



HAL
open science

A European Project on AI-based Robotics

Isabela Drâmnesc, Erika Ábrahám, Tudor Jebelean, Nikolaos Fachantidis,
Gábor Kusper, Sorin Stratulat

► **To cite this version:**

Isabela Drâmnesc, Erika Ábrahám, Tudor Jebelean, Nikolaos Fachantidis, Gábor Kusper, et al.. A European Project on AI-based Robotics. TALE2024 (International Conference on Teaching, Assessment and Learning for Engineering), Dec 2024, Bangalore, India. hal-04814646

HAL Id: hal-04814646

<https://inria.hal.science/hal-04814646v1>

Submitted on 2 Dec 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

A European Project on AI-based Robotics

Isabela Drămnesc
Department of Computer Science
West University of Timișoara
Romania
isabela.dramnesc@e-uvv.ro

Erika Ábrahám
Department of Computer Science
RWTH Aachen University
Aachen, Germany
abraham@cs.rwth-aachen.de

Tudor Jebelean
ICAM
West University of Timișoara
Romania
tudor.jebelean@e-uvv.ro

Nikolaos Fachantidis
LIRES Laboratory
University of Macedonia
Thessaloniki, Greece
nfachantidis@uom.edu.gr

Gábor Kusper
Department of Computer Science
Eszterházy Károly Catholic University
Eger, Hungary
kusper.gabor@uni-eszterhazy.hu

Sorin Stratulat
Université de Lorraine
CNRS, LORIA
Metz, F-57000, France
sorin.stratulat@univ-lorraine.fr

Abstract—We introduce the project *Artificial Intelligence based Robotics (AiRobo)*, a partnership of universities from France, Germany, Greece, Hungary, and Romania. AiRobo’s aim is to significantly raise the level of competence and skills of academic staff in the field of artificial intelligence (AI) based robotics, thereby also increasing the attractiveness and reputation of the related departments at the partner universities. We further address the European priority in national contexts regarding inclusion in higher education, covering social inclusion and outreach to people with less opportunities, e.g. people with disabilities or with migrant background. The project partners will collaboratively write a comprehensive book on AI-based robotics, provide tools and video tutorials to support the construction and analysis of robotic systems, develop robotic applications in various fields of high interest to the industry, implement trainings for academic staff of the partners, organize an international summer school and an international conference, and disseminate the project results through various channels.

The outcomes of the project will include the training of 25 academic staff from partner universities in teaching AI-based robotic courses, a comprehensive set of teaching materials including the above-mentioned book, 7 robotic applications in different fields, tools and video tutorials, as well as scientific publications.

Index Terms—Higher Education, Computer Science, Robotics, Artificial Intelligence, Formal Verification, Problem-based Learning

I. INTRODUCTION

In this paper we report on a recently started project [1], which addresses an innovative subject intersecting three important domains: robotics, artificial intelligence, and formal verification.

The purpose of this presentation is to make this project known to the scientific community, in order to stimulate interaction and cooperation with international partners. The results of the project will be available in the public domain on the project home page [1] as soon as they are obtained. Furthermore, during the project period we will organize various events (summer school, international conference), which will be worldwide open to higher education students, academic staff, researchers, and industrial experts.

Both in academic research and industrial applications, artificial intelligence (AI) and robotics belong to the most rapidly growing areas. Further strong development can be expected in the future, which will have a fundamental impact on the labour market. Robots play an increasingly important role in modern society, bringing significant benefits in various fields (manufacturing, medicine, space exploration, scientific research, human assistance, and more) representing a constant source of innovation and research. Artificial intelligence improves the efficiency of robotics in education, healthcare, agriculture, industry, and other fields. AI-based robotics transforms the way we approach automation, making it more efficient and sophisticated than ever before. AI-based robots are capable of performing complicated tasks with accuracy, adapting to changing circumstances, and learning from their experiences. AI-based robots in education have the potential to alter the way we learn and teach, leading to improved academic performance and preparing students for the jobs of the future. They have the potential to improve education by offering students tailored and engaging learning experiences. Robots can serve as learning assistants, providing feedback, answering questions, and leading students through classes. They may also adapt their instructions to each student’s individual learning style, speed, and preferences, making the learning process more successful and efficient. However, great power comes with increased risks: errors in the robots’ design can have costly and dramatic consequences, even fatalities, especially when direct interaction with humans is involved. Therefore, formal verification for ensuring correct design is crucial.

