AIROBO: A EUROPEAN PROJECT FOR SOFTWARE ENGINEERS

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Abstract

We introduce the innovative European project AiRobo: Artificial Intelligence based Robotics, a cooperation partnership of five excellent universities from Romania, Greece, Hungary, Germany, and France. The target groups are: academic staff, researchers, and higher education students of all levels (Bachelor, Master, PhD). The goal of our ongoing project, running from 2023 to 2026, is to enhance academic staff competences and skills in Artificial Intelligence (AI), Robotics, and Formal Verification. Given the growing significance of AI-enhanced robotics in modern society, strengthening education in these domains is vital for the future development of both these technologies and society. The activities in the project plan include: four trainings for academic staff; the production of a comprehensive teaching material (which consists in a book "Artificial Intelligence based Robotics"; seven AI-based robotic applications in different domains such as academic, agricultural, industrial, medicine, some of them will contribute to the inclusiveness of people with disabilities and migrant background; tools and video tutorials; scientific publications); as well as two international events welcoming participants from around the world (an international summer school for students and an international conference for academics). The intellectual outputs of the project will be freely available on the project's website, providing academic staff and researchers the opportunity to utilize them for their own educational or research activities.

Keywords: Higher education, Artificial Intelligence, Robotics.

1 INTRODUCTION

The increase of Artificial Intelligence (AI) and robotics in modern life underscores an urgent need to realign educational priorities within Computer Science higher education. The convergence of AI, robotics, and formal verification methods represents a transformative force across numerous industries—including healthcare, agriculture, manufacturing, and education—requiring a new generation of professionals equipped with both technical skills and ethical awareness. As AI systems grow in complexity and autonomy, ensuring their safety, reliability, and transparency becomes paramount, particularly in domains where direct human interaction is inevitable. This underscores the necessity of integrating formal verification methods into educational curricula to support rigorous design and risk mitigation. At the same time, higher education must respond proactively to the dynamic nature of technological innovation. Robotics and AI are among the fastest-growing fields in both research and industry, and their influence on the global labor market is expected to be profound. AI-enhanced robotic systems are capable of learning from experience, adapting to new environments, and executing complex tasks with high precision. In educational contexts, these systems have the potential to revolutionize teaching and learning, offering interactive, personalized, and inclusive learning experiences that enhance student engagement and performance. However, the powerful capabilities of AI-powered robotics also introduce significant challenges. Failures in design or implementation can result in critical malfunctions or even fatal outcomes, especially when systems interact closely with humans. Thus, formal verification techniques—used to mathematically prove the correctness of systems—are vital in ensuring safe and reliable deployment.

This paper presents the ongoing project *Artificial Intelligence-based Robotics* [1], an innovative and interdisciplinary initiative aimed at enriching higher education through the integration of AI, robotics, and formal methods. The project is designed to address the evolving educational needs of both academic staff and students in these key areas, promoting excellence, innovation, and inclusion.

The target groups of the project are: academic staff and researchers in the fields of AI, robotics, and formal methods; and students at all higher education levels (Bachelor, Master, and PhD candidates, including those from underrepresented or disadvantaged backgrounds).

The scope of this presentation is threefold: first, to introduce the AiRobo project to the international scientific community; second, to encourage collaboration among academic institutions and research groups working at the intersection of AI, robotics, and formal methods; and third, to raise awareness of the project's outcomes so that academic staff may incorporate them into their own teaching practices. Moreover, the project team actively seeks feedback from users of its resources, aiming to refine and adapt the materials based on real-world academic needs and classroom experiences.

2 METHODOLOGY

The AiRobo 2023–2026 project is built upon a structured, goal-oriented methodology that supports both pedagogical innovation and technological advancement in higher education. The project follows a multi-phase implementation strategy aligned with its key objectives, which aim to strengthen institutional and academic expertise in AI, robotics, and formal verification, while also emphasizing inclusion, accessibility, and international collaboration.

