IAES International Journal of Robotics and Automation (IJRA)
Vol. 13, No. 4, December 2024, pp. 361~372
ISSN: 2722-2586, DOI: 10.11591/ijra.v13i4.pp 361-372

The future of artificial intelligence-driven robotics: applications and implications

Tole Sutikno[1,2]
[1]Master Program of Electrical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Embedded Systems and Power Electronics Research Group, Yogyakarta, Indonesia

Article Info

Article history:

Received Jun 23, 2024
Revised Sep 21, 2024
Accepted Oct 1, 2024

Keywords:

AI-driven robotics
Artificial intelligence
Healthcare
Industries
Intelligent machines
Machine learning
Robotics

ABSTRACT

Artificial intelligence (AI)-driven robotics is a rapidly evolving field that is transforming various industries, including healthcare, manufacturing, transportation, logistics, security, retail, agri-food, and construction. The integration of artificial intelligence algorithms and machine learning techniques has propelled robotics beyond mere automation, enabling machines to modify, alter, adjust, learn, and interact with the world in ways previously deemed science fiction. The relentless pursuit of creating intelligent robotic systems has led to a symbiotic relationship between human inventiveness and AI, with AI-driven autonomous cars, drones, and robots transforming transportation, healthcare, and exploration. It offers flexibility and learning capabilities, transforming the way machines interact with humans. The integration of AI and robotics marks a transformative era in which machines become companions and cognitive extensions of human capabilities. In the future, we expect AI-driven robotics to bring significant changes to employment and societal well-being. However, the development of AI-driven robotics, which is the integration of AI and robotics, faces numerous challenges, including ethical concerns, legal issues, regulations, societal implications, and job market impacts for the proliferation of intelligent machines. Furthermore, it also presents challenges in terms of technical complexities in its development.

Corresponding Author:

Tole Sutikno
Master Program of Electrical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan
Ahmad Yani Street (South of Ring Road), Tamanan, Yogyakarta 55166, Indonesia
Email: tole@te.uad.ac.id

1. INTRODUCTION

Advancements in artificial intelligence (AI) have revolutionized the field of robotics, leading to the development of AI-driven robots with enhanced capabilities and intelligence. Industries like healthcare, manufacturing, transportation, and exploration are now utilizing these robots, which provide innovative solutions and boost efficiency. The integration of AI and robotics, however, raises ethical concerns regarding societal implications, job displacement, and the need for ethical guidelines in its design and operation. As AI-driven automation continues to shape the job market and employment landscape, it brings about both opportunities for economic growth and challenges in terms of regulations, ethical considerations, and societal preparedness. AI-driven robotics has immense potential in the future, but its development and deployment present complex ethical, legal, and technical challenges that require careful consideration [1]–[15].

Moreover, the future of AI-driven robotics holds enormous promise and raises numerous ethical considerations. AI integration into robotics presents a transformative era where machines are no longer just tools but extensions of human cognition and companions [16]–[20]. This convergence of human intellect and AI

prompts the need for ethical guidelines to govern its design and operation. AI-driven automation has a positive impact on economic growth and productivity, as well as on the job market and employment landscape. Despite the positive contributions in sectors like manufacturing, the development of AI-driven robotics is not without its challenges. The responsible advancement of AI-driven robotics requires addressing key hurdles such as ethical and legal issues, societal readiness, and technical complexities in human-robot interaction [21].

The integration of AI and robotics in various industries has ushered in a new era of technological advancement, with significant implications for the future. As AI continues to drive innovations in robotics, exploring the future implications becomes crucial to navigating the transformative landscape. The comprehensive role of AI in revolutionizing industry standards and practices, as highlighted in [1], underscores the need to understand the evolving dynamics and challenges that come with this technological shift. Similarly, Mennella *et al*. [19] emphasize the importance of addressing ethical considerations, data privacy, and regulatory frameworks in the realm of AI applications in healthcare, shedding light on the broader ethical implications of AI-driven robotics. By examining the current applications, ethical dilemmas, job market impacts, and development challenges associated with AI-driven robotics, we gain deeper insight into the complexities of these advanced technologies and their far-reaching consequences for society and industry.

When exploring the landscape of AI-driven robotics, it is critical to consider the wide array of applications currently in use across industries such as healthcare, manufacturing, and transportation [22]–[26]. These advancements highlight the versatility and impact of AI-powered robots in streamlining processes and improving outcomes. However, alongside these technological advancements comes a pressing need to address the ethical implications that arise from integrating AI into robotics. The evolving relationship between human intellect and AI raises concerns about job displacement, access to technology, and the ethical use of AI in decision-making processes [27]. Additionally, as AI-driven robotics continue to evolve, the challenges in their development become more apparent, from regulatory hurdles to ethical considerations in human-robot interactions. Ultimately, by delving into these topics, we can develop a comprehensive understanding of the future of AI-driven robotics and navigate the complex implications they bring to society.

2. CURRENT APPLICATIONS OF AI-DRIVEN ROBOTICS

The transformative integration of AI in robotic solutions has revolutionized diverse industries such as healthcare, manufacturing, and transportation as shown in Figure 1. AI-driven robots exhibit enhanced flexibility and learning capabilities, enabling them to perform tasks with precision and adaptability [28]–[32]. For example, in healthcare, these robots deliver tailored therapies and access inaccessible environments, such as disaster zones. The ethical implications of AI-driven robotics loom large, touching on societal impacts, job market dynamics, and equitable access to advanced technology. As machines evolve into companions and collaborators, ethical guidelines are imperative to govern their interactions with human intellect. Moreover, the advent of AI-driven robotics has reshaped the job market by boosting productivity and creating opportunities in sectors like manufacturing. However, challenges persist in the ethical and legal realms, necessitating a thoughtful approach to navigating the complex landscape of AI and robotics integration. The current applications of AI-driven robotics showcase a promising yet nuanced landscape that requires careful consideration of ethical, societal, and technological factors for sustainable advancement [16].

