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Artificial intelligence-powered robotics across domains: challenges and future trajectories

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ABSTRACT

The rise of artificial intelligence (AI) in robotic systems raises both challenges and opportunities. This technological change necessitates rethinking workforce skills, resulting in new qualifications and potentially outdated jobs. Advancements in AI-based robots have made operations more efficient and precise, but they also raise ethical issues such as job loss and responsibility for robot decisions. This study explores AI-powered robotics in both of their challenges and future trajectories. As AI in robotics continues to grow, it will be crucial to tackle these issues through strong rules and ethical standards to ensure safe and fair progress. Collaborative robots in manufacturing improve safety and increase productivity by working alongside human employees. Autonomous robots reduce human mistakes during checks, leading to better product quality and lower operational expenses. In healthcare, robotic helpers improve patient care and medical staff performance by managing routine tasks. Future research should focus on improving efficiency and accuracy, boosting productivity, and creating safe environments for humans and robots to work safely together. Strong rules and ethical guidelines will be vital for integrating AI-powered robotics into different areas, ensuring technology development aligns with societal values and needs.

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1. INTRODUCTION

As artificial intelligence (AI) continues to be used in robotic systems, it is important to look closely at the challenges and future paths that come with it. Ethical issues are a major factor, creating big questions about the moral guidelines that influence AI decisions. Because ethics is subjective, putting moral behaviors into machines is very difficult, as there are no clear or universal definitions. At the same time, the risk of job loss raises worries about economic stability, since tasks once done by people are now being taken over by AI robots. This change in technology requires us to rethink the skills needed in the workforce, leading to new qualifications and making some jobs possibly outdated. Understanding the effects of AI in robotics is crucial for dealing with today's societal issues and for helping direct future progress in this fast-changing area.

The joining of AI with robotics goes beyond just automation, creating systems that can adapt well and handle complex tasks. AI-powered robots show how systems use machine learning, computer vision, and natural language processing to improve efficiency in different industries. These robots can learn on their own and adjust to changes in their surroundings in real time, which improves their accuracy and ability to make

decisions. For example, advancements in robotics are crucial in fields like manufacturing and healthcare, where AI-enhanced robots can carry out complex surgeries or help with quality control, thus reducing human errors and improving results [1]. However, mixing AI and robotics also brings up significant ethical issues, such as the need for responsibility and clarity in how decisions are made. As this area develops, it will be vital to understand the key features and uses of AI-powered robots to address the challenges and future paths in this fast-growing field [2].

The growth of robotics is closely linked to the history of technology progress, showing a path from simple machines to advanced systems powered by AI. At first, early machines that helped with human work were created during the Industrial Revolution, setting the stage for automation. Later, the rise of computer technology in the late 20th century was a significant change, making programmable machines possible, which improved accuracy and flexibility in tasks. As noted in [3], modern robotics not only deals with operational and maintenance issues in fields like offshore wind but also brings up ethical questions about job loss for humans and responsibility. Moreover, the spread of AI, mentioned in [4], has increased the availability of advanced robotic solutions, encouraging new ideas in different industries. This historical path has led to a time where robotics could change productivity, but important challenges still need to be addressed to make sure ethical and practical uses are achieved.

The joining of AI and robotics represents a big change that greatly improves how robotic systems work. AI lets robots handle many data using complex algorithms, which helps them make better decisions and operate independently without needing constant human control. For example, in the offshore wind industry, AI helps in making maintenance and monitoring more efficient, which can lower long-term costs and aid the industry's growth goals [1]. Also, adding AI makes robotic applications more flexible and accurate in different fields, enabling them to perform complicated tasks, such as surgeries and disaster response, with better accuracy and safety [2]. As robots get better through AI advances, there is a chance for major improvements in productivity, reducing risks, and improving overall performance in various areas, highlighting the need for continuous research and development in this combined field [5].

As AI-powered robots keep getting better in many fields, there are big problems to deal with, especially about ethics and how people engage with machines. Ethical decision-making is tricky because different cultures and situations have different values. This raises the issue of whether AI can make reliable moral choices in real time, as current systems depend a lot on filtered data to make decisions [6]. Additionally, the loss of jobs due to automation is a major social issue; history shows that while new technologies create jobs, they also make some skills less useful, increasing economic gaps [1]. Also, how people and robots interact is complicated because of unpredictability and the need for emotional understanding. This highlights the importance of having strong systems in place that ensure safe and meaningful interactions in various settings [2]. Tackling these issues is crucial for the responsible growth of AI-powered robotics.

As society deals with the fast use of robots powered by AI, many possible paths come up that might change our future. Better efficiency from self-operating robots lets companies pass off boring jobs, allowing human workers to focus on tasks that need thinking and creativity, which can encourage a more innovative workplace. Also, the better accuracy and output provided by AI technologies could lead to advancements in many fields, such as healthcare, where robots designed for precision could lower risks in complex operations. On the downside, this tech growth brings ethical issues and major job losses, as some usual jobs might disappear, requiring a shift in society to retrain and upgrade the skills of those affected [1]. Future rules should aim to balance these improvements with ethical concerns, highlighting the need for teamwork between humans and smart systems to ensure fair progress in society [7]. The path ahead is complicated but necessary for making the most of AI-powered robotics.

2. CHALLENGES IN AI-POWERED ROBOTICS

The use of AI robots in different fields brings up many problems that need to be thought about carefully. One big problem is the ethical issues linked to how decisions are made because AI systems might have a hard time with the personal nature of human morals. It is tough to teach machines how to make ethical choices, showing a lack in current AI training methods, especially when looking at the needed ethical guidelines in [8]. Additionally, the risk of job losses because of automation raises worries about how workers will transition and what the job market will look like in the future. While some believe that tech progress opens up new jobs, the short-term effects on society and economy must not be ignored [1]. Also, privacy and security problems arise since robots that collect data face risks from data theft and harmful attacks [2]. Thus, tackling these overlapping issues is essential for a responsible and fair growth of AI robots.

2.1. Ethical considerations

Navigating the complex ethics involved in AI-powered robots needs a careful look at cultural sensitivities and moral ideas, which are personal and differ a lot across different societies. Since it is tough to

define ethical views in machine learning programs, a major question arises: how can we make sure that AI systems make choices that reflect human values? Right now, training AI uses selected datasets, but this approach does not fully provide a deep understanding of ethics and morals to these systems, which could cause unexpected issues [9]. Additionally, using AI in legal areas presents major questions about responsibility and openness, as shown in Bhatt et al.'s discussion on the legal effects of robotics, highlighting the urgent need for an ethical framework that connects technology improvements with social fairness [10]. Tackling these issues is very important; only then can we hope to create a future where AI technologies help society while following ethical standards.

Understanding the complex link between AI and ethical decision-making reveals significant problems based on cultural and personal views of morality. Different moral systems in various cultures make it hard to embed ethical rules into AI, since these systems often use filtered data that may not fully capture the complexity of human morals [11]. As AI technology progresses, especially in areas like self-operating robots, the chances for ethical issues grow, particularly when decisions affect human lives. For example, using AI in military settings brings up important questions about responsibility and the moral impacts of autonomous weapons [12]. Furthermore, as discussed in [2], the rise of roboethics highlights the need for strong frameworks to tackle these concerns. This situation shows the importance of continued research that not only explains AI's ethical guidelines but also includes various cultural viewpoints to create a more complete understanding of morality in AI-powered robotics.

As AI technologies spread into many fields, the cultural effects of ethics in AI start to appear. Ethics, which are tied to cultural norms, are a big challenge when it comes to coding AI systems to make good moral choices, especially since societal values differ greatly among groups. Current methods often use filtered datasets that might continue existing biases and miss out on various cultural views, showing the ethical issues involved with machine learning and decision-making algorithms [2]. Additionally, using AI in legal systems questions accountability, especially concerning the independent actions of AI tools and their ability to cause unfairness in broken systems [1]. It is important for people in tech and cultural studies to talk together to make sure AI use meets ethical standards that respect human dignity and address cultural concerns, helping to create a future were technology aids social advancement.

Ethical frameworks are meant to help integrate AI and robotics responsibly, but their current issues make it hard to govern effectively in this fast-changing field. These frameworks often do not consider that ethical standards are subjective and shaped by culture, leading to a one-size-fits-all approach that does not respect different moral views [13]. Also, as robots become more advanced, especially in areas like disaster response and healthcare, the existing rules are slow to adapt. This leaves many problems, including job loss, privacy issues, and the question of accountability, not properly addressed [1]. Many frameworks miss the risk that technology can reinforce biases or worsen inequalities, as seen in AI applications that might unintentionally harm marginalized groups. Additionally, the lack of strong oversight makes the risks of using autonomous systems worse, highlighting the urgent need for flexible and detailed ethical guidelines that take into account ongoing advancements in technology and their effects on society [14].

In the fast-changing world of AI-powered robots, it is very important to create ways to show transparency to build trust and follow ethical rules. Transparency helps people understand how decisions are made by AI systems, which deals with important ethical issues like accountability and bias. This idea is supported by research that shows how AI is changing industries like offshore wind energy, where ethical concerns need to be balanced with how well things operate [15]. Also, using clear frameworks is key not just for improving efficiency but also for better human-robot interactions [1]. The rise of AI technologies requires laws that protect individual rights while encouraging new ideas, as discussed about the legal aspects of robotics [2]. In the end, strong transparency in AI systems creates a setting that allows for innovation while reducing ethical risks and boosting public trust in robot applications.