Our target groups are (i) *academic staff* (teachers of courses in robotics, teachers of topics that have applications in robotics, researchers in the field of robotics, AI and formal methods, researchers in fields that have applications in robotics) and (ii) *students* of all levels (Bachelor, Master, PhD) from higher educational institutions.

The main motivation of the project is that higher education in computer science needs to permanently adapt to rapid technological changes. By several needs analysis and

discussions with the students, the academic staff, and people from industry, we identified the following needs at the partner universities: (i) insufficient educational offer and research in the field of robotics, in particular using AI; (ii) not sufficiently attractive and motivating curriculum, leading to low interest for university studies and significant school dropout; (iii) the tendency of computer science students after Bachelor level to avoid Master studies in order to already work in industry; (iv) the tendency that during their studies, computer science Master students work in the industry (even full time), which reduces the quality of their participation in the learning process and consequently their competence after graduation; (v) a significant gap between the industry-required skills and the competences provided by the academic curricula.

In the frame of our European AiRobo project, we address these problems by supporting the specialisation of academic teachers in the field of robotics, in particular based on AI and their formal verification. Besides the development of teaching material that can be used for a large number of courses (including research directions and practical applications, addressing problems from real world), we expose concrete robotic applications in various fields that are currently relevant to the contemporary technological, economical and social environment.

The main goal of AiRobo is to significantly raise the level of competence and skills of academic staff in the field of AI-based robotics and formal verification, leading to increased attractiveness and reputation of the involved departments at the partner universities. Our objectives include to contribute to the inclusiveness of students with disabilities and people with migrant backgrounds by providing accessibility, promoting diversity and inclusion, offering valuable technical skills and knowledge, building confidence and self-esteem, and promoting ethical considerations in the development and use of these technologies.

Figure I illustrates our methodology to achieve these goals. In AiRobo, we will train academic staff of the partner institutions in the fields of AI-based robotics and formal verification, as well as in pedagogical methods for teaching these. We will provide four training units in central areas of AI-based robotics, covering theoretical aspects as well as applications and tool usage. To release multiplier effects, the trained staff will themselves train further colleagues in successive training-after-training modules. In addition, we will elaborate high-quality teaching and research material, organize dissemination events, produce related scientific publications, and present the project results at international conferences.

Related work

In the Erasmus+ project ARC [2], [11], we followed a similar methodology to improve the state-of-the-art for Automated Reasoning in the Class, among others publishing an open-access book [16] designed for teaching the subject. There are also some recent initiatives in the formal methods community to support advances in teaching; an excellent example is the Formal Methods Teaching (FMTea) Committee, whose aim

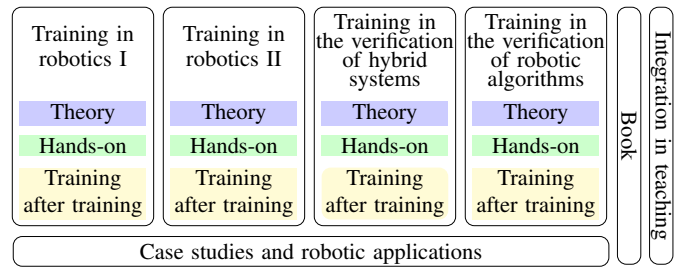


Fig. 1. The AiRobo project structure

is to “support a worldwide improvement in learning formal methods, mainly by teaching but also via self-learning” [19]. FMTea organizes an annual workshop and talk series, and offers a database of courses and case studies. The employment of AI-based robots in education has been researched in e.g. [5], [27]. However, we are not aware of any related work or project on teaching AI-based robotics.

