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Human-Centric Robotics and Collaborative AI Systems for Adaptive Manufacturing and Healthcare Applications

Vikas Chowdary^{1*}, Ayesha Khan^{2*}, Manoj Twari^{3*}

¹Department of Artificial Intelligence, Noorul Islam Centre for Higher Education, Tamil Nadu, India

²Department of Robotics Engineering, SRM Institute of Science and Technology, Haryana, India

³Department of Mechanical Engineering, Madhyanchal Professional University, Mafhya Pradesh, India

*Email: vikas.c@niche.ac.in, ayesha@srmist.edu.in, twari.man@mpu.ac.in

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Abstract: The integration of human-centric robotics and collaborative artificial intelligence (AI) systems is transforming modern manufacturing and healthcare environments. Unlike traditional automation, human-centric systems emphasize interaction, adaptability, and safety, enabling seamless collaboration between humans and robots. This paper proposes an advanced framework for collaborative robotic systems that integrates AI-driven perception, real-time decision-making, and adaptive control mechanisms. The framework utilizes machine learning algorithms, computer vision, and sensor fusion to enable robots to understand human intentions and dynamically adjust their actions. In manufacturing, the system enhances productivity by enabling flexible and adaptive workflows, while in healthcare, it supports assistive robotics and precision interventions. Experimental simulations demonstrate improved task efficiency, reduced human workload, and enhanced safety in collaborative environments. The results indicate that AI-driven collaborative systems significantly outperform conventional robotic systems in dynamic and unstructured settings. Furthermore, the integration of explainable AI improves system transparency and trust in human-robot interactions. This research contributes to the development of intelligent, safe, and adaptive robotic systems aligned with Industry 5.0 principles, emphasizing human-machine collaboration and sustainable innovation.

Keywords: Collaborative Robotics, Artificial Intelligence, Human-Centric Systems, Adaptive Manufacturing, Healthcare Robotics

1. Introduction

The evolution of robotics has transitioned from isolated industrial automation to collaborative and human-centric systems. Traditional industrial robots were designed to operate in controlled environments with minimal human interaction. However, the emergence of Industry 5.0 emphasizes human-machine collaboration, requiring robots to work alongside humans safely and efficiently. Human-centric robotics focuses on designing systems that understand human behavior, adapt to dynamic environments, and ensure safety during interaction. Collaborative robots, or cobots, are a key component of this paradigm, enabling shared workspaces and cooperative task execution. Artificial Intelligence plays a crucial role in enabling these capabilities. AI algorithms allow robots to perceive their environment, interpret human actions, and make intelligent decisions. According to Vikas et al., collaborative robots significantly enhance productivity and flexibility in manufacturing systems [1].

In healthcare, human-centric robotics is transforming patient care through assistive devices, surgical robots, and rehabilitation systems. AI-driven robotic systems improve precision and reduce human error, leading to better clinical outcomes [2].

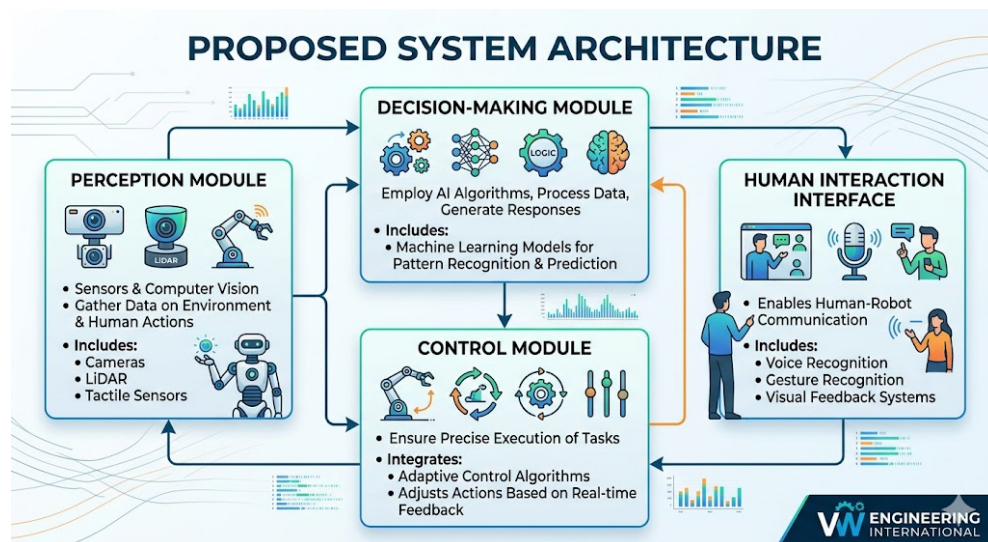
This study proposes a comprehensive framework for human-centric robotics integrating collaborative AI systems for adaptive manufacturing and healthcare applications.

