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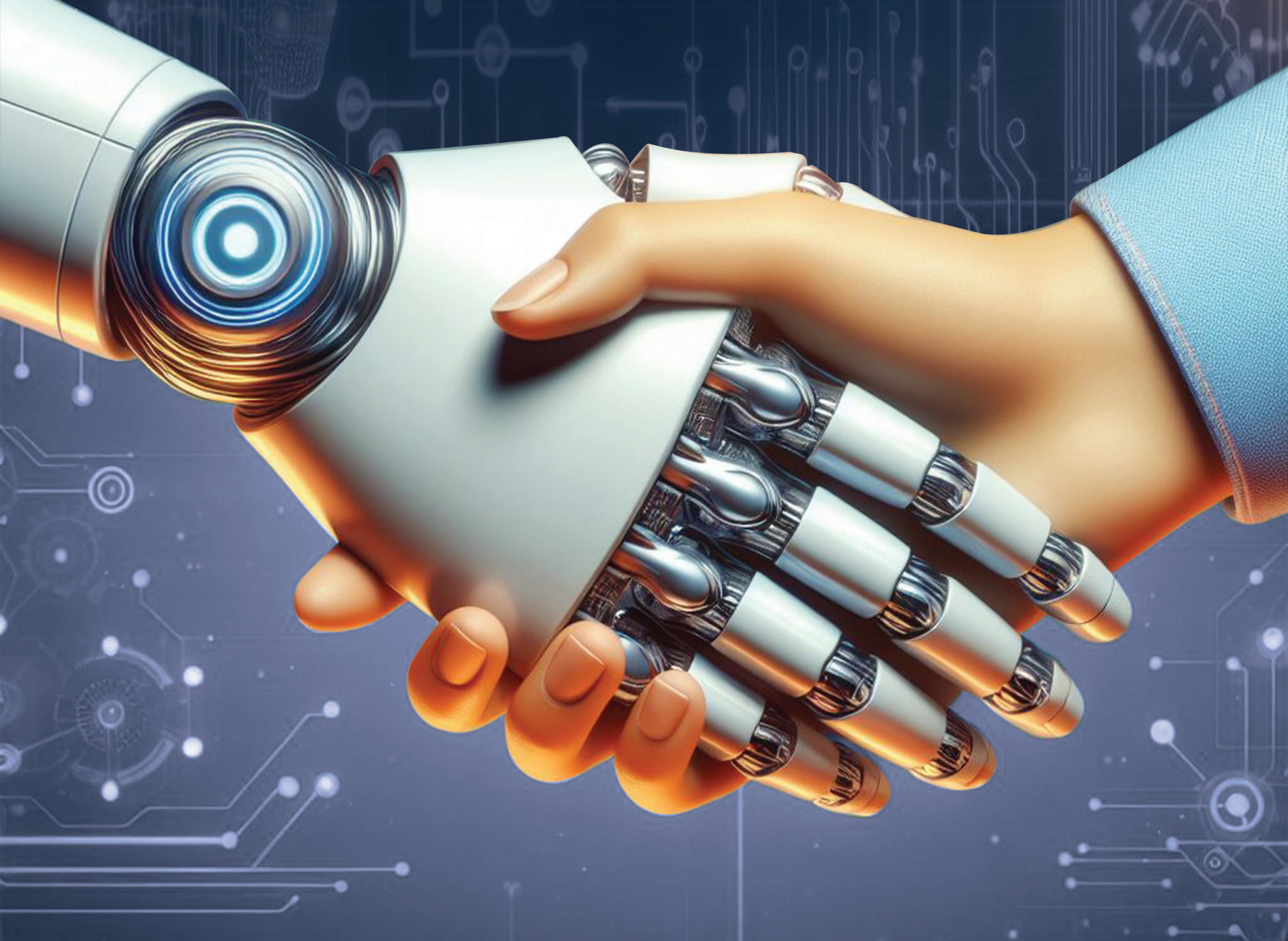

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# RIMC Robotics : Integration, Manufacturing and Control

**Journal of Robotics: Integration, Manufacturing and Control** is an open access biannual international peer-reviewed publication providing a global platform for the dissemination of research articles, case studies, and reviews across diverse disciplines, focusing on robotics integration and manufacturing.