Outline

The rest of this paper is structured as follows. In Section II we introduce AiRobo-Kit, the main targeted output of the AiRobo project. Section III is devoted to our training methodology, whereas in Section IV we discuss our dissemination activities. In Section V we conclude the paper.

II. THE AIROBO-KIT: TEACHING AND RESEARCH MATERIALS

In AiRobo, we will collaboratively develop the AiRobo-Kit, a collection of an open-access book, tools and video tutorials, seven robotic applications, and further research output.

A. The Book

We will jointly develop a book as a support material for teaching AI-based robotic courses at our partner universities. The book will integrate theoretical and practical aspects of AI-based robotics, addressing research directions in the fields, as well as real-world problems as case studies. The book will also serve as a support with practical applications of other (more theoretically oriented) courses such as automated theorem proving, algorithm synthesis and mathematical theory exploration, modelling and certifying algorithms in Coq, verification of hybrid systems, and graph theory. By using the book in these courses, the students can see also the practical relevance of these theoretical subjects, with the expected impact of increased interest and motivation.

The book will be entitled *Artificial Intelligence based Robotics* (short AiRobo book). Written in English and estimated to have around 440 pages, it will integrate theoretical and practical aspects in the following 5 main chapters:

- 1) *Introduction to Robotics*: The first chapter will provide an introduction to robotics with details about the construction of robots, the usage of robots in education, the era of industrial robots, manipulation and dexterity, locomotion and navigation, sensors and robot control,

actuators and driver motors, DC motors, power electronics for servo motors, kinematics of robot manipulators, and dynamics of single-axis drive systems.

- 2) *Programming and Simulation of Robots*: The second chapter will detail robot programming approaches, the simulation of robots, digital twins, using robot operating systems (ROS) in simulations, the usage of computer vision annotation tools (CVAT), training set and annotation for computer vision on robots, and some simple tutorial applications.
- 3) *AI for Robotics*: The third chapter will give an introduction to AI and computer vision, it will detail their integration in robotics, and address ethical aspects.
- 4) *Verification of Robotic Algorithms*: The fourth chapter will be dedicated to the verification of robotic algorithms, including the verification of mixed discrete-continuous (hybrid) systems [29], certifying algorithms [10], [17] in Coq [6], the synthesis [12]–[14] and verification of algorithms [15] in the *Theorema* system [4], and running time analysis.
- 5) *Complex Robotic Applications*: Finally, chapter five will consist of seven subchapters, each of them describing robotics in the domains of (i) robotics for the support of people with disabilities and special education needs, (ii) robotics for vulnerable groups (e.g. foreign-language people, refugees, seniors, etc.), (iii) intelligent agricultural robots, (iv) collaborative robots in industry, (v) robotics in health and treatment, (vi) telepresence robots, and (vii) soft robotics.

The book will also include the practical conclusions from certain practical robotic applications that will be developed within the project and will include links to the code implementation, as well as tools and videos of the robotic applications that will be developed.

In order to illustrate the intended content of the book, below we sketch two topics that will be part of the fourth chapter and the second chapter.

1) *Synthesis and Certification of Sorting Algorithms on Lists*: Some of the algorithms that we intend to use in the project already exist (e.g., A* [26]), others should be invented. One solution is to synthesize them from given specifications. However, even if their specifications are small, it is a challenge to synthesize, verify and certify them.

In our project, we will consider different types of algorithms in different forms. In the below illustration we consider sorting algorithms, that are very important to the robotics field and applications that require to handle big amounts of data, and focus on the certification task. We assume that we are given a sorting algorithm in the form of a function (or a functional program) that can be applied to lists of natural numbers. Below we briefly explain our approach for certifying - with the automated tools used in the project - that the sorting algorithm sorts its input list in increasing order.