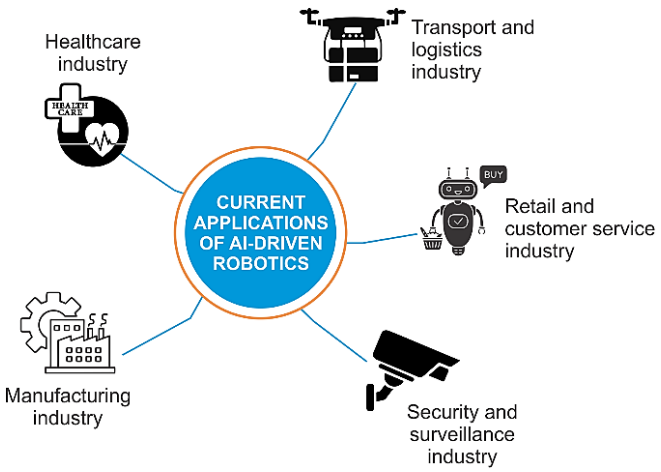

Figure 1. Current applications of AI-driven robotics

2.1. Healthcare industry applications

The integration of AI and robotics is revolutionizing industries, with the healthcare sector benefiting significantly from AI-driven robotics applications. AI-powered robots in healthcare offer tailored therapies, improved outcomes, and the ability to access perilous or remote locations, such as disaster zones or space missions. These advancements underscore the transformative potential of AI-driven robotics in improving patient care, optimizing medical procedures, and enhancing overall efficiency. Moreover, the utilization of AI in robotic solutions exemplifies the evolving landscape of technology-driven healthcare delivery, enabling precision medicine and innovative solutions to complex challenges. As AI keeps improving robotic capabilities in healthcare, it is important to think about the moral issues and societal impacts to make sure that these technologies are used in a fair and responsible way. This will help create a future where AI-powered robotics improve patient outcomes and drive healthcare innovation [1].

2.2. Manufacturing industry applications

AI-driven robotics have revolutionized the manufacturing industry by enhancing efficiency, precision, and productivity. The integration of AI in robotic systems enables real-time data analysis, predictive maintenance, and adaptive manufacturing processes, leading to reduced downtime and improved quality control. Through automated tasks such as material handling, assembly, and inspection, AI-driven robots optimize production workflows and minimize errors, ultimately increasing operational effectiveness. Moreover, collaborative robots, or cobots, equipped with AI capabilities, work alongside human workers to streamline complex manufacturing tasks, providing a safe and efficient working environment. As manufacturing industries continue to embrace AI-driven robotics, opportunities for innovation and growth abound, transforming traditional production methods and driving the industry toward a more automated and intelligent future. However, as this technological shift unfolds, we must carefully navigate considerations regarding ethical implications, workforce displacement, and regulatory frameworks to ensure a harmonious integration of AI-driven robotics in manufacturing [33].

2.3. Transport and logistics industry applications

From a transport and logistics industry perspective, AI-driven robotics offer a myriad of applications that streamline operations and enhance efficiency. Autonomous vehicles equipped with AI technology have the potential to revolutionize the transportation sector by ensuring safer and more eco-friendly travel options. By leveraging artificial intelligence, logistics companies can optimize route planning, fleet management, and inventory tracking, thereby reducing costs and improving overall service quality. Additionally, AI-powered robotics can handle intricate tasks such as package sorting, warehouse management, and last-mile deliveries with greater precision and speed. These advancements not only boost productivity but also enable companies to meet the evolving demands of a fast-paced global marketplace. As shown in [34], the integration of AI in the transport and logistics industry is poised to reshape supply chain dynamics and drive innovation for years to come.

2.4. Security and surveillance industry applications

Moreover, the integration of AI-driven robotics has revolutionized the security and surveillance industry. With advancements in computer vision and machine learning algorithms, AI-powered robots are now capable of performing tasks such as facial recognition, object detection, and behavior analysis in real-time. These capabilities have significantly enhanced the efficiency and effectiveness of security systems, allowing for proactive threat detection and response. Additionally, AI-driven robots are able to operate autonomously, reducing the need for human intervention and potentially minimizing risks to security personnel. However, the ethical implications of using AI-driven robotics for surveillance raise concerns regarding privacy, data security, and the potential for misuse of information [27]. As the security and surveillance industry continues to adopt AI technologies, it is crucial to establish clear guidelines and regulations to ensure responsible and ethical use of these powerful tools.

2.5. Retail and customer service industry applications

Moving forward, the retail and customer service industries also stand to benefit significantly from the applications of AI-driven robotics. By incorporating AI into their operations, retailers can enhance customer experiences through personalized recommendations, streamlined checkout processes, and efficient inventory management. AI-powered robots can assist in restocking shelves, improving the accuracy of orders, and even providing virtual customer service support. These advancements not only boost efficiency and productivity but also elevate the overall quality of service provided to customers. Moreover, AI-driven robotics can help retailers better understand consumer preferences and behavior through data analytics, thereby enabling them to tailor their offerings and marketing strategies more effectively. However, as with any technological innovation, we must address ethical considerations like data privacy and the displacement

of human workers. By navigating these challenges thoughtfully and responsibly, the retail and customer service industries can harness the full potential of AI-driven robotics to revolutionize their operations and deliver unparalleled value to customers [35].

3. ETHICAL IMPLICATIONS OF AI-DRIVEN ROBOTICS IN THE FUTURE

The integration of AI and robotics raises ethical issues, including societal implications, job market impacts, and the democratization of access to advanced technology, shaping the future landscape of AI-driven robotics as shown in Figure 2. The convergence of human intellect and AI in robotics marks a transformative era where machines become companions, collaborators, and cognitive extensions of human capabilities, necessitating ethical guidelines for their design and operation [36]. As AI-driven automation boosts productivity and job creation in certain sectors post-recession, it also poses challenges such as ethical and legal considerations, regulations, and societal readiness for intelligent machines [37]. The relentless pursuit of intelligent robotic systems underscores the critical importance of ethical governance and the ethical dimension of developing and implementing AI innovations in robotics, emphasizing the need for proactive strategies in navigating the evolving landscape of AI-driven robotics [18].