**RIMC** strives to contribute essential research findings to the international community, aiding researchers, scientists, institutions, and societies in staying abreast of new developments in theory and applications. We welcome experimental, computational, and theoretical studies that enrich the understanding of robotics related challenges.

**RIMC** also publishes survey and review articles in the scope. The scope of RIMC includes but is not limited to the following topics: technologies for manufacturing applications, Control algorithms for robots, Sensor technologies, Human-robot collaboration, Robotics for Industry 4.0 and sustainable manufacturing.

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# ⌜ The Role of Underwater Robotics Competitions in Shaping Postgraduate Research and Industry ⌟

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## ABSTRACT

*This paper investigates the impact of unconventional learning experiences, such as participation in underwater robotics competitions, on the research productivity of postgraduate students after graduation. These experiences provide students with valuable training and hands-on practice in a competitive environment. We argue that such experiences are not only beneficial for research but also for developing highly skilled graduates in hardware and software engineering. Furthermore, these competitions can foster an entrepreneurial spirit, motivating graduates to launch their own Small and Medium Enterprises (SMEs) in the field of underwater robotics. The paper showcases examples of impactful postgraduate research directly influenced by such experiences, alongside successful startups founded by competition alumni.*

**Key-words**: Unofficial, underwater, robotics, start-ups, education

## I. INTRODUCTION

The demand for industrial units in Egypt has led to significant growth in feeder industries. Each year, these industries recruit engineers specializing in a range of fields such as Embedded Software Engineering, IT Engineering, Technical Training, Software Application Development, Embedded SW Testing and Validation, C++, C and Java Plugins Tooling Engineering, Principal Software Engineering, and Algorithm Development for Autonomous Vehicles.

With a population of approximately 110 million people, a prominent position in Middle Eastern politics, and a strategic location spanning Europe, Asia, and Africa, the Egyptian market holds great importance. Each month, the market presents around 5000 engineering positions, with a notable focus on embedded hardware and software engineers. This demand is driven by the corresponding growth of international and national feeder industrial firms, resulting in a 30% annual increase in employment opportunities over the past three years.

The early studies in the late 90's, showed the erg need for spreading the knowledge of informatics and mechatronics to non-university and university students. As a result, The Arab Academy for Science, Technology and Maritime Transport established the Regional Informatics Centre [1] in 2002. The centre has 3 main goals

- gathering and encouraging talented youngsters and youth;
- attracting their attention to the importance of **informatics, mechatronics, and robotics**,

- orientating their interest towards channels that are advantageous to the community in terms of development and inventiveness.

To achieve these goals, the center began by providing a competitive environment for pre-university students through programming and robotics workshops and training courses. The main challenge is to participate in national and international competitions.

In 2012, the center took a significant step by organizing the local Egyptian competition for underwater robotics, known as the Egypt MATE ROV competition. The competition has two main categories: 1) Explorers for university students, 2) Rangers for pre-university students.

Students must consider themselves as "entrepreneurs" and transform their teams into businesses that create, market, and sell "products" in order to compete in the MATE competition. In addition to designing ROVs, students will apply what they've learned in class about physics, arithmetic, electronics, and engineering to real-world difficulties in the marine industry. Mentors (teachers, parents, and working professionals) are expected to confine their contributions to educational and inspirational roles, and are encouraged to concentrate on the benefits of the learning process rather than submit technical papers, poster displays, and engineering presentations to be presented to working experts who will serve as competition judges.

## II. Underwater Robotics Research

The post graduate students who participated in this competition and other competition related to such area resulted in successful research and development and start-ups. For example, a well research was done in Unmanned Underwater Vehicles (UUVs. The work focuses on designing a nonlinear controller for the purpose of controlling MIMO Autonomous Underwater Vehicle (AUV) in all degrees of freedom (DOF). The appropriate and efficient control system design is achieved by formulating an inverse kinematic model for the AUV, using Fuzzy Logic rule base for online tuning of the PID parameter, and using Quaternions in rotations observation and control. The presented vehicle configuration allow the AUV to have a fully-actuated 6 DOF. This work is a simulation based where a rigid body dynamic model and underwater environment hydrodynamic model are formulated and utilized in this study to validate the control design.