More formally, we assume a function f that inputs a list of natural numbers. We consider f to be correct if and only

if for each possible input list, 1) the output list is sorted in increasing order and 2) it is a permutation of the input list.

a) *Certification in Theorema*: To formalize correctness in *Theorema*, we define some auxiliary functions and predicates, expressing the fact that the output is sorted (predicate *IsSorted*), and that it has the same elements as the input list.

We define the predicate *IsSorted* by the following two formulae (where \smile denotes the prepending of an element at the beginning of a list, like *cons* in *Lisp*):

$$\forall_{a,U} \left(\begin{array}{c} \text{IsSorted}[\langle \rangle] \\ \text{IsSorted}[a \smile U] \iff (a \leq U \wedge \text{IsSorted}[U]) \end{array} \right)$$

We express the fact that the input and the output have the same elements by the equality of the multisets [21] of the two lists. These are defined in *Theorema* as below, where \uplus denotes the additive union of multisets:

$$\forall_{a,U} \left(\begin{array}{c} \mathcal{M}[\langle \rangle] = \emptyset \\ \mathcal{M}[a \smile U] = \{\{a\}\} \uplus \mathcal{M}[U] \end{array} \right)$$

Finally, the specification is expressed as:

$$\forall_U (\text{IsSorted}[f[U]] \wedge \mathcal{M}[U] = \mathcal{M}[f[U]])$$

b) *Certification in Coq*: To formalize the correctness of f in Coq, the predicate *IsSorted* can be defined essentially equivalent as in *Theorema*:

```
Inductive IsSorted : list nat → Prop :=
  snil : IsSorted nil
| s1 : ∀ x, IsSorted (x::nil)
| s2 : ∀ x y l, IsSorted (y::l) → x ≤ y →
  IsSorted (x::y::l).
```

where the list of natural numbers has the type *list nat*, 0 and *S* (the ‘successor’ function) are the constructors of *nat*, while *nil* (the empty list) and *::* (the ‘cons’ function) are the constructors of *list*. *IsSorted l* holds if *l* is sorted.

Instead of multisets, we choose an alternative way by defining the following *permutation* function:

Definition *permutation l l'* := $\forall x, (In\ x\ l \leftrightarrow In\ x\ l')$.

where *In* is the (membership) predicate which checks whether some natural number is in a list. This definition says that two lists are in a permutation relation if they contain the same elements.

The correctness of f can now be formalized in Coq by the following theorem:

Theorem *f-is-correct*: $\forall l, \text{permutation } (f\ l)\ l \wedge \text{IsSorted } (f\ l)$.

The proof of this theorem can be done in two steps: i) the ‘permutation’ step, by trying to prove $\forall l, \text{permutation } (f\ l)\ l$, and ii) the ‘sorting’ step, for checking if $\forall l, \text{IsSorted } (f\ l)$.

In the frame of the project, we apply these approaches to certify different sorting algorithms like *Insert-Sort*, *Bubble-Sort*, *Merge-Sort*, *Quick-Sort*, *Min-Max-Sort* [10], [17].

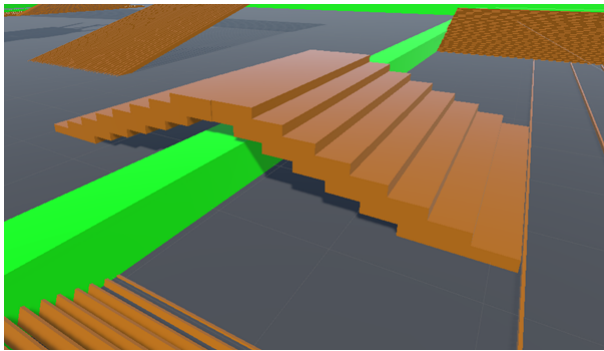


Fig. 2. A test suite: Stairs

2) *Agricultural Robot using Digital Twin Technology:* Agriculture robots need to satisfy certain safety and precision requirements. These robots operate in fields where human presence is limited, which means they must be safe, but not to the same degree as self-driving cars. Additionally, they require a high level of precision, though in agriculture, precision is typically measured in centimeters rather than millimeters.