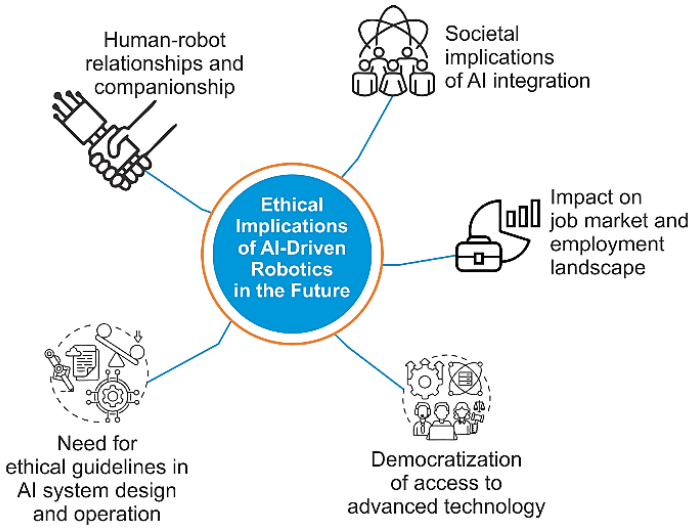

Figure 2. Ethical implications of AI-driven robotics in the future

3.1. Societal implications of AI integration

The relentless march of AI into the realm of robotics has triggered significant societal implications that warrant close scrutiny in the domain of technological advancement. As elucidated in the scholarly discourse [38], the fusion of AI with robotics not only revolutionizes industry standards but also poses ethical considerations that underscore the need for coherent regulatory frameworks. This confluence of human cognition with machine intelligence heralds a new era where robots transcend mere tools to become integral companions and collaborators, necessitating ethical guidelines to govern their design and operation. Moreover, the amalgamation of AI-driven robotics propels changes in the job market landscape, as evidenced by the positive impact on manufacturing employment post-recession [39]. The intricate interplay of AI-enhanced automation with economic productivity underscores the dual nature of technological progress, underlining the imperative for addressing challenges in ethical, legal, and societal domains while navigating the complexities of AI-driven robotics development.

3.2. Impact on the job market and employment landscape

The integration of AI and robotics raises ethical concerns, such as societal implications, job market effects, and the democratization of access to advanced technology. AI-powered automation helps to boost economic growth by overcoming challenges like a lack of domain expertise and decision-making complexity, which has a significant impact on the job market and employment landscape. According to studies, AI technologies are poised to revolutionize industries, potentially causing job losses in sectors such as manufacturing and customer service. However, AI opens up new opportunities in emerging fields such as AI

development and data analysis, necessitating workforce reskilling and upskilling efforts. Advancements in AI-driven robotics face challenges such as ethical concerns and societal readiness for intelligent machines, emphasizing the importance of ethical guidelines and comprehensive policies in navigating this changing landscape. Finally, proactive measures are required to maximize AI's potential while mitigating negative effects on employment and ensuring a diverse and inclusive workforce in the digital age [17].

3.3. Democratization of access to advanced technology

The relentless pursuit of creating intelligent robotic systems has led to a symbiotic relationship between human inventiveness and AI, prompting the need for ethical guidelines for the design and operation of AI systems. The integration of AI and robotics raises ethical issues, including societal implications, job market impacts, and the democratization of access to advanced technology. The convergence of human intellect and AI in robotics marks a transformative era where machines become not just tools but companions, collaborators, and cognitive extensions of human capabilities, raising ethical considerations. AI-driven robots are helping in healthcare by providing tailored therapy and better results, as well as exploring dangerous and distant places like space missions and disaster zones. This democratization of access to advanced technology is reshaping industries and societies, propelling the development of AI-driven robotics into uncharted ethical territories and calling for responsible innovation and regulation to ensure a harmonious coexistence between humans and intelligent machines [40].

3.4. Human-robot relationships and companionship

In considering the future of AI-driven robotics and its implications for human-robot relationships and companionship, the integration of AI into human-robot interaction (HRI) stands as a transformative force. Current advancements in AI-driven HRI, as outlined in [41], showcase personalized interactions, seamless communication enabled by natural language processing (NLP), and enhanced perception through computer vision. These developments pave the way for robots not just as assistants but as companions capable of emotional support, particularly in healthcare settings. Furthermore, the concept of hybrid intelligence systems (HIS), as explored in [42], accentuates the collaborative synergy between human expertise and AI, fostering inclusivity and democratization in problem-solving processes. This integration of human cognition with machine intelligence holds promise in enriching decision-making and innovation, underscoring the evolving nature of human-robot relationships toward a more collaborative and intellectually stimulating future.

3.5. Need for ethical guidelines in AI system design and operation

As AI-driven robotics continue to advance and integrate into various industries, the need for ethical guidelines in their design and operation becomes increasingly imperative. The ethical implications of AI-powered robotics in the future are vast and multifaceted, touching on societal impacts, job market transformations, and accessibility to advanced technology. The evolution of AI-driven robotics signifies a profound shift where machines are not solely tools but also companions and collaborators, blurring the lines between human capabilities and artificial intelligence. This paradigm shift necessitates a framework of ethical guidelines to ensure that the development and deployment of AI systems adhere to principles of fairness, transparency, and accountability. Without these ethical guardrails, the potential for unintended consequences and societal harm looms large in the rapidly advancing landscape of AI-driven robotics [20].

4. IMPACT OF AI-DRIVEN ROBOTICS ON THE JOB MARKET AND EMPLOYMENT LANDSCAPE

The rapid advancements in AI technologies, particularly in the realm of robotics, are reshaping the job market and employment landscape in profound ways as shown in Figure 3. AI-driven robots are increasingly being integrated into various industries such as healthcare, manufacturing, transport, logistics, security, and retail, revolutionizing operations and capabilities [36]. These AI-powered robots offer increased flexibility, learning abilities, and efficiency, leading to enhanced productivity and performance across sectors. However, as AI-driven robotics continue to evolve, ethical considerations loom large. The ethical implications of AI in robotics encompass societal impacts, job market transformations, and the democratization of advanced technology. The convergence of human intelligence and AI in robotics poses complex ethical dilemmas, necessitating robust guidelines for the ethical design and operation of intelligent systems. Despite the positive contributions of AI-driven robotics to certain sectors, challenges such as ethical and legal issues, regulatory frameworks, and societal readiness for intelligent machines persist. The interplay between AI, robotics, and employment dynamics underscores the need for nuanced strategies to navigate the complexities of this evolving landscape effectively.

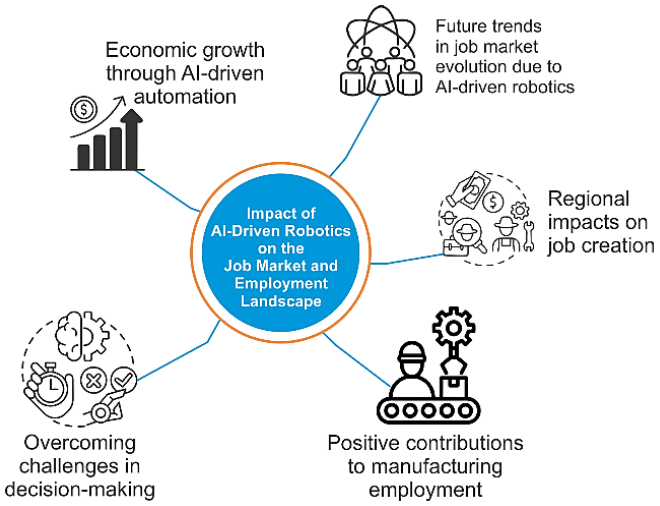

Figure 3. Impact of AI-driven robotics on the job market and employment landscape

4.1. Economic growth through AI-driven automation

As AI continues to advance, its integration with robotics is revolutionizing various industries and reshaping the future of work. Industries such as healthcare, manufacturing, transportation, and security are already reaping the benefits of AI-driven automation, leading to increased efficiency and productivity. However, this technological shift also brings about ethical implications that must be carefully addressed. The collaboration between human intellect and AI in robotics raises questions about job displacement, societal impacts, and the ethical use of these advanced technologies. It is essential to establish clear guidelines and regulations to ensure that AI-driven robotics are developed and operated in a responsible and ethical manner. While the integration of AI and robotics presents significant challenges, such as legal issues and societal readiness, it also offers immense potential for economic growth and innovation. By navigating these challenges thoughtfully, we can harness the power of AI-driven automation to create a more efficient and sustainable future [43].