The cascaded double loop control structure is presented in this work. It proves its high capability to make the system achieve the reference with minimum time response besides the attenuating of environment Gaussian disturbances rapidly. The inner and outer loops are designed to control both speed and position of the AUV, respectively. Regarding the Fuzzy Logic design, a Mamdani fuzzy rules are used to tune the parameters of the PID and the outputs membership functions are selected as Gaussian and Sigmoid functions to give better performance and response in the non-linear system.

The Quaternions mathematics are utilized in the control design to give wide grasp of control over AUV rotations in the 3D. Since one of the main advantages of the Quaternions that it overcomes the singularity took place when using Euler rotations method which is called Gimbal Lock phenomenon.

Several case study scenarios are conducted to validate the control system design with the utilization of the dynamic model of the AUV and underwater environment. Each case study has different kind of complex trajectory to demonstrate the performance of the controller. Beside 2 case studies that demonstrate the Gimbal lock phenomena and the performance of the Quaternions control. A conducted case study that shows the capability of control either velocity or position independently. A Gaussian noise disturbance are injected to the system and the time response results of the controller are presented. [2],[3]

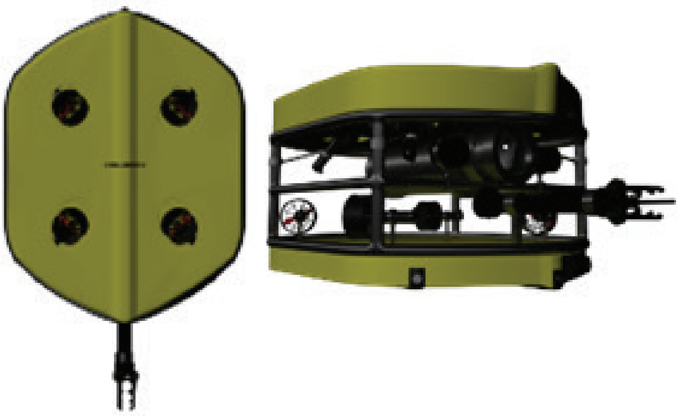

Figure 1 AUV body configuration

## III. Mecanum Wheeled Chair

Another research was done also with another postgraduate student from AASTMT for autonomous wheeled mobile robots. A novel navigational system for handicapped wheeled chairs with mecanum wheels. The wheels provide a flexible mobility represented with its 3DOF (Three Degrees Of Freedom) ability of mobility. The chair provides assistance for the user according to his/her medical situation. The user can control the chair using a joystick or vocal command signals.

The main contribution of this work is defined by the platform kinematics, dynamics modeling and its navigational control system. The mobile platform is kinematically and dynamically modelled and tested on the simulation level to illustrate its performance. The chair is able to navigate in a smart environment, for example, in handicapped house with a known map. The navigation system implemented on the chair will provide position, collision avoidance and local navigation behaviours. The environment is configured as nodes and the chair should follow a series of nodes to reach the desired room. Firstly, a node generator will propose a sequence of nodes, which must be reached respectively. The node generator is created using neural network algorithms. Secondly, the position control will drive from one node to another assuming reference trajectory of a straight line between each two nodes. Thirdly, the fusion between position control and collision avoidance will enable each behaviour according to the situation. The navigational control system is implemented on a hardware prototype and the experimental results are illustrated to show the acceptable performance of the whole system. [4],[5]