These properties along with the high relevance of agricultural robots makes them ideal candidates for a case study in our project. In the AiRobo book, we will consider agricultural robots from smart tractors to drones, and highlight different aspects like safety, precision, GPS technology, industrial standards, etc..

Due to restricted budget, we cannot purchase sensors, actuators, and robotic arms. Thus we sidestep to utilizing digital twin [3] technology, which accurately replicates the behavior of the actual robot in a virtual environment.

Creating a digital twin is a complex task. For developing a digital twin, one needs an FBX model [18] of the real robot, a procedural map generator, enhanced wheel colliders, simulated sensors, and a controller to define the robot's behavior. Despite these challenges, building a digital twin is highly rewarding because it allows experimentation in virtual reality, which is safer and more cost-effective than real-world testing.

The AiRobo book will contain a chapter on digital twin technology using the Unity simulation platform [30]. We will introduce the Unity framework, and highlight basic concepts which enable the creation of a rover, including raycasting, shaders, procedural map generation, shaders for map textures, enhanced wheel colliders, and steering such as Ackermann steering [23], and Skid steering [22].

We will then describe how to create a test track to evaluate our first digital twin, a rover. The test track includes:

- Moving platforms: Two platforms rotate in different directions next to each other. The goal is to drive the rover from the first platform to the second one.
- Horizontal sharp edges/grate: There are parallel thin bars forming a grate, with a small space between all bars. The goal is to go over the bars.
- Stairs: There are parallel wide bars forming stairs, there is no space between the bars, see Figure 2. The goal is

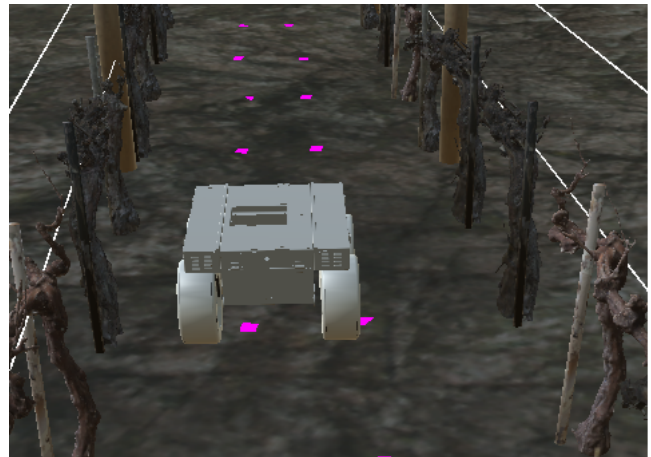


Fig. 3. A rover on a test track to learn self-driving

to go up the stairs.

Next, we demonstrate how to simulate various sensors, such as a 2D camera, LiDAR, bumper sensors, gyroscopes, GPS, etc. The fundamental technologies behind these simulations are collision detection and raycasting, followed by measurement principles using these sensors.

Next, we demonstrate how to use the Robot Operating System (ROS) [28] to control the digital twin, a simulated robotic arm, and a simulated motor. As a first step, we introduce ROS, which has the notion of nodes. A node can be a motor, a sensor, or any other part of the robot. Then we show how to integrate ROS and Unity using the so-called publisher-listener technology. Then we show how to implement a listener in general, and then for a motor and a robotic arm.

Finally, we show how to integrate Unity and neural networks using MLAGents technology [24]. For example, Figure 3 illustrates a simple rover which learns self-driving.

B. Tools and Video Tutorials

Besides the book and the case studies, the AiRobo-Kit will further contain a publicly available collection of

- video tutorials for the simulation of robots for chapters 1 (how to build a robot), 2 and 3 (simulation of robots using virtual environments and AI, in particular neural networks), and 5 (simulation of the 7 robotic applications described in the next subsection), and
- tools presented in the chapters 4 and 5 of the AiRobo book, including case-study-related files for *Theorema*, *Mathematica*, Coq, and SMT solvers. These files are needed for or produced by the formal synthesis, verification, and certification of robotic algorithms embedded in the robotic applications described in the next subsection.