Creating rules for ethical AI needs a varied approach that includes many different views from stakeholders, thus tackling the complicated nature of AI technologies. A major part of this plan is promoting transparency and accountability in AI systems, allowing users to see how decisions are made and ensuring ethical rules are applied consistently during AI use. The practical ethical guidance from the SIENNA project offers a basic model for handling ethical issues and regulatory problems in AI and robotics, highlighting the need for input from multiple stakeholders in discussions about ethics [2]. Also, adding strong data protection measures can ease worries about privacy and security that come from AI's ability to handle sensitive data [16]. Finally, as AI continues to progress, it is crucial to have flexible regulatory frameworks that keep pace with changing technology, which is essential for protecting civil rights, building public trust, and promoting innovation [17].

To ensure the responsible development and deployment of AI-powered robotics, a comprehensive regulatory framework is needed, grounded in scientific and ethical principles. Regulations should mandate rigorous safety and performance testing under standardized protocols before deployment, similar to clinical

trials in medicine. Data governance policies must be established to ensure that training data is ethically sourced, unbiased, and protected against breaches. Transparency requirements should obligate developers to provide explainable AI systems, enabling audits and accountability for decisions made by robots. Liability frameworks must clearly define responsibility in cases of malfunction or harm, promoting accountability across manufacturers, developers, and operators. Ethical guidelines, based on principles such as beneficence, non-maleficence, autonomy, and justice, should be legally integrated into the design and operational stages. Additionally, adaptive regulatory mechanisms, like regulatory sandboxes, should be used to allow innovation while testing real-world impacts in controlled environments. International cooperation is essential to create harmonized standards, preventing regulatory gaps that malicious actors could exploit. Together, these scientifically-informed regulations would foster safe, transparent, and ethical advancement of AI-powered robotics.

2.2. Job displacement

Technological progress often leads to big changes in the workforce, frequently causing many workers to lose their jobs. The move to AI-based robots has made many traditional positions unnecessary, leading to the need to change how the workforce operates. This change is seen in areas like manufacturing and services, where machines are taking on jobs that humans used to do, which raises unemployment rates and creates economic uncertainty for those impacted. Yet, it is important to understand that while some skills may no longer be needed, new jobs are being created that often require different skills [1]. As these changes transform the job market, the main challenge is to provide training programs that help workers learn the skills needed for new jobs [18]–[21]. In the end, being proactive in adapting the workforce is key to reducing the negative impacts of job loss due to these technological changes in the labor market.

Technological progress consistently changes work situations, causing big changes in job markets. As machines and AI technology become more common, jobs in various fields are changing, leading to both job loss and new chances [22]. The use of smart systems in areas like offshore wind energy shows this double effect; there is a rising demand for skilled workers who can handle these advanced technologies, but jobs that people used to do might now disappear [1]. This move towards automation requires a strong plan for workforce changes, highlighting the need for retraining programs and ethical issues related to job loss [23]. Additionally, as AI improves efficiency and precision, companies might focus more on tech spending rather than hiring people, making it harder for workers in at-risk industries to adapt [2]. Therefore, a forward-thinking strategy for workforce growth is crucial to lessen the negative effects of AI use and to unlock new job opportunities.

Quick changes in AI and robotics are changing the job market a lot, making some skills useless and requiring strong adaptation plans. As machines take over routine jobs, many common roles are no longer needed, so workers must learn new skills to keep their jobs. For example, while AI technologies help businesses work faster and better, they also create problems like job loss and skill gaps [24]. This situation requires us to rethink how we educate people and how the job market operates, focusing on the need for flexibility and ongoing learning as key qualities for workers of the future. Adapting effectively means having not just technical skills in new areas like software development and data analysis but also a focus on the ethical issues that come with using AI. Therefore, building new partnerships among lawmakers, companies, and schools is essential for preparing a workforce that can handle this technological change [25].

As technology in AI and robotics continues to spread in many fields, there is a change happening in the job market. New job chances are appearing even with worries about job loss. AI-powered robots are not just for automation; they help create jobs that need higher skills, especially in fixing, managing, and programming robotic systems. Research shows that in richer countries, using robots leads to more productivity and more job chances, indicating a move toward more skilled tech jobs [26]. Additionally, the growing offshore wind industry shows this trend, as new RAI technologies are expected to create many job opportunities by 2032, leading to thousands of new positions [1]. In this situation, smart investments in education and skill training are vital, preparing workers to handle this changing job landscape influenced by AI-powered robotics, which will help build a stronger workforce.

Big economic effects happen as automation technologies change the workforce. The first use of AI robots makes operations better and lowers costs in industries like manufacturing and finance [27]. However, it also leads to job loss, especially in jobs that are repetitive or need low skills. More use of autonomous systems could make certain job roles no longer needed, which several studies show about the sectors most at risk for automation [28]. As traditional jobs fade away, the need for skilled workers who can adjust to new job demands increases. This means we need to work hard on reskilling programs to reduce unemployment and deal with economic gaps from job loss. In the end, this change needs a complete strategy for managing the workforce, focusing on both technology progress and worker development to ensure steady economic growth during these changes.

As AI-powered robots change the job market, lawmakers must create good plans to reduce job losses. A full plan should include training programs and strong support for workers who lose their jobs.

Training should help people gain skills needed for new jobs, especially in areas affected by technology changes, as mentioned in [28]. Also, working together with schools, government, and businesses can make these training programs better, so they meet job market needs [1]. Plus, creating jobs in AI-related areas can help balance the losses in older job sectors. It's also important to deal with the ethical issues of AI in work, as pointed out in [29], to make sure that progress in technology does not worsen current inequalities, allowing for a more fair and strong transition for workers.

2.3. Privacy and security

As technology moves forward, worries about privacy and security in robots using AI become more urgent. The use of AI in robotic systems involves a lot of data gathering, often including sensitive personal details, which creates significant privacy dangers. These robots are linked to the internet, making them open to security issues, which allows bad actors to take advantage of these systems, as shown by the problems pointed out in [1]. The risk of unwanted data access and control needs strong security systems to protect both user data and how robots' function. Also, ethical guidelines, like those mentioned in human-robot teamwork [30], must tackle privacy issues, making sure that responsible methods are set up to build user trust. As AI technologies keep spreading in different fields, a forward-looking method to privacy and security is crucial for managing the difficulties and effects of their use in daily life.

The widespread use of AI-powered robots in different areas creates big worries about how data is collected and how user privacy is protected. As these systems get smarter, they keep collecting large amounts of data, often including sensitive personal information, raising issues about consent and data security. A key part of this issue is how these connected systems can be vulnerable to security breaches. This can result in unauthorized access to personal information and can be exploited by bad actors, leading to urgent demands for stricter regulations [2]. Additionally, the unclear legal status of robotic systems makes it hard to determine who is responsible when data collection results in privacy issues. This special mix of technology and ethics calls for a strong discussion on finding a balance between innovation and user rights, ultimately aiming for a flexible legal framework that aligns technological progress with safeguarding individual privacy [5].

The fast addition of AI into robotic systems brings many problems that can hurt their efficiency and safety. A key issue is privacy and security, since these systems frequently gather sensitive information, creating major risks if this data is breached [1]. Bad actors could take advantage of these flaws, resulting in major failures or unwanted surveillance. Furthermore, ethical issues related to decision-making processes add to the complexity; robots need to handle different cultural morals, which are tough to define in programming terms [2]. This gap in a strong ethical system raises doubts about responsibility, especially when AI-powered robots working in critical areas like healthcare and emergency response do not follow proper standards. In the end, solving these issues needs a broad approach that includes better regulatory frameworks and a focus on ethical programming, making sure that AI and robotics grow in a way that values user safety and public confidence.

In the changing field of AI-powered robots, the chance for bad use raises serious worries that need careful thought. As new technologies enter different areas, the danger of attacks becomes more clear; bad actors might take advantage of weaknesses in AI systems, causing serious problems. For example, attackers could disrupt AI-powered robots by adding noise or messing with signal classifications, as mentioned regarding 6G networks [31]. These weaknesses not only threaten how well systems work but could also lead to serious safety issues, especially when robots are used in important fields like healthcare or emergency response. Additionally, because robots gather and analyze large amounts of personal information, they become easy targets for privacy issues and data leaks, similar to problems found in other tech areas [29]. To tackle these issues, we need strong rules and technological protections to lower the risks and make sure that using AI and robots continues in a safe way.

The safety of robotic systems is very important because many industries now use AI technologies more and more. Good practices should include strong cybersecurity steps that protect against unauthorized access and data leaks, which can be serious threats since these systems often handle sensitive data [1]. Using security frameworks with multiple layers, such as intrusion detection systems and regular software updates, can help reduce risks and make systems stronger. Also, creating teamwork between engineers and cybersecurity experts ensures that safety measures are part of the development process. This overall strategy is reflected in the suggestions for testing AI systems in real life, which highlight issues in finding faults and coordinating tasks [8]. Moreover, creating clear rules, as seen in new AI frameworks, can help people reduce risks related to ethics and safety [33]. By following these all-encompassing practices, companies can better protect robotic systems, making sure they can be used safely and responsibly in society.

In the fast-changing world of AI robotics, it is critical to set up strong rules for data protection to keep people's privacy safe and maintain ethical practices. As seen with AI technologies being used in fields like offshore wind energy and legal work, the gathering and use of private data create serious worries about privacy and security [1], [2]. There is a risk of cybersecurity issues, especially when robotic systems connect

to networks, so it is important to have strict standards to reduce the chance of data being misused or accessed without permission. The European Union's AI Act shows a forward-thinking way to manage AI uses, but it might not fully address individual rights in detail [34]. Developing strong rules that can keep up with fast technology changes is necessary to make sure data protection stays a priority, especially as AI systems become more involved in daily tasks and decision-making.