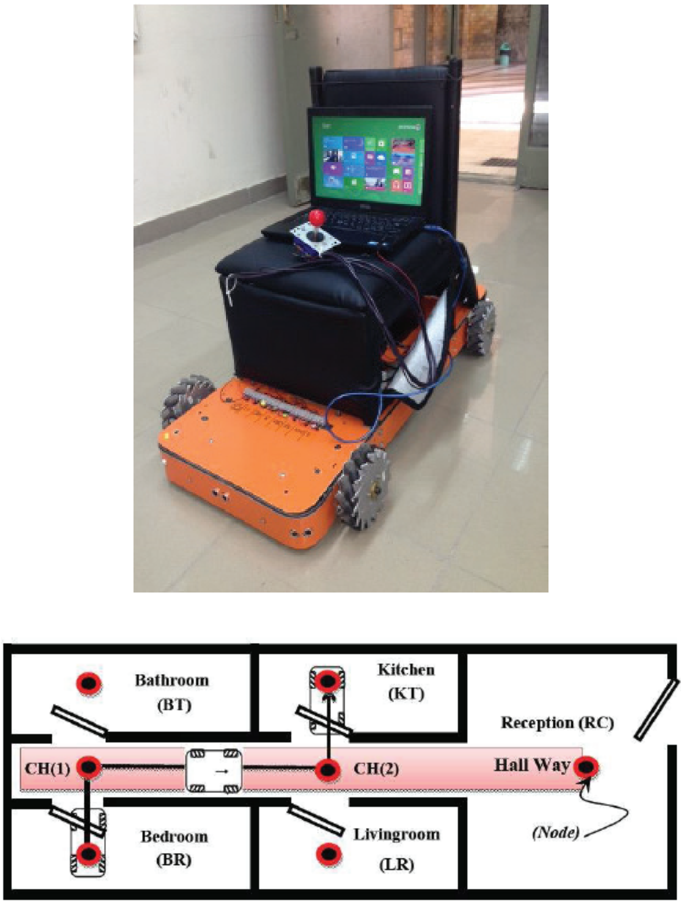


Figure 2 Autonomous wheeled chair for special needs (Left: prototype, Right: Navigation map)

## IV. Successful Startup

In 2018, The International winners wfor the Underwater ROV competition were a team named "Vortex". The members were mixed students from AASTMT and Alexandria University. Some of the team members decided to establish a startup for training and research and development of ROV. The members started by joining the rally of entrepreneurs which is running under the Center of Entrepreneurship in AASTMT [6]. The startup was established officially in 20218 and the first micro ROV for inspection was introduced in 2019.

Figure 3 The 2018 winning ROV: V-Drax

The company offers certified training for school and university student. In addition to inspection and training ROV kits like V-Drax, Swift AUV and V-ray. Vortex Robotics Academy succeeded to be the first ROV Manufacturer in the Middle East with its fully created designs and technology to start its renovation in the underwater world and provide innovative solutions for the marine industry. [7]

## V. Conclusions

The effect of unofficial education presented by the training and participation in competitive environments provided by the Regional Informatics Center in AASTMT, result a skilled graduated from engineering and computer science faculties. These graduates shown their outstanding skilled researchers and outstanding graduates working in large industrial firms in Egypt and other countries as well. The impact of such education resulted startups that impacted the Egyptian underwater ROV services for gas and oil pipe inspection and training as well.

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## Biography

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# Integration of AI and Collaborative Robotics: Transformative Applications and Ethical Considerations

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## ABSTRACT

*The independent advancements in Artificial Intelligence (AI) and robotics have paved the way for significant innovations. The convergence of these technologies, particularly in collaborative robotics (cobots), is revolutionizing various sectors by enhancing human-robot interaction. This paper reviews the integration of AI in robotics, focusing on collaborative robots, their applications, and the ethical considerations involved. We explore key areas such as AI-powered robot control, digital twins, and swarm robotics, highlighting the benefits and challenges of these advancements. Additionally, the paper discusses the future research directions that hold promise for the continued development of intelligent and ethical collaborative robots.*

**Key-words:** Artificial Intelligence, Robotics, Collaborative Robots, AI-powered Control, Digital Twins, Human-Robot Interaction, Ethical Considerations

## I. INTRODUCTION

Robots have long been envisioned as tireless assistants capable of performing complex tasks in diverse environments. Traditional industrial robots, despite their precision and efficiency, often require isolated workspaces due to safety concerns. The integration of AI with robotics bridges this gap, creating collaborative robots or cobots designed to work safely alongside humans. These cobots combine the physical capabilities of robots with the decision-making prowess of AI, enabling a new paradigm of human-robot interaction [1].