4.2. Overcoming challenges in decision-making

Fostering innovation and efficiency in decision-making processes is a pivotal aspect of navigating the evolving landscape of AI-driven robotics. As articulated in [16], the integration of AI technologies in supply chain management enables intelligent decision-making through predictive analytics and real-time visibility, addressing complexities and enhancing operational agility. Moreover, the review underscores AI's transformative impact on optimizing resource allocation and mitigating disruptions, emphasizing the critical role of decision support systems in enhancing supply chain resilience. Similarly, Soori *et al.* [44] highlight the advancements in robotics within manufacturing, showcasing the deployment of AI-powered systems for adaptive decision-making and enhanced productivity. These insights underscore the pivotal role of AI in overcoming challenges in decision-making by providing actionable insights, automation capabilities, and adaptive responses to dynamic market conditions. As AI continues to drive innovation across industries, leveraging its potential for informed decision-making is essential to harnessing the full benefits of intelligent autonomous systems.

4.3. Positive contributions to manufacturing employment

As AI-driven robotics continue to advance, they are significantly impacting the job market and employment landscape in manufacturing. Automation powered by AI has been a boon for manufacturing employment, contributing to economic growth and increasing productivity by overcoming various challenges. AI-driven robotics have played a crucial role in creating employment opportunities in the manufacturing sector. This positive contribution to employment highlights the potential of AI-driven robotics to support and enhance human labor rather than replace it entirely. However, as these technologies continue to evolve, they also present challenges in terms of ethical and legal considerations, as well as society's readiness to embrace the proliferation of intelligent machines [45]. Addressing these challenges will be essential for ensuring the responsible and sustainable integration of AI-driven robotics into the manufacturing sector.

4.4. Regional impacts on job creation

In examining the regional impacts on job creation within the context of AI-driven robotics, it is imperative to consider the multifaceted implications elucidated by recent research. The rapid advancement of AI technologies, particularly in the realm of robotics, has the potential to significantly alter employment landscapes in various sectors. As outlined in [36] and [46], the adoption of AI models for automation and task replacement is already reshaping industries such as manufacturing, logistics, and customer service, leading to both job losses and potential job creation. While certain occupations may face displacement due to AI-driven automation, emerging fields like AI development and data analysis offer new job opportunities. Regional disparities in job creation and displacement could arise as AI technologies are integrated differently across sectors and geographic areas, necessitating tailored strategies for workforce reskilling and upskilling to mitigate negative impacts and leverage the potential benefits of AI-driven robotics in promoting inclusive and resilient regional labor markets.

4.5. Future trends in job market evolution due to AI-driven robotics

The integration of AI with robotics is poised to redefine the future job market landscape, as evidenced by the rapid advancements in AI-driven technologies and their applications across industries. AI-driven robotics, currently utilized in sectors such as healthcare, manufacturing, and transportation, are revolutionizing traditional practices and enhancing efficiency. This transformation brings to the forefront significant ethical implications, prompting the need for ethical guidelines to navigate the evolving relationship between human inventiveness and artificial intelligence. Furthermore, the impact of AI-driven robotics on the employment market is multifaceted, contributing to economic growth and positively influencing manufacturing employment. However, this development is not devoid of challenges, including ethical and legal concerns, regulatory frameworks, and societal readiness for the widespread adoption of intelligent machines. As the field of AI-driven robotics continues to evolve, addressing these challenges will be crucial in shaping a responsible and sustainable future for employment and innovation [47]–[49].

5. CHALLENGES IN THE DEVELOPMENT OF AI-DRIVEN ROBOTICS

Moreover, the development of AI-driven robotics faces numerous challenges that must be addressed to fully realize the potential benefits of this innovative technology as shown in Figure 4. Key challenges include ethical and legal considerations, such as ensuring the responsible and ethical use of AI in robotics, as well as navigating complex regulations surrounding these technologies. Additionally, society must be prepared for the widespread adoption of intelligent machines and the potential impacts on various facets of daily life. Research into autonomous intelligent systems and AI platforms raises significant ethical dilemmas, highlighting the importance of establishing clear guidelines for the design and operation of AI systems. Technical challenges, such as AI integration complexities, sensing advancements, and ethical considerations in human-robot interaction, further complicate the development of AI-driven robotics. Addressing these challenges will be crucial in ensuring the successful and ethical integration of AI-driven robotics into various industries and society as a whole [50].

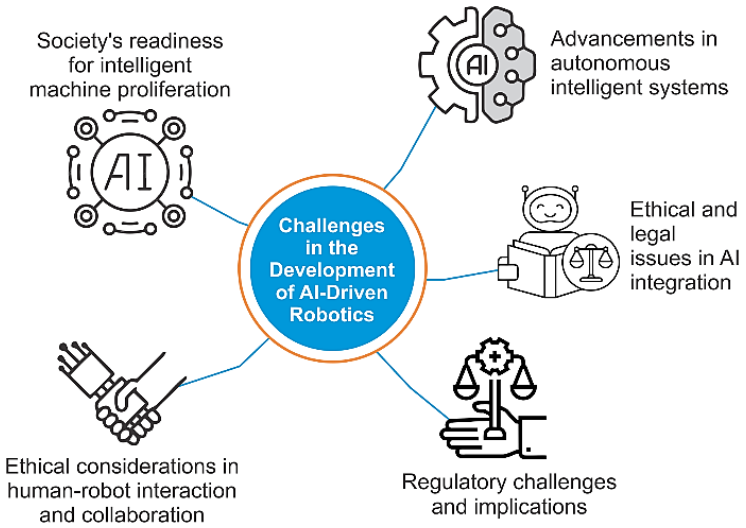

Figure 4. Challenges in the development of AI-driven robotics

5.1. Ethical and legal issues in AI integration

One of the key challenges in the development of AI-driven robotics is navigating the complex ethical and legal landscape surrounding their integration into society. As AI technologies become more sophisticated and pervasive, questions about accountability, transparency, and fairness arise. Ethical considerations, such as the potential for bias in AI algorithms, the impact on privacy and data security, and the consequences of AI-powered decision-making on human lives, must be carefully addressed. Furthermore, the legal framework surrounding AI integration needs to adapt to ensure compliance with existing regulations and safeguard against potential risks. Establishing clear guidelines and standards for the development and use of AI-driven robotics is essential to foster trust and mitigate ethical dilemmas in this rapidly evolving field [18]–[20], [51]. By proactively addressing these ethical and legal issues, we can harness the full potential of AI-driven robotics while safeguarding against potential harm.