To protect AI-powered robots from cyberattacks and malicious use, a multifaceted approach is necessary, grounded in both preventative and reactive strategies. First, robust cybersecurity frameworks should be implemented, including encryption, secure communication protocols, and regular software updates to patch vulnerabilities. AI models must be designed with adversarial robustness in mind, employing techniques such as adversarial training, which helps the system identify and resist manipulations of input data that could compromise performance. Additionally, using explainable artificial intelligence (XAI) techniques can enhance transparency, allowing operators to audit and understand the decision-making process of the robot, making it easier to identify anomalies or malicious behavior. Access control measures, like multi-factor authentication and role-based permissions, should be enforced to prevent unauthorized control. Monitoring and anomaly detection algorithms should continuously analyze robot behavior for unusual activity, ensuring that any potential breaches are swiftly identified. Finally, ethical guidelines and safety protocols must be embedded in the design phase, ensuring the AI is aligned with human values and prevents unintended harmful actions. These combined measures form a scientific and systemic defense against cyber threats and malicious use of AI-driven robots.

2.4. Interaction with humans

Robots need to deal with the complexities of how humans act to live well in different settings. This job requires not just better technical skills but also bringing emotional understanding into AI systems, allowing them to handle unexpected human actions. Current studies show that good interactions between robots and people can greatly improve how things work in different fields, such as the offshore wind sector, where AI-based robots help with safety and lower labor costs while solving the skills shortage [1]. In addition, the legal field is changing because of these interactions, as AI tools make tasks like writing contracts easier, which shows the need for ethical rules that ensure accountability and trust in these technologies [2]. Overall, creating strong frameworks for human-robot interactions is essential, as it encourages teamwork and safety, which are crucial for the ongoing use of AI-powered robots in work settings.

Big challenges still exist in human-robot interaction, coming from ethical, operational, and psychological areas. Ethical issues are very important, as robots may find it hard to make moral choices because ethics can be subjective. This can cause problems in society when AI solutions do not match cultural values [1]. Also, rapid growth in robotics raises worries about job loss, since automation can make certain skills useless, creating gaps in the job market [1]. Privacy and security problems add to the difficulty of interactions because AI systems that gather personal data might face unauthorized access, risking users' trust [2]. The unpredictability of human actions makes effective interaction tougher; creating robots with emotional understanding could improve connections, but this aim is still hard to reach. Thus, it is crucial to tackle these issues to encourage good teamwork between humans and smart machines across different fields, highlighting the need for rules and strong oversight to ensure ethical standards and public acceptance.

The use of emotional intelligence in robots is an important step in improving how humans and robots interact, especially in areas that require social skills. As robots take on roles in fields like healthcare and customer service, their ability to perceive and react to human feelings helps create a better working environment. Current AI technologies enable robots to learn from their interactions, changing their responses based on emotional signals, which is key for developing trust with users [2]. This is especially important in fields like elder care and therapy, where being emotionally aware can lead to better results and experiences for patients. Additionally, incorporating emotional intelligence in robots helps address ethical issues in human-robot interactions, making sure robots do more than just perform tasks—they also improve human engagement [35]. Therefore, focusing on emotional intelligence in robotic design aligns with future goals to create intelligent systems that naturally grasp human needs and behavior.

User-focused design in robotics needs a good grasp of differences in users' backgrounds and situations, which is important for making products accessible and improving user interest. Mitchell *et al.* [1] shows that smart robots have to be flexible and easy to understand, reacting smoothly to human actions and feelings. This kind of interaction requires a mix of engineering, psychology, and human-computer interaction ideas to build robots that do tasks and also create valuable connections. Ethical issues from AI-powered robots make this task harder, as these machines need to deal with tricky moral issues while keeping user confidence [36]. Additionally, using AI can improve how personal robotic interactions can be, as shown in fields like service and healthcare [2]. In the end, designing robots for a good user experience relies on balancing what technology can do with ethical responsibilities, making sure that user interactions are both safe and enjoyable.

With the quick addition of robots into everyday life, the mental effects of human-robot bonds need careful study. As robots take on jobs usually done by people, the emotional ties that people create with these machines may resemble family connections, affecting mental health and social interactions significantly. For example, the hospitality sector has begun using AI to improve guest satisfaction while also helping to build human connections with service robots [37]. This situation creates ethical issues, as depending on AI for emotional help can increase feelings of loneliness when human contact is replaced. Additionally, the focus on teamwork between humans and robots shows the link between thinking and feeling in these connections, requiring designers to include emotional understanding in robotic systems to effectively handle unpredictable human actions [1]. As societies continue to accept AI-based robotics, grasping these mental effects is crucial to ensure that these technologies enhance, not lessen, human experiences.

Big developments in AI are changing how humans and robots interact, leading to important studies on many parts of this changing connection. One important area for future study is ethics, especially concerning the moral issues of autonomous systems and the challenge of creating ethical principles that work across various cultures [38]. Moreover, as AI-powered robots become more common, it is important to focus on job loss and training programs to help current workers adjust to the new job changes caused by automation [1]. In addition, strong privacy and security measures will be necessary to reduce risks linked to the collection of sensitive data by AI systems [2]. In the end, these studies will help create a better working relationship between people and robots, enhancing teamwork while tackling the ethical and social issues that come up in this fast-changing world.

Humans and robots can collaborate effectively and safely by enhancing several aspects, such as: i) design for human-centered collaboration e.g., collaborative robots (cobots): these are specifically designed to work side-by-side with humans. They include built-in safety features like force limitations, soft edges, and real-time sensors to detect human presence; ii) clear role division which lets robot's handle: repetitive, dangerous, dirty, or ultra-precise tasks (e.g., lifting heavy objects, welding, and data entry). Let humans focus on problem-solving, creativity, emotional intelligence, and complex decision-making. This balance avoids redundancy and plays to each party's strengths; iii) shared interfaces and communication e.g. visual displays, gestures, lights, or speech: robots can communicate intentions clearly to human co-workers (e.g., showing when they'll move or need input). Human-in-the-loop systems: allow humans to step in, override, or guide decisions, especially in high-risk situations (like autonomous vehicles or robotic surgeries); iv) safety systems and protocols including: proximity sensors, cameras, and AI-based motion prediction can prevent accidents by detecting and responding to humans nearby. Emergency stop mechanisms should be easily accessible. Standardized protocols such as training for humans on how to safely interact with robots (and vice versa) build trust and smooth workflows; and v) continuous learning and adaptability including adaptive AI, where robots that learn from human actions and feedback become more intuitive and safer over time. For example, a warehouse robot that learns a worker's pathing habits can adjust its routes to reduce near-collisions.

3. FUTURE TRAJECTORIES OF AI-POWERED ROBOTICS

New advancements in AI-based robots show big changes in many areas, especially in making operations more efficient and precise. These technologies help carry out repetitive tasks on their own, which lets human workers focus on more complex jobs that require unique human skills, promoting workplace innovation [1]. Moreover, advanced algorithms, like deep learning and reinforcement learning, allow robots to reach new levels of accuracy, visible in various applications such as robotic surgery and complicated manufacturing tasks [2]. Although these advantages promise higher productivity and lower costs by reducing the need for human labor, they also bring up important ethical issues, such as job loss and responsibility for decisions made by robots. As AI in robotics continues to grow, it will be crucial to tackle these issues through strong rules and ethical standards to ensure safe and fair progress that benefits everyone, ultimately shaping the future of AI-based robots.

3.1. Enhanced efficiency

Adding AI-powered robots is a big step for better efficiency in many industries. These robots can work on their own without needing a lot of human supervision, which lets companies use their human workers for more important tasks that need smart thinking or creativity. This not only boosts how much work people can do but also lowers costs linked to human workers, since robots can keep going all the time without needing breaks or vacation days [1]. For example, in manufacturing, robots that use AI have made processes like quality checks and assembly better, resulting in higher product quality and fewer mistakes [39]. In healthcare, robotic systems have improved the accuracy of surgeries and cut down recovery times, showing how efficiency can grow in important operations [40]. Therefore, the idea of better efficiency goes beyond just replacing workers; it opens doors for new ideas in fields facing growing demands and limited resources.

The use of AI in robots is changing how things work in many fields, allowing machines to operate on their own without needing constant human help. This move to self-operation not only boosts efficiency but also improves precision, enabling robots to carry out complex tasks, from manufacturing to sensitive surgeries, more accurately than people do [1]. Additionally, AI-equipped robots can learn from their experiences and adjust to new settings, which helps increase productivity and lowers risks in dangerous scenarios, such as disaster response and military missions [2]. But the path to complete autonomy comes with difficulties, including moral questions about who is responsible and the risk of replacing human jobs with machines [41]. As we progress, it is important to tackle these issues to create a safe and ethically sound framework that supports the positive partnership of autonomous robots and society [42].

The move towards using robots in different industries is an important step for improving how businesses work and how they use their workforce. By letting robots take care of boring and repetitive tasks, companies can focus their human employees on jobs that need creativity and smart thinking. This change not only increases productivity but also reduces mistakes that can happen with humans doing dull work, as shown by improvements in AI robots that are more accurate and efficient [1]. Additionally, the ongoing development of these technologies, even though it brings up concerns about ethics and fears of job loss, makes a strong case for using them. For example, AI can manage tasks in dangerous situations all by itself, promoting safety and cutting labor costs [2]. Therefore, by adopting robotic systems, businesses can achieve more savings and better long-term operations, leading to a future where human creativity works alongside technology.

The rise of AI-based robots is a big change in how we work, letting machines run all the time without needing people. This means we can automate tasks that are dull and take a lot of time, which leads to better efficiency and productivity in many areas. These robots can work 24/7, cutting down on costs related to hiring people like paying salaries and giving benefits [1]. Also, using AI makes things more accurate and lowers risks, especially in dangerous places where it's risky for humans to be [2]. Yet, there are ethical issues about how these machines act on their own, especially when it comes to who is responsible for their decisions [30]. To tackle these problems, we need strong rules to make sure AI acts in a responsible way while also dealing with worries about job loss and privacy that come with more automation [8]. So, while the ability to work without human help is very promising, we need to think carefully about how it will affect society as a whole.