## II. Benefits and Applications of AI and Collaborative Robotics

### A. *Enhanced Learning and Adaptability*

AI equips robots with the ability to learn from their environment and adapt their behavior over time. This leads to improved performance in dynamic settings. AI algorithms enable robots to optimize their movements based on sensor data, resulting in increased precision and efficiency [2].

### B. *Improved Decision-Making*

AI allows robots to make real-time decisions, handling complex situations and unforeseen circumstances effectively. This capability is crucial in applications such as industrial automation, where robots must adapt to varying tasks and conditions on manufacturing floors [3].

### C. *Key Applications*

**1) Collaborative Robots (Cobots):** Cobots are the key for changing the industrial assembly lines paradigm. Unlike the traditional counterparts, cobots are designed for safe human-robot interaction, fostering a collaborative work environment [4]. This integration offers several advantages, such as cobots are the best choice for repetitive and physically demanding tasks such as material handling, screw driving, and product dispensing, which frees up human workers to focus on higher-level cognitive tasks and supervision that require problem-solving and decision-making skills [5]. Also, cobots enhance production consistency and quality control through their accurate and precise nature. Studies have shown that cobot integration in industry can significantly reduce assembly errors and improve overall product quality [6]. This highlights the potential of cobots to optimize production efficiency and to elevate human-robot collaboration within the Industry 4.0 paradigm.

**2) Healthcare:** The healthcare landscape is undergoing a significant transformation with the growing adoption of robots [7]. Surgical robots have transcended their initial role as assistants and are now performing complex procedures with unparalleled precision and control. A recent study investigated the effectiveness of robotic-assisted laparoscopic radical cystectomy for bladder cancer [8]. The results demonstrated that this minimally invasive approach offered several advantages, including reduced blood loss, shorter hospital stays, and improved oncological outcomes for patients. This translates to faster patient recovery and a quicker return to daily activities. Beyond surgery, robots are making significant contributions in the field of rehabilitation. Another article explored the use of robot-assisted gait training for stroke patients [9]. This study found that robot-assisted gait training led to significant improvements in patients' gait function and walking ability compared to conventional therapy. As research and development in healthcare robotics continues to flourish, its potential to revolutionize surgical practices, enhance rehabilitation efforts, and ultimately transform patient care delivery is undeniable.

**3) Logistics and Warehousing:** Warehouses are undergoing a significant transformation with the integration of robots, leading to increased efficiency, accuracy, and safety. Autonomous Mobile Robots are revolutionizing warehouse requirements by streamlining the movement of goods within warehouses [10]. A study explored the impact of AMRs on warehouse order fulfillment. The results demonstrated that AMRs significantly reduced order fulfillment lead times compared to traditional manual methods. This translates to faster order processing and improved customer satisfaction. Additionally, AMRs can be programmed to navigate dynamic environments and avoid obstacles, promoting a safer work environment for human warehouse personnel [11].

Beyond transportation, robots are also making significant contributions in warehouse picking and packing tasks. Robotic arms equipped with advanced grippers can efficiently pick and place items of various shapes and sizes. Authoros in [12] investigated the integration of robotic picking systems in warehouses. The study found that robotic picking systems improved picking accuracy and reduced musculoskeletal strain on human workers, leading to a more ergonomic and productive work environment. As warehouse robotics technology continues to advance, its potential to optimize storage space utilization, streamline workflows, and elevate overall warehouse efficiency is undeniable.Amazon uses cobots in its fulfillment centers to improve order accuracy and speed [13].

**4) Search and Rescue:** In the critical domain of search and rescue (SAR), robots are becoming increasingly valuable tools for saving lives. Unmanned Aerial Vehicles (UAVs), commonly known as drones, offer a unique perspective for search operations. A survey about using UAVs for locating missing people in disaster zones is presented in [14]. The results demonstrated that UAVs equipped with thermal imaging cameras could efficiently search large areas and identify potential survivors, significantly reducing search times compared to traditional ground search methods. Furthermore, UAVs can navigate hazardous environments inaccessible to human rescuers, minimizing risks associated with search operations. Another successful case of rescuing a man in poland using UAV along with a human detection algorithm is presented in [15].