5.2. Regulatory challenges and implications

The integration of service computing and AI presents a compelling synergy with far-reaching regulatory challenges and implications in the field of AI-driven robotics. The convergence of service computing's on-demand delivery of computing resources and AI's creation of intelligent systems intersect to create adaptive, data-driven services that respond to user needs [38]. As AI-driven robotics expand their applications across industries such as healthcare, finance, and manufacturing, regulatory frameworks play a crucial role in guiding responsible development and deployment [52]. Ethical considerations, including data privacy and algorithmic bias, must be addressed to ensure the ethical operation of AI-driven robotic systems. These challenges underscore the necessity of interdisciplinary collaboration and ethical guidelines to navigate the evolving landscape of AI-driven robotics and its regulatory implications effectively.

5.3. Society's readiness for intelligent machine proliferation

As society continues to embrace and integrate AI-driven robotics into various sectors, it is crucial to consider the ethical implications of this technological advancement. The integration of AI and robotics raises ethical issues that extend beyond technical capabilities, touching on societal impacts, job market transformations, and the democratization of advanced technology. The convergence of human intelligence and AI in robotics represents a paradigm shift where machines not only serve as tools but also as companions and cognitive extensions of human capabilities. This transformation necessitates the establishment of ethical guidelines to govern the design and operation of AI systems. Furthermore, the impact of AI-driven robotics on the job market and employment landscape cannot be understated, as automation and AI contribute to increased productivity and economic growth. However, challenges such as ethical and legal considerations, regulatory frameworks, and societal readiness for the proliferation of intelligent machines must be addressed to ensure a responsible and sustainable integration of AI-driven robotics in society [53].

5.4. Advancements in autonomous intelligent systems

The recent advancements in autonomous intelligent systems, particularly exemplified by materials acceleration platforms (MAPs) and device acceleration platforms (DAPs) [54], signify a transformative shift towards efficient and precise material discovery and device optimization in the realm of emerging photovoltaics and advanced materials. These platforms, integrating robotics, AI-driven data analysis, and experimental design, offer unparalleled capabilities in navigating complex multidimensional composition spaces, ultimately revolutionizing the traditional trial-and-error approaches. Concurrently, the integration of AI technologies in supply chain management is propelling the optimization of operations through predictive analytics, real-time visibility, and intelligent decision-making. The amalgamation of AI-driven technologies, spanning machine learning and robotic process automation, showcases the potential to enhance efficiency, agility, and responsiveness within supply chains, highlighting the broader impact of autonomous intelligent systems in diverse domains. Such advancements underline the critical role of AI in driving innovation and strategic optimization, laying the groundwork for a future characterized by intelligent autonomous systems across various sectors.

5.5. Ethical considerations in human-robot interaction and collaboration

The integration of AI into HRI has ushered in a new era of collaborative potential but also raised critical ethical considerations. AI-driven capabilities, such as machine learning algorithms and natural language processing, have enabled robots to personalize interactions and communicate effectively with humans. However, as AI-powered robotics become more integrated into society, ensuring ethical guidelines and addressing societal implications become paramount. The convergence of human intellect and AI in robotics introduces a transformative dynamic where machines serve as companions and collaborators, necessitating clear ethical frameworks for their design and operation. Challenges such as privacy concerns,

safety, and human-robot trust underscore the importance of interdisciplinary efforts to navigate the complex socio-technical landscape of AI-driven HRI. By addressing these ethical considerations thoughtfully, society can harness the benefits of AI-driven robotics while mitigating potential risks and ensuring responsible deployment [18]–[20], [50].

6. IMPLICATIONS AND FUTURE TRAJECTORIES OF AI-DRIVEN ROBOTICS

The future of AI-powered robotics holds immense promise and potential implications across various industries and societal landscapes as shown in Figure 5. The current applications of AI-driven robotics showcase its versatility and adaptability in sectors such as healthcare, manufacturing, transportation, and exploration. These robots not only enhance efficiency and safety but also offer innovative solutions to complex challenges. However, as we look ahead, ethical considerations loom large in the development and integration of AI-driven robotics. The impact on the job market and employment landscape is undeniable, with both opportunities and challenges emerging. It is essential to navigate the complexities of AI governance, regulations, and societal readiness to ensure a harmonious integration of intelligent machines in our daily lives. The journey toward a future brimming with AI-driven robotics is filled with potential but also requires thoughtful reflection and ethical guidance to ensure a positive impact on humanity as a whole.