The main objectives of the AiRobo project are:

- To advance the expertise of academic staff in the integrated fields of AI, robotics, formal methods, and pedagogical methods through high-quality training and learning activities;
- To develop inclusive, accessible educational materials for students at all higher education levels (Bachelor, Master, PhD), with particular attention to students with disabilities and those from migrant backgrounds;
- To design, verify, and deploy AI-based robotic systems with applications in various domains including education, agriculture, healthcare, and industry;
- To foster international academic collaboration and facilitate the transfer of knowledge and best practices across borders.

To achieve these objectives, the project undertakes a coordinated set of activities: training activities, development of joint research and educational material, and dissemination activities designed to promote awareness, encourage adoption, and foster international dialogue.

To support faculties specialization, the project consortium has designed and implemented four structured training programs for academic staff within the consortium. These trainings cover theoretical foundations and hands-on experimentation in AI-driven robotics, formal verification methods, and student centered pedagogical methods. The trainings are followed by continuous professional development activities, including trainings after trainings in each partner university, to ensure knowledge retention and application in teaching practice.

The key intellectual outputs developed to serve as teaching and learning materials include several components. These include joint research work as well as a comprehensive book, structured into five chapters, covering a progression from foundational concepts to advanced topics. The book integrates theoretical content, practical exercises, and real-world case studies from the fields of artificial intelligence, robotics, and formal verification, together with tools and video tutorials that support self-paced learning and address the needs of diverse learners. Additionally, seven AI-based robotic applications with cross-sector relevance (e.g., education, agriculture, healthcare, and industry) will be designed and developed to demonstrate practical integration of artificial intelligence and formal verification in real-world scenarios. The robotic applications will be developed through a structured process encompassing three main phases: design and simulation, where initial system architecture and behaviors are modeled using digital tools; testing and verification, including validation of functional correctness and performance, using formal methods where applicable; practical experimentation, during which physical prototypes will be deployed and evaluated in real or semi-controlled environments.

To maximize the impact of the project, all outputs will be disseminated through the official project website [1], ensuring open access to educational resources and technical documentation. Two major dissemination events are planned:

- The **International Summer School on AiRobo**, targeting students from various countries and academic levels. Scheduled for summer 2026, the International Summer School will be hosted by the partner institution in Greece and organized by academic staff from the project consortium. Designed for Bachelor's, Master's, and PhD students from partner universities, the program will span 12 intensive days of activities. The application process will open at the beginning of 2026, with 20 students selected based on their submitted applications;
- The **International Conference on AiRobo**, scheduled for Fall 2026 will be worldwide open to academics, researchers, and industry professionals outside the project consortium. Held in a hybrid format at the partner institution in France, the two-day event will present the project outcomes and encourage broader engagement. Interested participants must submit a motivation letter through the official platform, which will open several months in advance. A limited number of travel grants will be awarded based on the quality and relevance of these submissions.

These dissemination efforts are expected to generate substantial impact by extending the reach of the project's results beyond the partnership, enabling their integration into diverse educational and research contexts around the world, and stimulating innovation in curriculum design, teaching practices, and applied robotics.

3 RESULTS

The results of the AiRobo project mainly consist of two key components: first, the training of academic staff within the partnership in the fields of AI, robotics, formal methods, and student-centered pedagogical methods; and second, the development of the intellectual outputs as materials for teaching and learning support.

3.1 International Trainings

The partner universities organized four trainings for the academic staff (teachers and researchers) from partner institutions in the field of robotics, Artificial Intelligence, formal verification and advanced pedagogical methods student centered. At every training participated representatives from every partner institution, and after each training, the trained academic staff shared the information through their colleagues in the partner universities by organizing local trainings after trainings. These training activities will foster the development of the book and robotic applications, serving as teaching resources for AI-based robotics courses at our partner universities.