Beyond aerial search, ground robots are also playing a crucial role in SAR efforts. Small, agile robots can navigate collapsed structures and debris fields, searching for survivors trapped in confined spaces. An article in the explored the capabilities of snake robots in narrow spaces [16]. This study found that snake robots, with their flexible bodies and maneuverability, could effectively navigate complex environments and locate victims, providing valuable information to human rescue teams. As SAR robotics technology continues to develop, its potential to enhance search efficiency, improve victim location accuracy, and ultimately save lives in disaster scenarios is undeniable. AI-equipped robots can navigate hazardous environments and locate survivors in disaster zones, enhancing the efficiency of search and rescue operations [17].

## III. Key Areas of AI and Robotics Integration

### A. AI-powered Robot Control

AI algorithms analyze sensor data and environmental factors to control robot movements in real-time, enabling robots to adapt to dynamic situations. This is exemplified by the use of deep learning for robot arm control, which allows robots to perform complex tasks with high precision [18].

### B. Digital Twins

AI creates digital simulations of robots and their workspaces, known as digital twins. These simulations are used to test new procedures, optimize performance, and identify potential issues before deployment. Digital twins enhance the design and operation of robotic systems in various industries. For example, in manufacturing, digital twins can simulate production lines, allowing engineers to test and refine processes without disrupting actual operations [19].

### C. Swarm Robotics

AI enables the coordination of large groups of robots, allowing them to perform tasks such as precision agriculture and environmental monitoring. Swarm robotics leverages collective intelligence to achieve complex objectives, demonstrating the potential of AI in managing multi-robot systems. This approach mimics the behavior of social insects, like ants and bees, to achieve efficient task allocation and execution [20].

## IV. Challenges and Ethical Considerations}

### A. Safety and Security

Ensuring the safe and secure operation of AI-powered robots is crucial, especially in collaborative settings. Safety features such as force sensors, limited speed, and compliant materials are essential to minimize the risk of injury. The development of robust safety protocols and standards is necessary to prevent accidents and ensure the well-being of human collaborators [21].

### B. Explainability and Transparency

The decision-making processes of AI algorithms must be transparent and explainable to ensure trust and ethical deployment. Addressing the challenges of AI explainability is vital for gaining stakeholder confidence. Techniques such as explainable AI (XAI) are being developed to provide insights into how AI systems make decisions, enhancing their transparency and accountability [22].

### C. Job Displacement

The increasing automation through AI-powered robots raises concerns about job displacement. Ethical considerations include developing training programs to upskill and reskill the workforce, ensuring that humans can effectively collaborate with robots. Policymakers and industry leaders must work together to create strategies that mitigate the impact of automation on employment [23].

## V. Future Research Directions

### A. Enhanced Intelligence

Integrating advanced AI algorithms into cobots will enable them to learn from their environment and adapt to changing situations. Research is focused on developing cobots that can utilize computer vision and natural language processing, enhancing their ability to collaborate with humans. These advancements will lead to more intuitive and responsive robotic systems.

### B. Human-Centered Design

Future cobots will emphasize intuitive interaction and user experience. This includes features like natural language processing, shared workspace awareness, and advanced user interfaces, making cobots more accessible and effective. Human-centered design principles will ensure that cobots are easy to use and seamlessly integrate into various work environments.

### C. Ethical Frameworks

Developing ethical frameworks for the design, development, and deployment of AI-powered robots is essential for ensuring responsible use. This includes addressing concerns related to transparency, job displacement, and safety. Ethical guidelines and standards will help in creating trustworthy and socially acceptable robotic systems [24].

## VI. Conclusion

The integration of AI and robotics, particularly in the realm of collaborative robots, represents a significant leap forward in human-robot interaction. By addressing existing challenges and focusing on responsible development, this synergistic relationship holds immense promise for transforming numerous sectors. The future of AI-powered collaborative robots lies in their enhanced intelligence, human-centered design, and broader adoption across industries, ensuring ethical and effective collaboration between humans and machines.