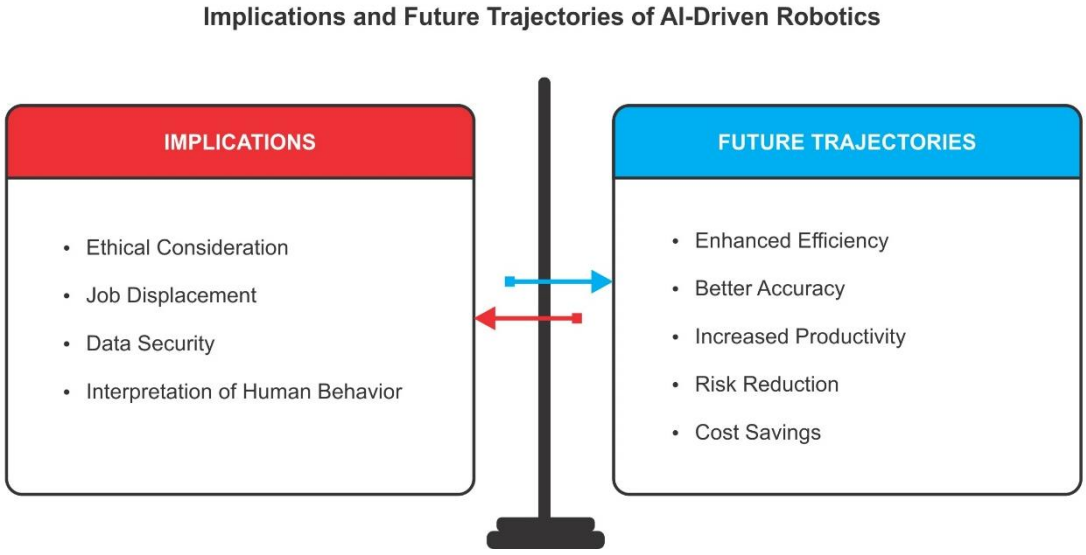

Figure 5. Implications and future trajectories of AI-driven robotics

The future of AI-driven robotics holds significant promise and potential implications across various industries. AI has already made significant advancements in robotics, providing flexibility and learning capabilities in sectors such as healthcare, manufacturing, transportation, and more. However, these advancements also raise ethical concerns regarding societal impacts, job market transformations, and the democratization of advanced technology [21]. As AI and robotics merge, ethical guidelines must be established to ensure responsible design and operation of AI systems. Moreover, AI-driven automation has the potential to positively impact economic growth and employment opportunities, particularly in manufacturing sectors. Yet, challenges in the development of AI-driven robotics persist, including ethical dilemmas, regulatory issues, and society's preparedness for the widespread implementation of intelligent machines. Overall, the integration of AI-driven robotics presents a complex landscape with multifaceted implications that require careful consideration and ethical governance.

The integration of service computing and AI presents a compelling synergy with far-reaching implications. Developing responsible AI-driven robotics necessitates ethical governance frameworks to address the pressing need for identifying ethical challenges in critical business decisions and navigating the ethical issues of AI-driven decision-making. The convergence of service computing and AI fosters the development of intelligent, data-driven services that adapt to user needs, emphasizing the significance of moral guidelines in AI applications. This integration not only highlights algorithmic biases and data storage issues but also underscores the importance of societal well-being and individual privacy in the responsible

deployment of AI. To realize the transformative potential of AI-driven robotics, interdisciplinary collaboration, and stringent regulations are essential, guiding the development and deployment of intelligent systems toward a more connected, intelligent, and ethical future [16]. Ultimately, a call to action for ethical governance and responsible development in AI-driven robotics is imperative to navigate the complex intersection of AI and privacy, aligning with ethical considerations and societal well-being in the advancement of intelligent systems [39].

7. CONCLUSION

AI-driven robotics have great potential across industries and sectors. The advancement of robotics by AI has transformed healthcare, manufacturing, transportation, and exploration, promising safer and more efficient solutions. However, AI and robotics integration raises ethical questions about society, job markets, and technology democratization. Ethics are needed to design and operate AI systems responsibly in the transformative era of human-machine convergence. AI-driven automation has also contributed to economic growth by increasing productivity and overcoming challenges in the job market. However, ethical issues, regulations, and societal readiness remain for AI-driven robotics development and adoption. To maximize AI-driven robotics' potential while minimizing risks, ethical governance and responsible innovation are essential. AI-driven robotics advancements and growing applications show great promise for shaping our society and economy. Further research into the future implications of AI in robotics shows that ethical considerations will guide the development and deployment of intelligent machines. AI integration into robotic systems raises complex ethical issues that require thoughtful and proactive solutions to protect society and promote human-machine harmony. Automation has increased productivity but has also made workforce adaptation and skill development difficult. For a responsible and sustainable future for AI-driven robotics, we must address the challenges and regulations surrounding its development as we navigate these complexities.

REFERENCES

[1] A. Bin Rashid and M. A. K. Kausik, "AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications," *Hybrid Advances*, vol. 7, p. 100277, Dec. 2024, doi: 10.1016/j.hybadv.2024.100277.

[2] Y.-C. Wu, Y.-C. Liu, C. Tsao, and R.-Y. Huang, "Microexpression recognition robot," *IAES International Journal of Robotics and Automation (IJRA)*, vol. 12, no. 1, pp. 20–28, Mar. 2023, doi: 10.11591/ijra.v12i1.pp20-28.

[3] S. Fredy H. Martínez, S. Fernando Martínez, and A. Holman Montiel, "Bacterial quorum sensing applied to the coordination of autonomous robot swarms," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 1, pp. 67–74, 2020, doi: 10.11591/eei.v9i1.1538.

[4] A. Al-Ansi, A. M. Al-Ansi, A. Muthanna, and A. Koucheryavy, "Blockchain technology integration in service migration to 6G communication networks: a comprehensive review," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 34, no. 3, pp. 1654–1664, 2024, doi: 10.11591/ijeecs.v34.i3.pp1654-1664.

[5] T. Sutikno, "An overview of emerging trends in robotics and automation," *IAES International Journal of Robotics and Automation*, vol. 12, no. 4, pp. 405–411, 2023, doi: 10.11591/ijra.v12i4.pp405-411.

[6] O. E. Beggar, M. Ramdani, and M. Kissi, "Design and development of a fuzzy explainable expert system for a diagnostic robot of COVID-19," *International Journal of Electrical and Computer Engineering*, vol. 13, no. 6, pp. 6940–6951, 2023, doi: 10.11591/ijece.v13i6.pp6940-6951.

[7] I. J. Jebadurai, G. J. L. Paulraj, E. Veemaraj, R. P. Sharance, R. Keren, and K. Karan, "Efficient traffic signal detection with tiny YOLOv4: enhancing road safety through computer vision," *International Journal of Informatics and Communication Technology*, vol. 13, no. 2, pp. 285–296, 2024, doi: 10.11591/ijict.v13i2.pp285-296.

[8] T. T. Huong and P. T. T. Ha, "Controlling mobile robot in flat environment taking into account nonlinear factors applying artificial intelligence," *Bulletin of Electrical Engineering and Informatics*, vol. 13, no. 5, pp. 3737–3745, 2024, doi: 10.11591/eei.v13i5.7818.

[9] S. Abdul-Khalil, S. Abdul-Rahman, S. Mutalib, S. I. Kamarudin, and S. S. Kamaruddin, "A review on object detection for autonomous mobile robot," *IAES International Journal of Artificial Intelligence*, vol. 12, no. 3, pp. 1033–1043, 2023, doi: 10.11591/ijai.v12.i3.pp1033-1043.

[10] O. Hamed, M. Hamlich, and M. Ennaji, "Hunting strategy for multi-robot based on wolf swarm algorithm and artificial potential field," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 25, no. 1, pp. 159–171, 2022, doi: 10.11591/ijeecs.v25.i1.pp159-171.