The joining of AI and robots is changing how jobs are allocated in different industries, creating both chances and problems. As jobs change with automation, many old skills are no longer needed, leading to a big need for retraining and new skills to meet the labor market's shifting needs. For example, even with worries about job loss, research shows that automation is seen more as a changer of job roles instead of a direct reason for unemployment, as noted in [43]. This change is clear in the offshore wind industry, where the expected higher demand for workers requires new skills that combine technical knowledge and robotics skills, according to [1]. Also, as AI improves efficiency in operations, companies might shift their workers to more valuable tasks, changing roles and responsibilities while seeking to boost productivity and lower risks, as pointed out in [19].

Case studies from different fields show how AI-based robots make operations run better. For example, in manufacturing, using collaborative robots has led to better product quality and less need for human workers, creating a safer workplace and higher productivity. In disaster response, advanced drones help carry out safer rescue missions and improve how resources are used—leading to better navigation and faster delivery. The healthcare field has also seen great progress; robotic surgical systems lower patient risks and improve surgical precision, which enhances patient care overall. This evidence highlights how AI-powered robots can change industries, as shown in studies that report significant efficiency gains [1], [2]. The use of these technologies marks the start of a new period, opening up possibilities for better productivity and reliability in various sectors.

3.2. Improved accuracy

Improvements in AI are changing how robots work in different fields. By using advanced technologies like deep learning and sensor blending, these systems can handle large amounts of data instantly, resulting in high accuracy in tasks that humans usually do. For example, AI-powered robots in healthcare have shown better accuracy in performing surgeries, allowing them to adjust grip strength and manage surgical tools with a level of precision that often goes beyond human skill [1]. In the manufacturing sector, AI-equipped robots improve product quality by greatly lowering defects through careful quality control methods [2]. Yet, these developments come with challenges, as incorporating AI into robotic systems requires strong regulations to ensure ethical use and responsibility. In conclusion, the path to better accuracy in AI-powered robots could transform industries while also tackling ethical and operational issues.

Advances in AI tech is important for improving accuracy in many fields, especially in robotics. Using methods like deep learning and sensor fusion, smart machines now perform tasks with great precision, doing better than humans in essential areas like surgeries and complicated manufacturing. For example, AI robots can handle sensitive parts with the care needed in industries that demand high-quality standards,

reducing errors and increasing productivity [1]. Additionally, these technologies help in dangerous situations, like responding to disasters, where drones and self-driving vehicles make rescue operations safer and more effective [30]. However, these improvements require looking again at rules to deal with ethical issues and responsibility in AI decisions, making sure that while technology grows, the effects on society are carefully considered [8]. In conclusion, the significant effects of AI on precise tasks are clear, but there are challenges that need to be addressed to make the most of its potential.

Self-learning algorithms in AI robotics can change many areas, making operations work differently. These algorithms allow robots to learn and improve their skills on their own, which helps make tasks more efficient and precise in fields like manufacturing and healthcare. For example, in assembly robots, self-learning methods reduce the need for human help while increasing accuracy, which meets the growing need for quality in industries [1]. Additionally, AI systems can analyze large amounts of data in real time, leading to better decision-making in complicated situations like disaster responses or farming logistics [2]. Yet, using these self-learning systems raises ethical questions, worries about privacy, and issues related to job loss, making it important to develop strategies for human-robot teamwork and its effects on society. Therefore, the blend of technology and ethics should shape how we build self-learning features in robotics in a responsible and beneficial ways.

The rise of advanced robots, combined with real-time data processing, marks an important change in many fields. These technologies allow machines to quickly understand large sets of data, which helps them make decisions fast and improves how they operate. For example, real-time analysis helps robotic systems in manufacturing and healthcare track performance, find problems, and adjust to new situations, leading to better processes and higher accuracy. This is particularly important in situations that need exactness and quick reactions, like using drones for disaster relief, which use real-time data to safely navigate tough areas [1]. Still, adding these technologies brings challenges, such as ethical issues and the risk of job losses that must be thought through carefully [44]. Therefore, while real-time data processing greatly enhances the abilities of AI robots, it also requires careful consideration of its wider social effects and the need for rules to ensure responsible use.

In the field of AI-based robots, accuracy is very important for key tasks in many areas. For example, in healthcare, surgeries with robot help have shown better accuracy, which lowers risks of problems compared to regular ways. The smart algorithms used in these systems, like deep learning and sensor merging, make real-time changes to ensure that even very delicate jobs are done with better precision [1]. In the same way, in manufacturing, robots that work on their own help with quality checks by reducing human mistakes during putting things together and inspections. This better accuracy results in better product quality and lower costs, helping create a more effective production setting [2]. Also, in emergency situations, drones with advanced navigation and imaging tools make rescue actions better, allowing quick and precise evaluations of tough environments [30]. These instances highlight how crucial accuracy is in using AI-powered robots to improve results and ensure safety in various uses.

Advancements in robotic accuracy are set to change many industries, using new AI developments to improve work capabilities. The use of deep learning and sensor fusion helps robots perform tasks with great precision, possibly doing better than humans in complicated situations like surgeries and fine assembly work [1]. Self-operating systems can change based on their surroundings while safely handling dangerous tasks, lowering the risks related to human jobs in hazardous areas [2]. Additionally, the ongoing development of AI algorithms will not just boost how robots learn and adapt but also allow for better teamwork between humans and robots, making sure that emotional understanding and ethical matters are brought into their work processes [17]. As these changes happen, they will greatly improve efficiency, increase safety, and open new job possibilities, highlighting how robotic precision can reshape the future of work and industry.

3.3. Increased productivity

The use of AI in robotics changes how productivity is understood in many fields. With autonomous and semi-autonomous robots, companies can assign routine and time-consuming jobs to machines, which allows human workers to focus on more difficult tasks that add value. Better accuracy from advanced AI algorithms and sensor technologies leads to improved quality outcomes with fewer mistakes, boosting overall efficiency in operations [45]. This change not only helps with productivity but also allows machines to function well in tough situations where humans might struggle [1]. As a result, AI-powered robots work continuously without the breaks needed for human workers, making productivity a key benefit of robotics in today's industries [42]. In conclusion, the combination of AI and robotics helps organizations reach new productivity heights while encouraging innovation and operational strength.

Efficiency and productivity are closely linked, especially in AI-powered robotics, where technology greatly boosts operational functions. With autonomous systems, companies can assign repetitive and time-consuming jobs to robots that work continuously, cutting down on human mistakes and raising

productivity. This connection shows in many industries; for example, the manufacturing sector sees gains in quality control from robotics, which significantly reduces defects, helping achieve higher output and better efficiency [17]. Moreover, studies show that as efficiency rises due to smoother processes and accurate execution, productivity increases as well, leading to a notable drop in operational costs [1]. However, the challenge is to ensure these growing technologies are used ethically, finding a balance between the benefits of automation and concerns over job loss and regulations, which calls for a thoughtful look at the societal effects of these advancements [17].

High-stakes situations, which have tough conditions and dangers, make it hard to use AI-based robots. How well these robots work in these places depends on advanced algorithms and solid design. As noted in [1], adding AI to robots can improve safety and efficiency, especially in fields like offshore wind energy, where bad weather and complicated logistics create problems. Also, Alahmadi *et al.* [8] shows that swarm robotics can do complicated tasks in unpredictable places, hinting at a way to handle real-world challenges. Still, ethical issues need attention, since human interactions with autonomous systems can be unpredictable and cause problems. Therefore, although AI-powered robots can lower risks and boost productivity a lot, a deep understanding and strong frameworks are crucial for dealing with the difficulties of tough environments.

The big change from using AI can be seen in the long-term productivity improvements in different fields. By taking over simple tasks, AI-powered robots improve efficiency, letting workers concentrate on more complex and strategic jobs, which promotes a more creative work setting. As noted in [1], the offshore wind industry is a good example of this, where AI and robots could make all processes better, from planning to final shutdown. Also, the ability of AI to boost precision and lower costs ties in with better productivity, as shown in manufacturing and healthcare uses [2]. Robots can work alone without needing people, allowing them to keep going even in tough conditions, achieving new levels of productivity. However, to take full advantage of this technological advancement, we must deal with regulatory and ethical issues, guiding industries towards stable growth and a stronger future.

The use of AI in robotics has led to notable productivity improvements in many industries, helping businesses make their operations better and more efficient. For example, in manufacturing, AI-based collaborative robots help with quality control, which results in better product quality while using less human effort. This advantage is also mentioned in [1], which points out the need for new ideas to solve problems in offshore wind energy, showing that AI is used for specific improvements in different sectors. Furthermore, the agriculture industry has benefited from tools like autonomous drones, which increase crop yields and cut down labor costs, in line with the rising global demand for food mentioned in [46]. As industries keep adopting AI technologies, the potential for improved productivity looks promising, offering not just better operations but also a strong competitive advantage in a changing market environment.

To evaluate how productivity improves with AI-based robots, a broad approach is needed, focusing on measurable metrics that connect to better efficiency and accuracy in operations. Typical productivity measurements, like output per labor hour, might change to include new indicators that show the special benefits of robotic systems, such as throughput rates, error reduction, and operational uptime. For example, autonomous robots in factories have shown they can work more efficiently by running continuously, leading to shorter cycle times and better overall quality control [1]. By setting benchmarks based on these metrics, businesses can more accurately gauge how robotics affect productivity, making sure they take full advantage of AI's transformative capabilities. Additionally, using real-time data analytics can help with ongoing adjustments to operational settings, creating a flexible understanding of productivity gains as technologies and market needs change [2]. In the end, a strong system for assessing productivity improvements will help industries maximize their investments in robotics, aligning them with strategic goals and eco-friendly targets.