3.1.1 Training in Robotics (I)

The goal of the training organized by the Hungarian partner was to learn about: mathematical basis and robot kinematics; reinforcement learning in robotics; the use of Digital Twin solutions for robots; virtual environments Unity and Gazebo for simulating real physics, like gravity, friction, and adhesion, including virtual sensors; Virtual Reality (VR); a standard description of the parts of the robots, like the inverse kinematic description of a robotic arm; ROS (Robot Operating System) that must be integrated or be able to use as a plugin; specific Artificial Intelligence features in robotics, in particular how to run neural networks, and how to use their outputs in the simulation of robots; and advanced robotic arms technologies, like how to build and implement a sorting robot.

Industry 4.0 leverages innovations like cyber-physical systems, digital twins, IoT, robotics, big data, and cloud computing, with their integration driving large-scale advancements. Among these, digital twins in robotics is an emerging field with immense potential. The study [2] examines the trends in Digital twins-integrated robotics—highlighting gaps, evolving and declining directions, potential opportunities, and challenges—and proposes a hypothesis-based framework for the future of Digital twins in robotics. Unity (https://unity.com) and Gazebo (https://gazebosim.org) are two 3D simulators, both used to enable realistic modelling, physics simulation, and testing of robotic systems before real-world deployment. Unity is a versatile game engine with advanced graphics, while Gazebo is a robotics-focused simulator integrated with ROS (https://www.ros.org). A comparison between Unity and Gazebo to simulate a certain robotic task is described in [3]. The Artificial Intelligence features in robotics play an essential

role in the development and the simulation of robots. AI based robotics has transformed the way we approach automation, making it more efficient and sophisticated than ever before. They are capable of performing complicated tasks with accuracy, adapting to changing circumstances, learning from their experiences, and having the potential to revolutionize a variety of industries, including healthcare, and education. AI robots in education have the potential to alter the way we learn and teach, leading to improved academic performance and preparing students for the occupations of the future.

This training enabled participants to be familiar with robotic operating systems and virtual environments, to use neural networks (and specific Artificial Intelligence) in robotics and learn advanced robotic arms technologies.

3.1.2 Training in Robotics (II)

This training was organized by the Greek partner and covered topics from basic to advanced social robotics.

The goal of the training was to learn about: social robotics and the use of social robots in educational settings, for children, for elderly people to improve the cognitive and motor senses, for people with disabilities; the Pepper (https://us.softbankrobotics.com/pepper) and the NAO (https://us.softbankrobotics.com/nao) robots (structure, sensors, components); programming fundamentals and advanced programming in Choreographer and Python; speech and interaction; autonomous robotics; vision and object recognition; project planning; human-robot interaction; as well as advanced social robot interaction.

The study [4] highlights the potential of social robots in educational settings, showing their ability to actively involve students and elevate the learning experience. The Pepper robot introduced by SoftBank Robotics (formerly Aldebaran Robotics) in 2014, is a social humanoid robot that was specifically design for human interaction. The study [5] demonstrates that Pepper substantially boosts student engagement and learning outcomes, particularly in language acquisition. Developed by SoftBank Robotics as well, the NAO robot marks a notable leap in integrating technology into educational settings. As a versatile humanoid robot, NAO is designed to foster interactive learning experiences, promoting student engagement and collaboration. Research studies [6] show that the NAO robot can enhance classroom dynamics by acting as an interactive teaching assistant, offering personalized instruction and fostering an engaging learning environment as well as the capability of NAO to engage students through interactive storytelling and gamified learning activities which can lead to improved motivation and academic performance [7]. Incorporating NAO into educational curricula has been shown to foster teamwork and communication skills among students as they collaborate to program and interact with the robot [8]**.** Overall, the deployment of social robots in educational settings not only enriches the learning experience but also prepares students for a future where technology plays an integral role in various domains of life [9].