[11] S. O. Owoeye, F. Durodola, P. O. Adeniyi, I. T. Abdullahi, and A. B. Hector, "Design and development of a quadruped home surveillance robot," *IAES International Journal of Robotics and Automation*, vol. 13, no. 2, pp. 233–246, 2024, doi: 10.11591/ijra.v13i2.pp233-246.

[12] J. S. Sanabria, R. Jimenez-Moreno, and J. E. M. Baquero, "Paper biological risk detection through deep learning and fuzzy system," *International Journal of Electrical and Computer Engineering*, vol. 13, no. 1, pp. 249–257, 2023, doi: 10.11591/ijece.v13i1.pp249-257.

[13] M. S. Kadafi, A. K. Yaqubi, and S. D. Astuti, "Alzheimer's prediction via CNN-SVM on chatbot platform with MRI," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 36, no. 1, pp. 64–73, 2024, doi: 10.11591/ijeecs.v36.i1.pp64-73.

[14] R. Yahya, R. Jailani, F. A. Hanapiah, and N. K. Zakaria, "A scoping review of artificial intelligence-based robot therapy for children with disabilities," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 33, no. 3, pp. 1855–1865, 2024, doi: 10.11591/ijeecs.v33.i3.pp1855-1865.

[15] T. T. K. Nguyen, M. T. Nguyen, and H. T. Tran, "Artificial intelligent based teaching and learning approaches: A comprehensive review," *International Journal of Evaluation and Research in Education*, vol. 12, no. 4, pp. 2387–2400, 2023, doi:

10.11591/ijere.v12i4.26623.
[16] O. S. Joel, A. T. Oyewole, O. G. Odunaiya, and O. T. Soyombo, "Leveraging artificial intelligence for enhanced supply chain optimization: a comprehensive review of current practices and future potentials," *International Journal of Management & Entrepreneurship Research*, vol. 6, no. 3, pp. 707–721, Mar. 2024, doi: 10.51594/ijmer.v6i3.882.
[17] Z. Tóth, R. Caruana, T. Gruber, and C. Loebbecke, "The Dawn of the AI Robots: Towards a New Framework of AI Robot Accountability," *Journal of Business Ethics*, vol. 178, no. 4, pp. 895–916, 2022, doi: 10.1007/s10551-022-05050-z.
[18] M. Pflanzer, Z. Traylor, J. B. Lyons, V. Dubljević, and C. S. Nam, "Ethics in human–AI teaming: principles and perspectives," *AI and Ethics*, vol. 3, no. 3, pp. 917–935, Aug. 2023, doi: 10.1007/s43681-022-00214-z.
[19] C. Mennella, U. Maniscalco, G. De Pietro, and M. Esposito, "Ethical and regulatory challenges of AI technologies in healthcare: A narrative review," *Heliyon*, vol. 10, no. 4, p. e26297, Feb. 2024, doi: 10.1016/j.heliyon.2024.e26297.
[20] C. Elendu *et al.*, "Ethical implications of AI and robotics in healthcare: A review," *Medicine*, vol. 102, no. 50, p. e36671, Dec. 2023, doi: 10.1097/MD.0000000000036671.
[21] A. Bohr and K. Memarzadeh, Eds., *Artificial Intelligence in Healthcare*. Elsevier, 2020. doi: 10.1016/C2018-0-04097-9.
[22] S. Loukili, A. Fennan, and L. Elaachak, "Email subjects generation with large language models: GPT-3.5, PaLM 2, and BERT," *International Journal of Electrical and Computer Engineering*, vol. 14, no. 4, pp. 4655–4663, 2024, doi: 10.11591/ijece.v14i4.pp4655-4663.
[23] R. E. O. Roxas and R. N. C. Recario, "Scientific landscape on opportunities and challenges of large language models and natural language processing," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 36, no. 1, pp. 252–263, 2024, doi: 10.11591/ijeecs.v36.i1.pp252-263.
[24] M. F. Riftiarrasyid and B. Soewito, "Monitoring water quality parameters impacted by Indonesia's weather using internet of things," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 35, no. 3, pp. 1426–1436, 2024, doi: 10.11591/ijeecs.v35.i3.pp1426-1436.
[25] A. Bouhlali, A. Elmansouri, A. El Mhouti, M. Fahim, and T. Boudaa, "Reviewing approaches employed in Arabic chatbots," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 35, no. 3, pp. 1751–1764, 2024, doi: 10.11591/ijeecs.v35.i3.pp1751-1764.
[26] A. Abdo and S. M. Yusof, "Exploring the impacts of using the artificial intelligence voice-enabled chatbots on customers interactions in the United Arab Emirates," *IAES International Journal of Artificial Intelligence*, vol. 12, no. 4, pp. 1920–1927, 2023, doi: 10.11591/ijai.v12.i4.pp1920-1927.
[27] E. B. Boukherouaa *et al.*, *Powering the digital economy: opportunities and risks of artificial intelligence in finance*. International Monetary Fund, 2021.
[28] T. Ha *et al.*, "AI-driven robotic chemist for autonomous synthesis of organic molecules," *Science Advances*, vol. 9, no. 44, 2023, doi: 10.1126/sciadv.adj0461.
[29] W. Wang, P. Gope, and Y. Cheng, "An AI-Driven Secure and Intelligent Robotic Delivery System," *IEEE Transactions on Engineering Management*, vol. 71, pp. 12658–12673, 2024, doi: 10.1109/TEM.2022.3142282.
[30] R. A. Zeineldin, D. Junger, F. Mathis-Ullrich, and O. Burgert, "Entwicklung eines KI-gesteuerten Systems für die Neurochirurgie mit einer Usability-Studie: Ein Schritt in Richtung minimal-invasive Robotik," *At-Automatisierungstechnik*, vol. 71, no. 7, pp. 537–546, 2023, doi: 10.1515/auto-2023-0061.
[31] J. Berdell, S. Kudernatsch, and H. Ferdowsi, "AI-Driven solid-state device to enable natural control of upper-extremity robotic exoskeletons," *Systems Science and Control Engineering*, vol. 12, no. 1, 2024, doi: 10.1080/21642583.2024.2331061.
[32] D. Dhabliya, G. Ghule, D. Khubalkar, R. K. Moje, P. S. Kshirsagar, and S. P. Bendale, "Robotic Process Automation in Cyber Security Operations: Optimizing Workflows with AI-Driven Automation," *Journal of Electrical Systems*, vol. 19, no. 3, pp. 96–105, 2023, doi: 10.52783/jes.654.
[33] D. Satishkumar and M. Sivaraja, Eds., *Industry applications of thrust manufacturing: convergence with real-time data and AI*. IGI Global, 2024. doi: 10.4018/979-8-3693-4276-3.
[34] Hebooks, *AI-powered logistics: how artificial intelligence will revolutionize transportation, shipping and logistics*. Hebooks.
[35] N. Vinoi, A. Shankar, R. Agarwal, and R. Alghafes, "Revolutionizing retail: The transformative power of service robots on shopping dynamics," *Journal of Retailing and Consumer Services*, vol. 82, p. 104085, Jan. 2025, doi: 10.1016/j.jretconser.2024.104085.
[36] R. D. Jadhav and A. Banubakode, "The implications of artificial intelligence on the employment sector," *International Journal For Multidisciplinary Research*, vol. 6, no. 3, Jun. 2024, doi: 10.36948/ijfmr.2024.v06i03.22716.
[37] H. Guliyev, "Artificial intelligence and unemployment in high-tech developed countries: New insights from dynamic panel data model," *Research in Globalization*, vol. 7, p. 100140, Dec. 2023, doi: 10.1016/j.resglo.2023.100140.
[38] "Revolutionizing industries: the impact of artificial intelligence applications," *CONFERENCE PROCEEDING*, 2024, [Online]. Available: https://api.semanticscholar.org/CorpusID:270041312
[39] J. Wang, "Navigating the AI Revolution: Job Replacements and New Opportunities in the Labor Market," *Advances in Economics, Management and Political Sciences*, vol. 46, no. 1, pp. 10–15, Dec. 2023, doi: 10.54254/2754-1169/46/20230309.
[40] A. Zirar, S. I. Ali, and N. Islam, "Worker and workplace Artificial Intelligence (AI) coexistence: Emerging themes and research agenda," *Technovation*, vol. 124, p. 102747, Jun. 2023, doi: 10.1016/j.technovation.2023.102747.
[41] A. Obaigbena *et al.*, "AI and human-robot interaction: A review of recent advances and challenges," *GSC Advanced Research and Reviews*, vol. 18, no. 2, pp. 321–330, Feb. 2024, doi: 10.30574/gscarr.2024.18.2.0070.
[42] K. Venigandla, N. Vemuri, and N. Vemuri, "Hybrid intelligence systems combining human expertise and AI/RPA for complex problem solving," *International Journal of Innovative Science and Research Technology (IJISRT)*, pp. 2066–2075, Apr. 2024, doi: 10.38124/ijisrt/IJISRT24MAR2039.
[43] J. T. Gonzales, "Implications of AI innovation on economic growth: a panel data study," *Journal of Economic Structures*, vol. 12, no. 1, p. 13, 2023, doi: 10.1186/s40008-023-00307-w.
[44] M. Soori, F. K. G. Jough, R. Dastres, and B. Arezoo, "AI-Based Decision Support Systems in Industry 4.0, A Review," *Journal of Economy and Technology*, Aug. 2024, doi: 10.1016/j.ject.2024.08.005.
[45] J. C. Lok, *Artificial intelligence brings positive or negative impaction to influence human job nature*. Amazon Digital Services LLC - KDP Print US, 2019.
[46] A. Ajithkumar, A. David, A. Jacob, Alen Alex, and F. A. Thomas CMI, "Impact of AI on employment and job opportunities," *International Journal of Engineering Technology and Management Sciences*, vol. 7, no. 4, pp. 507–512, 2023, doi: 10.46647/ijetms.2023.v07i04.067.
[47] Y. Shen and X. Zhang, "The impact of artificial intelligence on employment: the role of virtual agglomeration," *Humanities and Social Sciences Communications*, vol. 11, no. 1, p. 122, 2024, doi: 10.1057/s41599-024-02647-9.
[48] L. Guimarães and P. Mazeda Gil, "Looking ahead at the effects of automation in an economy with matching frictions," *Journal of*

