectory did not prioritize cost-effective production, hence impeding its imminent commercial viability [68]. The utilization of impedance control in mobile platforms is a crucial factor in facilitating secure human-robot interaction. To yet, this approach has been infrequently employed and is predominantly observed within the realm of scholarly investigations, if indeed it is there at all. If there were a greater emphasis on research pertaining to the safe interaction between humans and robots, with the objective of making mobile robot technology more accessible and affordable, it is plausible that these systems would become more prevalent in our daily lives and have a significant impact on the development of our society [69,70].

5.3 Tactile Robotics

Tactile robots, also known as haptic robots, are a type of robotic system that is designed to interact with and perceive Position-controlled rigid robots have been utilized in the industrial sector for over five decades to provide assistance in assembly and welding processes [71-73]. Due to their design for executing labor-intensive tasks demanding substantial force, the operational mechanisms of these robots are ill-suited for ensuring secure proximity with human beings. Consequently, it is customary to establish a physical barrier, such as a safety fence, to maintain separation between humans and these robots [74-76]. The utilization of robots has undergone a fundamental shift in recent decades. The utilization of delicate manipulation techniques and the increasing prevalence of close physical interaction between humans and robots have grown increasingly prominent in contemporary society. In order to accomplish this objective, researchers have created and deployed highly integrated lightweight systems that possess low inertia and high active compliance. Systems like as the Barrett WAM arm and the DLR lightweight robot series have emerged as a result, with their arm technology afterwards serving as the foundation for the development of the LWR iiwa robot by KUKA [77]. The Panda system, designed by Franka Emika, is considered one of the most advanced lightweight robot systems with a strong focus on human-centered design. The utilization of a high-precision force and impedance control system facilitates the execution of delicate and precise manipulation tasks, while also enabling a substantial level of compliance. This, when combined with the safety measures previously incorporated during the robot's design phase, ensures a secure environment for human-robot collaboration. In addition to safety, the operating, programming, and interaction interface between humans and robots is a crucial pragmatic element in human-robot collaboration [78,79]. Numerous collaborative robots employ a tablet computer and sophisticated software as their means of operation, programming, and interaction interface. The Panda system provides a well-designed interface that enables users to communicate with the robot in a natural manner using haptic interactions. These interactions include tapping on the robot gripper to halt its movements or to provide confirmation for a particular operation. Furthermore, within the instructional mode, it is feasible to impart a range of work procedures to the compliant robot by physically guiding it with a high degree of fluidity throughout the operation [80]. After the demonstration of the procedure, it can be replicated iteratively by merely activating a button. This type of programming is augmented by applications that encompass two tiers of engagement with the robot: the advanced-level robot application developer and the user who lacks any specialized understanding in robotics [81]. The specialist offers fundamental robot functionalities, which are afterwards assembled and utilized by the user to execute intricate procedures and achieve solutions. The aforementioned rudimentary robotic applications will be distributed through a cloud-based platform dedicated to robotic applications, so ensuring accessibility to a wide array of users [82]. The expansion of the robotics skills database is anticipated to give rise to a multitude of novel applications, thereby progressively integrating robotics into our everyday existence [83].

6. FUTURE PERSPECTIVES AND CONCLUSIONS

The potential for artificial intelligence (AI) in the field of robotics is extensive and holds considerable promise. The subsequent phase of artificial intelligence, sometimes referred to as AGI or Artificial General Intelligence, with the capacity to attain a degree of comprehension comparable to that of humans. The crucial aspect of this endeavor involves the integration of the computational framework of artificial intelligence with a robotic system. In order to function effectively, the robot must exhibit the essential attributes of mobility, sensory perception (including touch, vision, and hearing), and the capacity to engage with physical entities. These capabilities are crucial for enabling the system to acquire real-time sensory input in response to its actions. The presence of this feedback loop facilitates the system's ability to acquire knowledge and understanding, hence advancing its progress towards attaining genuine Artificial General Intelligence (AGI) [84].

The present emphasis on artificial intelligence (AI) in the field of robotics is undergoing a transition from the inquiry into the tasks that robots are capable of executing for humans, to the examination of the kind of input that a robot can furnish to the cognitive faculties of AI. By providing AI systems with the opportunity to engage in the exploration and experimentation of tangible items, it becomes feasible for them to attain a more profound level of comprehension, akin to that of a human child. The integration of artificial intelligence (AI) with robots is anticipated to provide substantial progress across several industries, encompassing manufacturing, healthcare, security, and space exploration.

The potential for significant advancements in our understanding and interaction with the world is promising when we consider the future of artificial intelligence (AI) in the field of robotics. The integration of artificial intelligence's computing capacity with the physical capabilities of robots has the potential to facilitate exploration and invention, thereby bringing us closer to achieving true artificial general intelligence (AGI).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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