3.4. Risk reduction and safety

The use of AI-based robots in risky places marks a big change in how we keep operations safe and reduce risks. Using smart machines in dangerous situations, like labs with harmful chemicals or military areas, helps limit how much human workers face possible hazards. Also, robots improve worker safety in factories by taking on risky jobs, which cuts down on accidents and injuries [47]. The accuracy and dependability of AI technology, especially in medical fields like robotic surgeries, help make these procedures less invasive, leading to better patient results [44]. These developments highlight the need for strong rules to control how these technologies are used, focusing on ethical issues and necessary oversight [2]. In the end, adopting AI-powered robots not only improves how efficiently work gets done but also creates a safer environment for workers and at-risk groups, changing industry standards and practices.

Hazardous places have special problems that need new tech solutions, especially with AI-powered robots. These robotic systems can work alone in risky areas, which greatly improves safety for human workers by reducing the dangers from chemicals, high heat, and other unsafe materials. These modern robots with AI can carry out important jobs like watching over industrial tasks, doing maintenance in nuclear sites,

and helping in search and rescue in disaster areas [1]. Also, using advanced sensors lets these robots find and deal with dangers quickly, making their work more effective and precise [48]. As robotics becomes more common in tough environments, it leads to a big change in safety and efficiency, helping to create a stronger and greener way of handling dangerous work across many fields.

Using AI-powered robots in workplace safety rules is a big step forward for reducing risks and making work more efficient. By using smart machines in places that usually have many dangers, companies can greatly lower the threats to human workers. For example, cobots can work next to people, which reduces accidents and increases productivity and quality control [1]. Also, new AI technologies make it possible to do riskier tasks more accurately, like dealing with dangerous materials or doing complex surgeries, where accuracy is very important [49]. These new tools not only help solve immediate safety issues but also create a proactive risk management culture in fields like manufacturing and healthcare. Even though there are still issues with rules and the ethical concerns of robots taking charge, the push toward smarter, safer workplaces is clear and likely to change how worker safety rules are made in the future [50].

New technologies in robots are changing how we handle emergencies, offering new chances to improve efficiency and safety. Robots with smart AI can do dangerous tasks that put human lives at risk, like searching for survivors in areas hit by disasters [51]. Drones and self-driving ground vehicles have been very good at exploring dangerous places, helping responders focus their rescue efforts better [1]. Moreover, using robots in emergency work lessens the chance for humans to face risky situations, thus lowering the dangers linked to biological, chemical, or structural threats. But using these technologies also brings up ethical issues, especially about who is responsible for decisions made by machines [52]. As these problems are worked on, the ongoing development of robots in emergency response shows their ability to greatly influence future paths, leading to better readiness and strength in dealing with disasters.

In healthcare places, the use of AI and robots is not just an upgrade but a big change that could greatly improve safety standards. By using AI-based robotic systems, healthcare centers can reduce human mistakes, which is a common issue in medical settings, especially during difficult tasks like surgeries [2]. Developments in robotic surgery show this potential; these systems have proved to be more accurate, resulting in fewer problems and better patient results since they can perform tasks with precision that surpasses human skills [53]. Also, AI's role in predictive analytics helps find possible safety issues early, encouraging quick actions [50]. Yet, the change must tackle ethical points, like ensuring responsibility in robot choices and keeping patient data safe, which are crucial for maintaining trust and security in healthcare environments. So, while AI-powered robots promise significant safety gains, it is important to carefully balance technology and ethics.

As AI robots keep changing different fields, the need for better risk management is getting more important. Companies have to deal with ethical issues about machine choices, especially when AI is used in important fields like healthcare or manufacturing [1]. Risks like job losses also need to be addressed, requiring strong systems to help workers adapt, learn new skills, and retrain. Additionally, using AI and robotics can lead to privacy and security risks, as these technologies often handle sensitive information in linked systems [25]. How well risk management works will depend on spotting these problems early, enforcing clear regulations, and encouraging teamwork across different fields to make sure that moral values align with human interests while using AI technologies effectively. Taking these steps is vital to handling the challenges of risks involved in using these game-changing technologies.

3.5. Cost savings

The use of AI-powered robots in different industries shows great chances to cut costs, mainly by improving how operations run and lowering labor costs. AI systems can work all the time without taking breaks, which boosts productivity a lot compared to humans. This ability to work continuously helps companies use their labor more efficiently since fewer workers are required to oversee or maintain the robots, which brings down salary and benefit expenses. For example, as noted in [54], hospitals can use AI tools to improve diagnosis and patient monitoring, leading to lower costs and better patient care. Likewise, the construction sector can take advantage of predictive analytics and data insights to speed up project timelines and decrease delays, thus cutting overhead costs [55]. In the end, these advancements show that AI and robotics are not just initial costs but also powerful tools that can provide important long-term economic advantages.

The use of AI robots in different fields makes it necessary to look closely at the starting costs compared to the savings these systems can provide over time. While the initial investment for advanced robots can be high, the expectation of better efficiency and lower operating costs in the future often makes this expense worthwhile. For example, research shows that investing in robotics can simplify tasks, which boosts productivity and reduces the need for human labor, leading to lower labor costs and more accurate results [1]. Additionally, AI systems that can operate around the clock without needing typical employee benefits further strengthen this argument for cost savings. Still, it is important to consider challenges like

ethical issues and job losses that need careful management to ensure that these technologies are used sustainably, balancing the upfront costs with expected financial benefits [56], [57].

The use of automation technologies in many different fields has changed how they operate, mainly by cutting down on labor costs. With AI-powered robots, companies can rely less on human workers for tasks that are repetitive and take a lot of time, allowing them to focus their resources on more important activities that need human thinking and creativity. For example, as shown in [1], the offshore wind industry is using robots to make operations more efficient while also dealing with high maintenance costs for turbine care. This is also seen in the food and beverage sector, where automation improves service and lowers the need for staff, which helps increase profits and customer satisfaction [58]. Even though there are worries about job loss, it's important to see automation as a way to create new jobs that need more skills. So, adopting automation not only saves money but also energizes the workforce by increasing the need for skilled workers in AI technologies.

As more industries are using AI robots, the money saved from better efficiency is clearer. By using automation for simple tasks like robotic inspection and maintenance in offshore wind areas, businesses can cut costs a lot while letting workers focus on more important jobs, which helps drive innovation and productivity [1]. Also, AI systems help robots work more accurately and consistently, which lowers waste and defects in production, leading to savings over time. The article by Bhatt et al. says that using AI in legal work not only makes legal processes easier but also allows for handling more cases, which can save money [2]. In the end, moving to AI-based automation shows strong business reasons, as companies can gain from better efficiency and significant long-term savings, putting them in a good spot for future growth as technology changes.

In many case studies, AI robots have shown they can save money in different industries. For example, in manufacturing, using robots that can work by themselves has cut down costs by needing fewer human workers for repeated tasks, which means less spending on pay, benefits, and training over time. Plus, robots that work with people have made productivity and safety better, leading to fewer accidents at work [1]. In the agriculture field, using advanced drones for managing crops has also lowered labor costs, demonstrating how robots can increase production while wasting less [5]. These cases illustrate not just the initial money spent on robotic systems but also the ongoing financial gains, highlighting the important role AI and robotics will have in changing how costs work in many industries.

Evaluating return on investment (ROI) in robotics needs a complex approach that looks at both numbers and less measurable aspects. Standard financial models like discounted cash flow (DCF) or net present value (NPV) help judge how financially sound robotic use is across different fields. However, these models need changes to consider the special advantages that come from modern AI-powered robotics, which include better efficiency, productivity gains, and long-term cost savings, as mentioned in [1], [2]. Important points like major drops in labor expenses and lessening human mistakes are essential for accurately figuring ROI. Additionally, the review must include metrics related to safety gains and risk reduction, which are becoming more important in industries like manufacturing and healthcare. Therefore, it is necessary to create solid economic models that take these detailed factors into account to support smart investment choices in robotics. This will help ease issues that come with integration and use in professional settings.

3.6. Job creation opportunities

There are a few roles that can be created in the era of AI and robotics, such as; i) AI and robotics development: demand for roles such as AI engineers, roboticists, data scientists, and machine learning specialists is growing rapidly; ii) maintenance and supervision: robots still require human oversight. This leads to jobs in monitoring, maintenance, diagnostics, and repair; iii) training and implementation: workers are needed to train robots, set up systems, and tailor AI for specific business needs; and iv) ethics and compliance: with increased AI use, roles in governance, ethics, and legal oversight will become more prominent. On the other hand, there are human-AI collaboration jobs, including: cobots which assist humans in factories, logistics, or healthcare, creating roles where people work with robots rather than being replaced by them and AI-assisted creatives, such as writers, designers, and marketers can leverage AI tools to boost output and quality, spawning hybrid creative roles.

3.7. Augmenting human capabilities

In terms of augmented human capabilities, there are a few things that can be enhanced using AI and robotics, such as: i) productivity, where robots can handle repetitive, dangerous, or highly precise tasks, allowing humans to focus on complex problem-solving and innovation. For example, in manufacturing, AI-powered robots handle assembly while humans oversee quality and optimize processes; ii) accessibility and inclusion, where AI-powered exoskeletons and assistive robots can help people with disabilities or elderly individuals perform tasks independently. Augmented reality (AR) and AI-powered devices help workers with limited skills or training perform complex jobs more easily; iii) decision support, for example in healthcare, finance, and logistics, AI systems provide real-time data analysis and recommendations,

helping humans make better, faster decisions; and iv) remote work and telepresence, where robotics combined with AI enables remote operations (e.g., surgery, inspections, teaching), extending human presence and skills to new locations. AI-powered robotics isn't just about replacement—it's about enhancement and collaboration. As long as societies invest in reskilling, ethical frameworks, and inclusive access, these technologies have the power to generate new economic opportunities and help humans reach new heights in productivity and innovation.