Economic Dynamics and Control, vol. 144, p. 104538, Nov. 2022, doi: 10.1016/j.jedc.2022.104538.
[49] G. Damioli, V. Van Roy, D. Vértesy, and M. Vivarelli, "Drivers of employment dynamics of AI innovators," *Technological Forecasting and Social Change*, vol. 201, p. 123249, Apr. 2024, doi: 10.1016/j.techfore.2024.123249.
[50] J. von Braun, M. S. Archer, G. M. Reichberg, and M. S. Sorondo, *Robotics, AI, and humanity: science, ethics, and policy*. Springer International Publishing, 2022.
[51] M. Corrales, M. Fenwick, and N. Forgó, *Robotics, AI and the future of law*. Singapore: Springer Singapore, 2018. doi: 10.1007/978-981-13-2874-9.
[52] Z. Liu, "Service computing and artificial intelligence: technological integration and application prospects," *Academic Journal of Computing & Information Science*, vol. 7, no. 5, 2024, doi: 10.25236/AJCIS.2024.070523.
[53] S. De Spiegeleire, M. Maas, and T. Sweijs, *Artificial intelligence and the future of defense: strategic implications for small- and medium-sized force providers*. The Hague Centre for Strategic Studies, 2017.
[54] J. Zhang, J. A. Hauch, and C. J. Brabec, "Toward self-driven autonomous material and device acceleration platforms (AMADAP) for emerging photovoltaics technologies," *Accounts of Chemical Research*, vol. 57, no. 9, pp. 1434–1445, May 2024, doi: 10.1021/acs.accounts.4c00095.

BIOGRAPHIES OF AUTHORS

Tole Sutikno is a lecturer and the head of the Master Program of Electrical Engineering at the Faculty of Industrial Technology at Universitas Ahmad Dahlan (UAD) in Yogyakarta, Indonesia. He received his Bachelor of Engineering from Universitas Diponegoro in 1999, Master of Engineering from Universitas Gadjah Mada in 2004, and Doctor of Philosophy in Electrical Engineering from Universiti Teknologi Malaysia in 2016. All three degrees are in electrical engineering. He has been a professor at UAD in Yogyakarta, Indonesia, since July 2023, following his tenure as an associate professor in June 2008. He is the Editor-in-Chief of TELKOMNIKA and Head of the Embedded Systems and Power Electronics Research Group (ESPERG). He is one of the top 2% of researchers worldwide, according to Stanford University and Elsevier BV's list of the most influential scientists from 2021 to the present. His research interests cover digital design, industrial applications, industrial electronics, industrial informatics, power electronics, motor drives, renewable energy, FPGA applications, embedded systems, artificial intelligence, intelligent control, digital libraries, and information technology. He can be contacted at tole@te.uad.ac.id.