The training enabled participants to program social robots and to be familiar with social assistive robotics, and pedagogical principles for inclusive robotics courses in education for people with special needs (with disabilities, migrant background).

3.1.3 Training in Verification of Robotic Hybrid Systems

This training organized by the German partner was dedicated to hybrid systems and formal methods. Hybrid systems are systems with mixed discrete and continuous behavior [10]. Typical examples are physical systems which continuously evolve over time and are controlled by some discrete controller. The robotic systems are all hybrid in this sense. The behavior of hybrid systems is often safety-critical. For example, robots which interact with humans need to satisfy certain safety requirement to assure that they do not cause any danger to humans. To assure the correct functioning of such safety-critical hybrid systems, their automatic synthesis and analysis is of high importance. Introduced in the 1970s to guide novice programmers toward systematic program development [11], formal methods provide rigorous tools for analyzing system correctness. By applying logic and discrete mathematics to specify, design, and analyze hardware and software, they represent requirements in a mathematically structured model suitable for precise examination. Research in this field [12] focuses on maximizing automation of this analytical process.

The goal of this training was to learn: how to model hybrid systems and how to analyze the behavior of the models using formal methods to solve the reachability problem: to decide whether any state from a given target set is reachable in a model; hybrid automata as a modelling language for hybrid systems; how to define several sub-classes of hybrid automata with increasing expressive power, and for each

sub-class to identify whether the reachability problem is decidable, algorithms for their analysis, over-approximative computations, and extensions of hybrid automata models and their analysis methods to cover also random (probabilistic) aspects of hybrid systems; as well as state-of-the-art tools and their usage for verification.

The training enabled participants to: be familiar with verification methods and leading-edge tools for verification of hybrid systems and to be able to use and apply these tools to verify safety properties of robotic systems.

3.1.4 Training in Pedagogical Methods (Problem based Learning) and Robotic Algorithm Verification and Synthesis

The training was organized by the academic staff from the partner institution in Romania and was focused on: modern student centered pedagogical teaching principles, methods for algorithm synthesis and verification in Theorema, verification of algorithms in Coq, neuroscience technologies, and practical applications with the neuroscience headsets, and robots.

Numerous studies have investigated methods to enhance students' cognitive abilities and learning processes through brain-computer interfaces (BCIs), underscoring the transformative potential of advanced AI and robotics technologies in education [13], [14], [15]. PBL (Problem-Based Learning) and PCL (Project-Centered Learning) [16] represent student-focused teaching approaches aimed at nurturing advanced thinking abilities. Their purpose is to introduce participants to novel, learner-centered teaching strategies and to support the creation of engaging and motivating teaching materials. Because design errors in robotics can lead to serious or even fatal consequences, formal verification is crucial for ensuring both safety and reliability. The participants were trained to use two systems Theorema and Coq in order to do formal verification. The Theorema system [17], [18], is an automated theorem prover based on Mathematica [19] used for natural style proving and for algorithm development and verification, while the Coq system [20] is a proof assistant used to certify algorithms.

This training enabled participants to: be familiar with modern student centered pedagogical methods, with neuroscience technologies, with robotic algorithm synthesis and certification methods, and to use the two systems Theorema and Coq for synthesizing and verifying robotic algorithms.

3.2 Intellectual outputs

The Intellectual output are under development. We describe below some partially results obtained.