4. AI APPLICATIONS IN ROBOTICS ACROSS DOMAINS

The use of AI in robotics is changing many industries by improving how they operate and their efficiency. In manufacturing, for example, collaborative robots make safety better and increase productivity since they can work next to human employees to carry out complicated tasks more accurately. Also, autonomous robots are changing quality control by reducing human mistakes during checks, leading to better product quality and lower operational expenses [2]. In the healthcare field, robotic helpers improve patient care and help medical staff boost their performance by managing routine tasks, which leads to more tailored experiences for patients [59]. In addition to these areas, AI-based robots are important for disaster response, using advanced drones for safer and more effective rescue operations, showing their wide-ranging uses and powerful impact across different sectors [15]. Therefore, adding AI to robotics not only improves operational efficiency but also tackles difficult issues in safety and productivity, setting the stage for future advancements.

4.1. Manufacturing

The use of AI in manufacturing is changing old practices by making operations more efficient and accurate. By using AI robotics, manufacturers can automate tasks that take a lot of labor, allowing humans to focus on tasks that need critical thinking and creativity, as shown in Figure 1. This change improves workflow and raises product quality, as robots can perform precise tasks with little human help, which reduces mistakes and waste [60]. Additionally, collaborative robots in production settings help create a safer work environment by lowering the risks linked to manual labor, which encourages innovation [1]. However, as these technological advances come, manufacturers also face challenges like ethical issues and the possibility of job loss due to automation. As the industry changes, finding a balance between the advantages of technology and its effects on workers will be essential for growth that lasts.

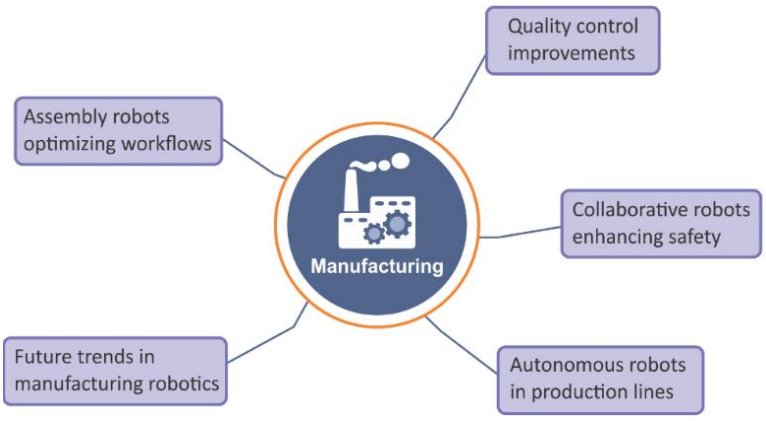

Figure 1. AI applications in robotics for manufacturing

4.1.1. Quality control improvements

In the field of robotics, big improvements from AI are changing how quality control works in different industries. Using complex algorithms and real-time sensor information, AI systems make defect detection more accurate, lowering human mistakes and ensuring better product quality. Adding robotics to quality control helps with ongoing monitoring and allows automatic changes to manufacturing processes when problems arise, keeping operations running smoothly. Also, the capability to review large data sets supports predictive maintenance, which cuts downtime from equipment failures and boosts production efficiency [1]. This move towards automated quality checks decreases the need for manual work, tackling

labor shortages, and increases trust among stakeholders in product reliability [61]. As industries adopt these changes, the clear effects of AI-powered robotics in quality control become more obvious, leading to better accuracy and stronger operations.

4.1.2. Collaborative robots enhancing safety

Bringing in collaborative robots into different industrial areas is now seen as a key way to improve safety in many situations. These smart machines operate alongside human workers to lower risks, especially in places where there are physical dangers or repetitive tasks that can cause injuries. By using advanced sensors and AI technology, collaborative robots, or cobots, keep an eye on their work environments, helping them react quickly to the presence and actions of humans, which helps lower the chance of accidents. The use of these technologies greatly reduces the load on human workers, allowing them to concentrate on more complex tasks that need critical thinking and problem-solving skills [1]. Additionally, in fields like manufacturing and healthcare, collaborative robots have proven to enhance operational safety, improving the overall effectiveness of processes while keeping human workers safe from possible risks [62]. As AI-based robots keep advancing, their part in creating a safer workplace will surely grow, tackling both existing issues and future developments.

4.1.3. Autonomous robots in production lines

The use of autonomous robots in production lines shows a big change in how manufacturing works, using advanced AI to make operations better. These robots can do tasks without always needing humans, which raises important issues like job loss and ethics, needing careful thought on how to mix them into the workforce. By taking over repetitive tasks, autonomous robots cut down on labor costs and let human workers concentrate on solving complex problems and being creative, which boosts productivity and accuracy in production settings [1]. But worries about ethics and the risk of job cuts mean a careful method is needed, including thorough training programs and ethical guidelines to direct AI use [63]. As manufacturing changes, working together with human skills and robotics will be crucial for ensuring growth and new ideas in the industry.

4.1.4. Assembly robots optimizing workflows

As more industries use automation, adding assembly robots has become an important part in making work processes better. These robots make tasks easier by doing repetitive jobs very quickly and accurately, which lowers the chances of human mistakes and maintains product quality. For example, AI-powered assembly robots can work on their own, letting human workers tackle more complex tasks that need thinking and planning, thus using resources better [1]. Also, new developments in sensor technology and machine learning help these robots adjust in real-time to changes in the production line, raising efficiency and cutting downtime. But, with these advantages come ethical issues, like job loss and the need for strong rules to keep workers safe and protected [2]. It is necessary to handle these problems to fully use the benefits of assembly robots in today's work processes.

4.1.5. Future trends in manufacturing robotics

The path of manufacturing robotics is set to change significantly due to improvements in AI. The use of AI in robotics is expected to increase efficiency, allowing machines to do repetitive tasks non-stop, which lets humans focus on more complicated jobs. Recent research, including [64], shows that the cooperative settings promoted by Industry 5.0 enhance this efficiency while also keeping workers safe and engaged. Additionally, better accuracy from advanced algorithms helps improve tasks like quality control and assembly, leading to fewer mistakes and increased output. Using smart robots in dangerous settings also boosts safety by lowering risks connected to human work, as noted in [1]. These expected developments not only respond to current work issues but also point to a future where saving money becomes key through lesser dependence on traditional work models, changing the manufacturing industry.

4.2. Aerospace

The use of AI in the aerospace industry is not just an upgrade; it marks a significant change in how work gets done, improving both effectiveness and safety, as shown in Figure 2. As noted by [1], self-driving rovers and sophisticated drones show AI's ability to make research and rescue operations more effective, improving how objects are found and navigated in tough situations. However, ethical issues are a serious concern, especially as AI systems take on critical roles, highlighting the need for strong monitoring systems to ensure compliance and responsibility [65]. In addition, depending on AI brings added challenges regarding how humans and robots work together, showing the importance of creating systems that can read human emotional signals to keep operations running smoothly [2]. As these technologies move forward, focusing on

enhancing human skills and reducing risks is crucial, making sure the aerospace industry benefits from AI while tackling its challenges.

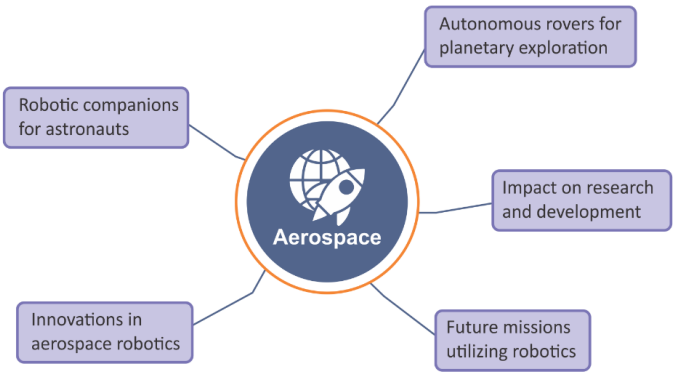

Figure 2. AI applications in robotics for aerospace

4.2.1. Autonomous rovers for planetary exploration

The progress of robotic technology brings major possibilities for exploring other planets, especially with autonomous rovers. These robots are made to work in tough space settings, able to do scientific studies, move across rough ground, and handle unexpected situations on their own. The creation of platforms like Aria shows a move toward advanced autonomy, using Bayesian networks to improve sensor merging and decision-making skills. Post. As space missions become more ambitious, like the successful landing of the Yutu rover on the moon, the demand for more dependable and flexible systems is clear [66]. Also, adding AI to these rovers can greatly boost how efficiently and accurately they operate, reducing the risks that come with human control and making sure accurate data is gathered quickly. In the end, these autonomous rovers not only mark a big step in exploration technology but also highlight the need to think about ethical issues in how autonomous systems react and engage with possible alien environments.

4.2.2. Robotic companions for astronauts

As humans go further into space exploration, using robotic helpers for astronauts stands out as an important step forward. These robotic systems, made to help with many tasks, can greatly improve astronauts' work and efficiency during long missions. They offer real-time help, handle maintenance tasks, and improve communication with mission control, which can ease the mental and physical stresses of isolation and limited living conditions often faced in space. However, it's crucial to consider ethical issues in this process, especially related to decision-making rights, data privacy, and the risk of job loss for crew members [1]. Also, as astronauts work with these AI robots, issues about emotional understanding and teamwork between humans and robots must be resolved to ensure effective interactions that respond to the unpredictable nature of human actions [67]. In the end, the successful partnership between astronauts and their robotic assistants will influence the future of space exploration.