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## Biographies

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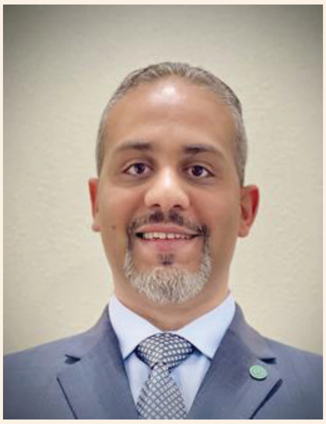
He is an associate professor in the electrical and control department in the Arab Academy for Science, Technology and Maritime Transport since 2022. His research includes control systems modelling and design, and machine learning.



**Tarek Elderini** *received his Ph.D. degree in December 2021 within the field of Autonomous UAVs from the School of Electrical Engineering and Computer Science, University of North Dakota, ND, USA. He has received his M.Sc. degree in December 2013 within the field of Robotic Systems from the Arab Academy for Science, Technology & Maritime Transport (AASTMT), Alexandria, Egypt. In addition to his B.Sc. degree in Electrical and Automatic Control Engineering from the AASTMT in 2009. He is currently an instructor at School of Electrical Engineering and Computer Science at the University of North Dakota, ND, USA. His research interests include wheeled mobile robots, unmanned aerial vehicles, computer vision, and control systems.*

# Challenges in Closing the Gap Between Software and Hardware in Robotics

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## ABSTRACT

*The integration of sophisticated software into robotics, especially with the emergence of generative AI and other AI technologies, marks an important step in the domain of automation and intelligent systems. As robotic systems become increasingly complex, there is a growing demand for advanced AI-driven software solutions that can ensure efficient and seamless operations. This paper explores some of the challenges in the integration of software and robotics, such as interoperability, real-time processing, and user-centric design, and proposes AI-centric strategies to address these challenges.*

**Key-words:** AI-driven solutions, Generative AI, Intelligent systems, Robotics

## I. INTRODUCTION

Robotics has transitioned from simple mechanized tools to complex systems capable of intricate behaviours and interactions, largely due to advancements in AI technologies [1]. The synchronization of software development, particularly generative AI, with robotics, aims to enhance both the capability and adaptability of robots. This integration is crucial in sectors such as healthcare, manufacturing, and personal assistance, where AI can offer unprecedented levels of efficiency and personalisation.

AI technologies have significantly transformed robotics by empowering robots to learn, adapt, and autonomously make decisions, revolutionizing tasks once deemed too complex or hazardous for humans. In sectors like healthcare, AI-integrated robots excel in surgical procedures, patient monitoring, and diagnostics, enhancing efficiency, reducing errors, and ultimately saving lives. Similarly, in manufacturing, AI-driven robots optimize production with adaptable automation and real-time data analysis, enabling rapid customization and boosting competitiveness.

Furthermore, AI-integrated robots are reshaping personal assistance, offering tailored support that ranges from virtual assistants in smartphones to empathetic social robots. This personalized interaction not only enhances independence and quality of life for individuals requiring assistance but also marks a significant advancement towards intelligent companionship. As AI and robotics continue to advance synergistically through machine learning and cognitive computing, they promise a future where human-robot collaboration achieves unprecedented achievements across diverse industries.

## II. Challenges in Integrating Software and Robotics

Three key challenges hinder the seamless integration of AI-based software with robotics: interoperability of systems, real-time processing demands, and user-centric design. To address these challenges, AI technologies, including machine learning models adaptable to different hardware architectures, enhance interoperability. Real-time processing, powered by AI and deep learning techniques, enables immediate decisions based on sensor inputs. Meanwhile, user-centric design, incorporating natural language processing and personalized adjustments, ensures accessible and safe robot control.

### *Interoperability*

Robotic systems involve a diverse array of sensors, actuators, and processing units. The integration challenge is to develop software that can seamlessly function across these varied components. AI technologies, such as machine learning models that adapt to different hardware architectures, are now being developed to improve this interoperability [2].

### *Real-Time Processing*

Robotic operations require real-time processing to make immediate decisions based on sensor inputs. The introduction of AI, particularly deep learning techniques, has enabled the development of software that can process and respond to streaming data with minimal latency, enhancing performance in critical applications like autonomous driving and real-time diagnostics in healthcare.

### *User-Centric Design*

As robots become more integrated into everyday environments, the controlling software must be accessible to users with varying technical skills [3]. AI-driven interfaces, including natural language processing and machine learning for personalized adjustments, can facilitate easier control and interaction with robots, ensuring safety, usability, and acceptance.