Sorting algorithms play a fundamental role in numerous computational processes and underpin a wide range of applications across various domains, including those related to environmental monitoring, climate change, and data-intensive systems. Their importance lies in the ability to efficiently organize and process increasingly large and complex datasets. As data volume continues to grow, the efficiency, reliability, and correctness of sorting algorithms become critically important. In the field of robotics, sorting algorithms are integral to intelligent systems used for tasks such as parcel distribution, waste management, and material classification. These applications often involve dynamic environments with human-robot interaction, multi-robot coordination, and potential safety risks, making the formal verification of robotic algorithms not only valuable but essential. We performed the formal verification and certification of several sorting algorithms operating on lists of natural numbers and we developed tools and scripts in two formal systems Theorema [18] and Coq [20]. Each system provides distinct tools and frameworks for rigorously reasoning about algorithm correctness. In real-world robotic applications, the natural numbers used in these algorithms can represent measurable attributes such as color codes, weights, sizes, or other quantifiable parameters critical to sorting tasks. The methods, experiments and developed tools are detailed in [21], [22], [23]. The intended outcome of this work is the integration of these formally verified sorting algorithms into a robotic arm application, simulating an intelligent sorting robot intended for manufacturing environments. Additionally, the verification tools and resources will be included as materials in the AiRobo book, enriching its practical and instructional value.

Other significant results achieved during the development of the robotic application designed to assist people with orientation within our institutions are the following. A case study was conducted to explore autonomous navigation in indoor environments using advanced 3D mapping techniques. The study [24] utilized the Agilex Scout Mini robot equipped with a 3D LiDAR sensor and the Robot Operating System (ROS) for real-time data acquisition and processing. The DBSCAN clustering algorithm was applied to segment the point cloud data, achieving a density of approximately 5,000 points per cubic meter, which enabled highly detailed environmental representation. These 3D maps were subsequently integrated into the Pepper humanoid robot, developed by Aldebaran Robotics, enabling it to autonomously

navigate and deliver location-based services at the West University of Timișoara. The system demonstrated efficient clustering (average computation time of 3 seconds per data segment) and a high path smoothness score of 0.8, reflecting significant improvements in navigation performance. Future enhancements include the integration of Intel RealSense cameras to support color mapping and object recognition, broadening the scope of real-time autonomous service robotics. Another relevant contribution within the AiRobo project involved experimental work focused on generating accurate 2D maps for indoor navigation using the Pepper humanoid robot and the Agilex Scout Mini [25]. The goal was to enable Pepper to autonomously guide individuals through university facilities—a functionality made challenging by its limited built-in environmental awareness. To address this, the Scout Mini, equipped with LiDAR, was used in combination with Pepper's onboard sonar sensors to document the layout of the environment. The mapping process included the evaluation of sensor limitations, integration challenges between the two robotic platforms, and the selection of suitable noise-reduction algorithms to ensure the generation of high-quality and reliable 2D maps. These maps serve as a foundational layer for enabling Pepper's autonomous movement and delivery of location-based assistance within the institution.

4 CONCLUSIONS

The AiRobo project represents a forward-looking initiative in higher education, combining AI, robotics, and formal verification to enrich both teaching practices and technical competence among academic staff and students. Through an integrated methodology that includes specialized trainings, collaborative resource development, and the implementation of real-world robotic applications, the project addresses the growing demand for interdisciplinary and inclusive education aligned with emerging technological trends. Key outcomes include the creation of a comprehensive book, the development of AI-based robotic applications for various sectors, and the formal verification of fundamental algorithms such as sorting routines. These verified components not only enhance educational content, but also support safe and reliable deployment of robotic applications in sensitive environments. The project further demonstrates the importance of formal methods in robotics, especially where interaction with humans and complex environments is involved. Two significant case studies—one focusing on 3D mapping and indoor navigation using LiDAR-equipped mobile robots and another on 2D mapping for autonomous guidance using Pepper—highlight the practical impact of the project. These implementations reinforce the role of robotics in real-world service and educational environments, contributing to both academic understanding and institutional innovation. The project's dissemination strategy—including scientific publications at international conferences, an international summer school, a global conference, and open access to all outputs—ensures a wide-reaching impact. By making the developed materials and tools freely available, AiRobo encourages continued collaboration, feedback, and adoption by the broader academic and research communities. The AiRobo project not only advances the state of education in AI and robotics, but also demonstrates how ethical, verified, and inclusive technology can be integrated into university ecosystems to benefit both learners and society at large.

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