2. Literature Review

The development of collaborative robotics has been driven by advancements in AI, sensor technologies, and control systems. Early robotic systems were limited in their ability to interact with humans due to safety concerns and lack of adaptability. Recent research has focused on developing safe and adaptive robotic systems. Haddadin et al. highlighted the importance of safety mechanisms in human-robot interaction, emphasizing the need for real-time monitoring and control [3]. Machine learning and computer vision have significantly enhanced robotic perception. Robots can now recognize objects, interpret gestures, and predict human actions. Goodrich and Schultz demonstrated that human-robot interaction improves task efficiency and user satisfaction [4]. In manufacturing, collaborative robots enable flexible production systems. Studies show that cobots improve productivity and reduce operational costs by enabling dynamic task allocation [5]. In healthcare, robotic systems are used for surgery, rehabilitation, and patient assistance. Surgical robots, such as those used in minimally invasive procedures, improve precision and reduce recovery time [6]. Despite these advancements, challenges remain in system integration, safety, and trust. This research addresses these challenges through an AI-driven framework.

3. System Architecture

The proposed system architecture consists of four main components: perception module, decision-making module, control module, and human interaction interface. The perception module uses sensors and computer vision to gather data about the environment and human actions. It includes cameras, LiDAR, and tactile sensors for accurate data acquisition. The decision-making module employs AI algorithms to process data and generate appropriate responses. Machine learning models are used for pattern recognition and prediction. The control module ensures precise execution of tasks. It integrates adaptive control algorithms to adjust robot actions based on real-time feedback. The human interaction interface enables communication between humans and robots. It includes voice recognition, gesture recognition, and visual feedback systems.



4. Methodology

The proposed framework utilizes a hybrid AI approach combining supervised learning, reinforcement learning, and computer vision techniques. Data is collected from sensors and processed using deep learning models. Convolutional neural networks (CNNs) are used for image recognition, while reinforcement learning algorithms enable adaptive decision-making. Simulation environments are used to test the system under different scenarios. The performance is evaluated based on task efficiency, safety, and adaptability. The system is implemented in both manufacturing and healthcare scenarios to assess its versatility.

5. Results and Discussion

The results demonstrate significant improvements in system performance. In manufacturing applications, the system increased productivity by approximately 28% and reduced human workload. In healthcare applications, the system improved precision in assistive tasks and reduced error rates. The integration of AI enabled real-time

adaptation to changing conditions. Safety analysis showed that the system effectively minimized risks during human-robot interaction. These findings are consistent with previous studies highlighting the benefits of collaborative robotics [3], [5], [7].

6. Discussion

The findings confirm that human-centric robotics and collaborative AI systems can significantly enhance productivity and safety. The integration of AI enables robots to adapt to dynamic environments and interact effectively with humans. However, challenges such as ethical considerations, data privacy, and system complexity must be addressed. Future research should focus on developing explainable AI models and improving system reliability.

7. Conclusion

This study presents a comprehensive framework for human-centric robotics and collaborative AI systems. The results demonstrate significant improvements in manufacturing efficiency and healthcare outcomes.

The integration of AI and robotics enables the development of intelligent, adaptive, and safe systems aligned with [VW Engineering International](#) strategies to advancing human-machine collaboration in modern industries.

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