4.2.3. Innovations in aerospace robotics

The field of aerospace robotics is changing fast, with new developments that improve efficiency and safety in many uses. A key advancement is the use of autonomous rovers on other planets, which makes research and identifying objects on places like Mars easier, broadening our knowledge of these alien environments. Also, robotic helpers are becoming important for astronaut missions, greatly helping the work experience and effectiveness in tight spaces where human interaction is limited [1]. As these technologies develop further, they present hopeful solutions to long-standing challenges, such as minimizing risks in dangerous missions where safety is essential. However, ethical issues relating to autonomous decision-making in critical situations are still a major concern that needs a strong set of rules to guarantee responsibility and adherence to safety protocols [60]. Therefore, the changes in aerospace robotics present both unique chances and important challenges that the industry must deal with.

4.2.4. Impact on research and development

The meeting point of AI and robotics brings a big change in research and development in many areas. As the offshore wind sector works to grow capacity greatly by 2030, using AI-powered robots could

help make processes more efficient and safer from planning to decommissioning [1]. In the legal area, using AI for things like contract writing not only makes operations smoother but also requires strong ethical rules to deal with accountability and privacy issues [2]. Also, as companies look for more automated options, it is clear that research from different fields is needed, focusing on not just improving tech but also on how humans interact with robots and the effects on society. Therefore, it's important to build a complete research and development setting that focuses on ethical matters while looking into new uses of AI-powered robotics to ensure sustainable growth that keeps up with changing industry demands.

4.2.5. Future missions utilizing robotics

As technology keeps changing in different fields, missions that use robots are ready for big growth. Future plans will use AI-powered robots to make operations better, especially in crucial places like offshore wind farms, where [1] notes the need for advanced robots for monitoring and maintenance. The automation these systems provide helps solve issues like high costs and a lack of workers, letting people focus on more complex jobs needing emotional skills and critical thought. Also, looking into uses in farming, healthcare, and emergency responses shows that there's more dependence on smart robots to boost productivity and safety. Since the ethical concerns of using these technologies require careful thought, it is essential to create strong guidelines to ensure AI advancements match community values, enhancing human skills instead of reducing them.

4.3. Disaster response

In the changing field of emergency management, using advanced robots and AI can greatly improve how we respond to disasters, as shown in Figure 3. Recent developments, like the use of advanced drones, make rescue operations much better, allowing for safer and more effective missions while focusing efforts based on current data analysis [1]. These technologies can go into dangerous situations that might put human responders at risk, which lowers the chances of injuries and increases overall efficiency [68]. Also, using AI-powered robots helps in collecting data accurately and making better decisions during emergencies, allowing for smarter use of resources [69]. As this field moves forward, we must consider the ethical issues related to using these technologies, especially concerning accountability and privacy, to ensure they are used responsibly in critical situations.

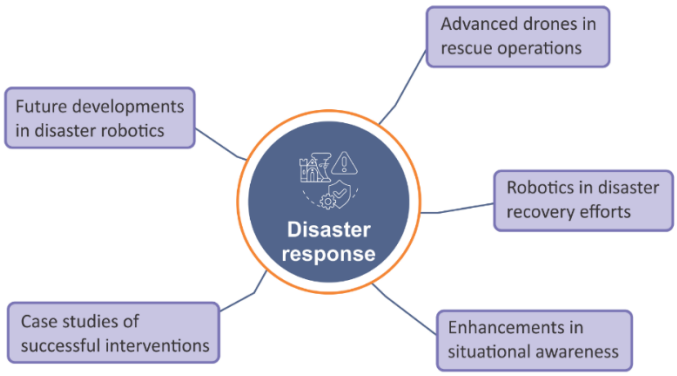

Figure 3. AI applications in robotics for disaster response

4.3.1. Advanced drones in rescue operations

In the past few years, new technologies have come up in emergency response, especially with drones that are now very important in rescue missions. These flying machines, using AI and advanced sensors, help responders understand situations better and quickly assess areas hit by disasters, allowing them to focus their efforts more effectively. By using AI for real-time data analysis, drones can fly through complicated spaces on their own, which reduces danger to people during risky missions [1]. Also, they can drop necessary supplies and share important information, which can greatly improve how ground teams work and respond [70]. As the integration of these systems becomes more complex, it is crucial to pay attention to ethical issues, privacy, and the impact on jobs. There is a need for rules that make sure these technologies support human tasks instead of taking over them, ultimately making rescue efforts safer and more effective in different crisis situations.

4.3.2. Robotics in disaster recovery efforts

The use of robots in disaster recovery is changing how we improve efficiency and safety. As natural disasters happen more often, it is more important to use new technologies quickly, allowing for fast responses that can save lives and reduce economic damage. For example, robots can help look at unsafe areas, giving important information without risking human lives, as noted in [71], which shows that robotic systems reduce the hard work usually needed in dangerous situations. Also, new technologies like autonomous drones and AI vehicles help with logistics and resource sharing, making recovery efforts much better after a disaster [extractKnowledge1]. While there are issues like ethics and job loss, the benefits of better accuracy, productivity, and safety highlight the need for strong rules to manage these technologies [72]. In the end, robots are set to change how we respond to disasters, providing tools that speed up recovery and ensure the safety of those involved in the recovery process.

4.3.3. Enhancements in situational awareness

Big improvements in technology have changed how we understand situations, especially in AI and robotics. By using real-time data and better sensors, AI-powered robots can now better understand complicated environments, which helps them make decisions in many fields like manufacturing and healthcare. For example, drones that can move on their own and have advanced navigation systems can quickly adapt to different landscapes during emergency responses, leading to safer and more effective rescue missions. Also, as robots get better at working with humans and improving communication and emotional skills, they lead to a more responsive work environment [1]. However, these advancements bring challenges too, especially around ethics and privacy, which require strong rules to ensure AI is used responsibly to improve situational awareness [73].

4.3.4. Case studies of successful interventions

Using many case studies, the use of AI robots in different fields shows big improvements and real benefits. For example, in manufacturing, there have been great gains in quality control and productivity by using collaborative robots, which improve safety and make operations easier (extractedKnowledge1). In healthcare, robotic helpers and surgical robots have improved patient care by lowering risks and enhancing precision in procedures, thus boosting medical staff performance (extractedKnowledge2). Also, in disaster response, advanced drones have changed search and rescue operations, leading to better results by effectively organizing efforts (extractedKnowledge1). These actions show the significant impact of AI robots and highlight the need for ongoing research and rules to tackle ethical issues and effects on jobs in this quickly changing field. By studying these actions, we can get a better idea of how to use AI's full capabilities while dealing with the challenges it brings.

4.3.5. Future developments in disaster robotics

Recent progress in robotics, influenced by AI, is leading to major changes in how we respond to disasters. Current trends show a shift towards systems that can function in dangerous settings, which helps make operations safer and more effective during emergencies. For instance, using advanced drones and self-driving vehicles can lead to better rescue efforts while handling tasks that are too risky for humans workers [1]. As this area keeps advancing, attention must be given to ethical issues and job loss, especially as robots take on jobs that people used to do. It is very important to create strong rules and ethical guidelines for how robots are used [2]. Future developments will probably use AI to not only increase the precision and speed of disaster responses but also to lower risks related to emergencies, ultimately leading to safer and more efficient disaster response methods.

4.4. Transportation and delivery

Big changes in technology are changing logistics a lot, especially in transportation and delivery. Using AI-powered robots makes operations run better and more accurately, allowing for quick navigation and route planning with advanced drones [1]. This helps speed up delivery times and reduces mistakes from humans, which boosts productivity in supply chain management. However, there are ethical issues about job loss since automated systems can take over traditional jobs, leading to urgent discussions about retraining and changing skills for workers affected [74]. Also, concerns about privacy and security are important because logistics relies on sensitive data, which requires strong protections against breaches and bad actors [2]. Therefore, as the industry grows, it needs to find a balance between the benefits of innovation and the effects on jobs and data security, creating systems that support both efficiency and responsible practices, as shown in Figure 4.

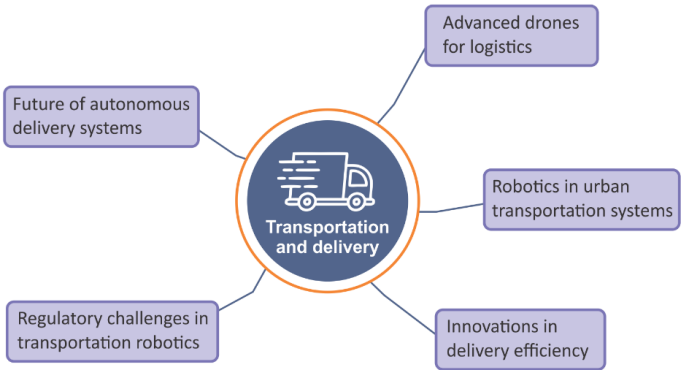

Figure 4. AI applications in robotics for transportation and delivery

4.4.1. Advanced drones for logistics

With the increasing difficulties in global logistics, the potential of advanced drones as important tools is clear. These drones make delivery easier and help solve big problems that traditional logistics faces, like poor infrastructure and a lack of workers. Using AI technology allows for drones to work on their own, leading to better efficiency and cost savings, since drones can fly all day and night without breaks, which cuts down on costs in the long run [75]. The fast rise of e-commerce also needs new solutions, and advanced drones are good at sorting and delivering packages quickly and accurately, which helps meet rising consumer demands [76]. Still, there are problems with privacy, security, and ethical issues related to using this technology. As the industry deals with these issues, using AI-powered drones can change logistics for the better, giving a new way to deliver goods in cities and the countryside alike.