Table 1 categorizes the integration challenges of software and robotics—interoperability, real-time processing, and user-centric design—based on difficulty, impact, feasibility, user importance, and technological advancement. Interoperability presents high difficulty due to complex system compatibility requirements, impacting integration significantly with moderate feasibility but critical user importance. Real-time processing, of medium difficulty, focuses on enhancing robotic responsiveness with moderate impact and feasibility, requiring advancements in edge computing and AI. User-centric design, also of medium difficulty, emphasizes intuitive interfaces aligned with user needs, crucial for user satisfaction and feasible through user research and AI advancements. Each challenge underscores specific strategic priorities and technological needs in optimizing integrated robotic systems.

**TABLE 1:** Integration Challenges in Software and Robotics: Assessment of Difficulty, Impact, Feasibility, User Importance, and Technological Requirements

| CHALLENGE | DIFFICULTY LEVEL | IMPACT ON INTEGRATION | FEASIBILITY | USER IMPORTANCE | TECHNOLOGICAL ADVANCEMENT REQUIRED |
|---|---|---|---|---|---|
| INTEROPERABILITY | High | High | Medium | High | High |
| REAL-TIME PROCESSING | Medium | Medium | Medium | Medium | High |
| USER-CENTRIC DESIGN | Medium | Medium | High | High | Medium |

## III. Strategies for Bridging the Gap

### *Standardization of AI-Enabled Protocols*

Adopting and developing AI-specific standards is crucial for enhancing interoperability across robotic systems [4]. These standards not only streamline the integration of AI models and algorithms but also provide a framework that simplifies the process for developers to incorporate advanced functionalities into a wide range of robotic platforms. By establishing common protocols and interfaces, these standards promote compatibility and seamless communication among different AI-powered robots, fostering collaborative efforts in research and development. This interoperability not only accelerates innovation in robotics but also facilitates the deployment of sophisticated AI technologies across various industries, ultimately advancing the capabilities and effectiveness of robotic systems in diverse applications.

### *Advancements in AI and Edge Computing*

Combining AI with edge computing represents a powerful synergy that enables robots to process data in real-time directly on the robot or nearby devices, thereby minimizing latency. AI algorithms tailored for edge deployment excel in tasks like rapid image recognition and swift decision-making, bolstering the robot's ability to respond swiftly in dynamic and unpredictable environments [5]. This integration not only enhances operational efficiency but also empowers robots to autonomously navigate complex scenarios with heightened agility and precision, marking a significant advancement in the capabilities of AI-driven robotics.

### *Emphasis on AI-Driven User Experience (UX) Design*

Employing AI to prioritize user experience design is pivotal in crafting intuitive and adaptive user interfaces. By leveraging generative AI, developers can simulate user interactions and pre-emptively identify potential usability challenges, enabling the creation of interfaces that excel in functionality and user-friendliness [6]. This approach ensures that the design process is not only efficient but also highly effective, as AI-driven insights guide the refinement of interfaces to better meet user expectations and preferences. Ultimately, integrating AI into user experience design enhances the overall usability and satisfaction of interactive systems, setting a new standard for intuitive human-technology interactions.

## IV. Conclusion

The integration of AI technologies, particularly generative AI, into robotics software represents a transformative step forward in robotics. By focusing on AI-specific strategies such as standardization, leveraging edge computing, and enhancing user interfaces with AI, we can bridge the existing gaps and significantly enhance the capabilities and usability of robotic systems. These advancements promise not only operational improvements but also a broader acceptance and integration of robotics into everyday life.

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## Biographies

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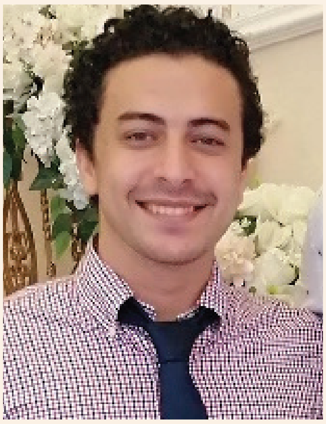

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