4.4.2. Robotics in urban transportation systems

Cities are using robots more and more in their transportation systems. The use of self-driving cars, drones, and smart traffic management can improve efficiency and safety while tackling issues like traffic jams and pollution [1]. However, these changes bring up important ethical issues, such as the risk of job loss when traditional transportation jobs disappear. There are also big concerns about privacy and security because AI systems need to gather and handle a lot of data, which can lead to data breaches and misuse [77]. In the end, for robots to work well in urban transport, we need solid rules and public support to make sure these technologies improve mobility and access without hurting social values or individual rights [2].

4.4.3. Innovations in delivery efficiency

The growth in robotics and AI has changed how delivery works in many industries. By using autonomous systems, companies can make their logistics and inventory processes more efficient, which lowers the time it takes for products to get to customers or other businesses. For instance, AI systems help with route planning, letting drones and self-driving vehicles move better, improving delivery speed while cutting down costs. In addition, these technologies raise precision because self-learning algorithms keep improving based on real-time information, leading to fewer mistakes in delivery and better customer experiences [1]. Still, there are issues like ethical concerns and possible job losses, which need careful thought and active regulations to balance new technology with its effects on society [78]. In the end, using AI and robotics not only boosts delivery efficiency but also changes how operations work in many fields, leading to greater productivity and sustainability.

4.4.4. Regulatory challenges in transportation robotics

The use of transportation robots brings many complicated rules that need clear systems to keep safety and ethics in check. Rules often fall behind new technology, which causes uncertainty as self-driving cars and drones become more common. There are important questions about who is responsible when an accident happens with an AI vehicle: who gets blamed when it hurts someone? This situation makes traditional laws complicated, showing the need for updated laws to handle new tech properly. We need to clarify the legal status of robots to ensure rights and duties are clearly defined. These regulatory issues are made worse by worries about privacy and data protection, since transport robots often gather sensitive data that can be at risk from cyber threats. Moreover, building public trust through clear information and strong oversight is crucial as society tries to accept AI transport systems while dealing with these complicated regulatory issues.

4.4.5. Future of autonomous delivery systems

The growth of self-driving delivery systems marks a key change in how logistics and supply chain work, possibly changing how operations are done. Using new technology in AI and robotics, these systems can boost efficiency, precision, and productivity by navigating busy city areas and delivering packages without needing people. As mentioned, AI-powered robots can work all day and night, providing steady service, which helps solve major issues like high costs and delays in delivery. Yet, the use of these systems raises concerns about privacy and job loss, as automation might make some jobs unnecessary [79]. Additionally, making sure that autonomous machines and humans can interact safely and reliably is an important issue, requiring ethical programming that enables friendly interactions [2]. In summary, while the future of self-driving delivery systems looks promising, it is important to handle ethical, social, and operational issues that come with such technological changes.

4.5. Healthcare

Big changes in technology are changing healthcare a lot, leading to better patient results and more efficient operations. Using AI-powered robots improves surgical accuracy, as shown in studies that demonstrate robotic help in many surgical areas, which reduces mistakes and helps patients recover faster [80]. These technologies not only make procedures run smoother but also lessen the load on healthcare workers, allowing them to manage more complicated tasks and connect with patients more effectively. Additionally, we need to carefully think about the ethical issues of using AI in healthcare, especially regarding data privacy and protecting sensitive patient details. Existing research shows that the risk of job loss raises worries about how healthcare workers will adapt as machines take over simple tasks. A teamwork approach that combines AI capabilities with human skills is crucial to tackle these issues and tap into the full benefits of technology in healthcare, as shown in Figure 5.

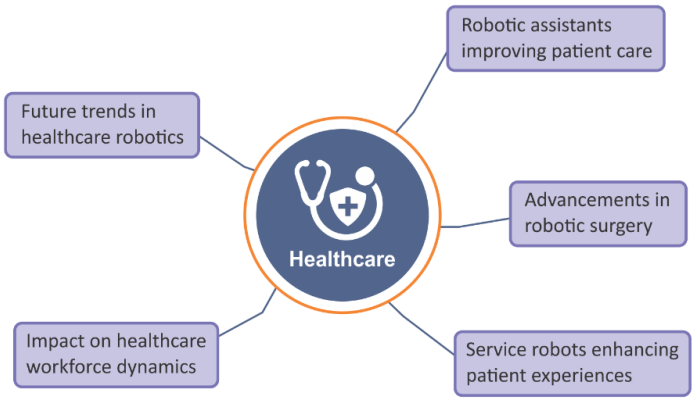

Figure 5. AI applications in robotics for healthcare

4.5.1. Robotic assistants improving patient care

Advances in robots have caused big changes in how patients are cared for, shown by their ability to make clinical results better and make operations run smoother in healthcare places. Robotic helpers can do jobs like handing out medicine and watching patients, which helps lessen the workload on healthcare workers, allowing them to pay more attention to patients [1]. Also, robots powered by AI use complex data analysis and machine learning to provide personalized care that fits each patient's needs, which helps boost patient involvement and happiness. These changes not only make processes easier but also lower the chance of human mistakes, which improves treatment precision and safety [2]. However, bringing in robotic helpers also brings up ethical issues, especially around losing jobs and privacy. A careful method to use them, which focuses on both tech efficiency and human control, is key to getting the most out of their use in patient care.

4.5.2. Advancements in robotic surgery

The growth of robot tech in surgery shows a mix of new ideas and exactness. As surgical methods improve, adding AI-based robots starts a new time of less invasive operations and better accuracy. AI systems using deep learning and sensor fusion help surgical robots to do complex jobs more skillfully than human hands, which cuts down on complications [81]. These improvements are changing patient results by lessening injury and recovery time and also creating new ways for better efficiency in medical facilities [82].

Yet, while the gains are big, important ethical issues must be addressed, like worries about job loss and the need for strong rules to make sure safety and effectiveness in robot-assisted surgeries. Looking to the future, there is still a lot of potential for more growth in robotic surgery, thanks to ongoing progress in AI and machine learning tech.

4.5.3. Service robots enhancing patient experiences

The technology mix in healthcare has changed how patients interact, especially with service robots. These systems are made to help medical staff and to improve patient experience by offering tailored services for individual needs. For example, service robots can help with communication, bring important items, and even chat with patients, which helps reduce feelings of loneliness and anxiety during hospital stays. Also, they can collect and analyze real-time data, which leads to better monitoring of patient health and quicker actions when needed [5]. These interactions create a sense of companionship and can improve emotional and psychological results for patients, which is important for recovery. As this field grows, it is crucial to deal with challenges related to ethics, how humans interact with robots, and privacy protections to fully benefit from service robots in healthcare environments.

4.5.4. Impact on healthcare workforce dynamics

Changes in healthcare caused by AI and robots are changing how workers interact in significant ways. As AI is used more in clinical settings, healthcare workers are experiencing a change in their roles and responsibilities. The ability of AI to take on tasks like diagnostic imaging and robotic surgeries raises fears about job loss, leading to worries about a skills gap that could put some workers at risk while also requiring new skills in healthcare technology. There are also important ethical questions about how AI affects patient care, as increased use of automated systems makes it essential to have human oversight to provide caring and personalized treatment [2]. In the end, building a system that successfully combines human skills with AI capabilities will be crucial for ensuring workforce stability and improving services in healthcare [83].

4.5.5. Future trends in healthcare robotics

As healthcare changes, using robots powered by AI will change medical practices a lot. Future trends say that better efficiency and accuracy will be very important, letting robots do complex tasks like surgery with a precision that can be better than humans, thanks to advances in deep learning and sensor technologies. Also, this tech shift is expected to boost productivity in healthcare by reducing the burden of boring tasks, letting healthcare workers focus more on caring for patients. Furthermore, reducing risk is a main focus—robots can work in dangerous places, keeping safety while managing infectious materials or helping in emergencies. These advancements fit well with main goals in healthcare to lower costs while keeping quality high, which significantly changes how care is delivered, as shown in foundational studies on healthcare robotics [84].

5. CONCLUSION

AI-powered robots are a rapidly evolving technology that has both positive and negative implications for society. They bring about better efficiency, greater accuracy, and higher productivity, but also raise ethical questions about how these systems make choices due to their subjective nature. The risk of job loss is significant as automation threatens regular jobs, requiring a new look at work skills and education. Privacy and security concerns arise from data collected by AI-powered robots, making safety a concern against harmful individuals. Future paths should focus on better efficiency and accuracy, while also boosting productivity and creating settings where humans and robots work together safely and reduce risks. Tackling these issues with strong rules and ethical guidelines will be vital for integrating AI-powered robotics into different areas, ensuring that technology development matches societal values and needs. The use of AI robots is set to change social systems and business methods, bringing important effects in many areas. However, these improvements raise ethical issues about job loss, as many workers might have their jobs made unnecessary, leading to important issues about retraining and adapting the workforce. Additionally, concerns about privacy and security arise as AI systems gather large amounts of personal data, needing strong rules and ethical standards to safeguard individual rights. In the fast-changing world of robotics using AI, the complicated problems we face need a varied way of thinking that uses different skills. It is important for engineers, ethicists, healthcare workers, and legal experts to work together to tackle ethical issues and privacy problems that come with AI technology. Building teamwork across different fields will be key to moving forward with AI-powered robotics while ensuring that society is safe and technology remains trustworthy, leading to a responsible and sustainable future. Future research in AI robotics should aim at creating ethical guidelines that help apply AI technologies while making sure humane values are part of it, reducing worries about AI decision-making. Research should also carefully look at privacy and security

measures to safeguard sensitive information collected by robots, especially as they become more connected. Overcoming these various problems while making the most of the advantages will decide how well AI-powered robots fit into society, strengthening their role as key players in a quickly changing tech world.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va: **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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