C. The Robotic Applications

We will develop 7 AI-based robotic applications from academic, agricultural, industrial and medical domains, with the aim to be used (i) in research to evaluate algorithms, and

(ii) in teaching AI-based robotic courses as well as theoretical courses at our partner universities. Three of the robotic applications will be designed as a support for people with disabilities and special education needs, and for vulnerable groups (e.g. foreign-language people, refugees, seniors).

We will consider the phases (i) design and simulation, (ii) testing and verification, and (iii) practical experiments, which might involve the following steps:

- Create the robot, which includes:
 - Install a ROS on the robot.
 - Calibrate the sensors or camera on the robot to optimize their accuracy.
- Make the robot functional, including:
 - Train neural networks and deploy them on the robot.
 - Write and formally verify further algorithms that are needed for the functionalities.
 - Test the corresponding algorithms on a small-scale.
 - Deploy the algorithms on the robot and test their performance in various environments.
- Create a digital twin of the robot in its environment using a software like, e.g., Autodesk Maya, Blender, SolidWorks, or SketchUp. This includes among others the following steps:
 - Gather reference images (top, side, front, and back views) of the robot that we want to model.
 - Create the basic shape of the robot using 3D modeling tools.
 - Extend the robot model with features like arms, legs, joints, and sensors.
 - Render the model to create a static 3D image that can be used for various purposes.

We iterate the steps above based on the results of simulation and testing, incorporating feedback from the robot's performance, and continuously monitor the robot's ability and refine the algorithms as necessary.

The steps above are based on multiple theoretical topics that are covered in our partner universities' curricula. Some of these are:

- *Graph theory*: As the backbone of path finding algorithms, it helps to understand how to represent the robot's movement as a graph in a 2D or 3D map, where nodes represent locations and edges represent feasible paths between locations.
- *Search algorithms*: To find the shortest path between the start and the end point of the robot's path, there are several search algorithms such as breadth-first search, depth-first search, the A* algorithm [26], or Dijkstra's algorithm [8].
- *Grid-based path finding algorithms*: If we represent maps as grids, we can use grid-based path finding algorithms with reduced complexity like, e.g., jump point search [20], Theta* [7], and lazy Theta* [25].
- *Heuristic functions*: Providing an estimate of the distance between two points on a map helps to optimize the search process and estimate the total cost of the robot's path.

- *Motion planning*: To find a feasible path for a robot, we can consider its kinematics, obstacle avoidance, and physical constraints.
- *Path finding based on machine learning*: Some machine learning techniques, such as deep reinforcement learning and neural networks, can also be used in path finding algorithms to learn the best policies for the robot's path.
- *Analysis*: Related to the verification of the algorithms that will be used in robotic applications, our partner universities offer lectures on automated theorem proving, algorithm synthesis and mathematical theory exploration, modelling and certifying algorithms in Coq, and verification of hybrid systems.

III. TRAINING ACTIVITIES

The goal of the trainings is to train academic staff (teachers and researchers) in the field of robotics, AI, formal verification and advanced student-centered pedagogical methods, such as problem-based learning, from partner universities by organising 4 training activities, as well as 16 trainings after trainings for a period of 14 months. The training activities will contribute to the development of the book and of the robotic applications as a support material for teaching AI-based robotic courses at our partner universities.

The four trainings are as follows:

- 1) Training in robotics (I):
 - was organized in March 2024 at the partner in Hungary (12 days of activity),
 - enabled participants to: be familiar with robotic operating systems and virtual environments, to use AI (and specifically neural networks) in robotics and learn advanced robotic arms technologies.
- 2) Training in robotics (II):
 - was organized in June 2024 at the partner in Greece (12 days of activity),
 - enabled participants to: be able to build (using 3D printers, Arduino, MakeBlock sets, etc.) and program a robot, to be familiar with social assistive robotics, and pedagogical principles for inclusive robotics courses in education.
- 3) Training in verification of robotic hybrid systems:
 - was organized in September 2024 at the partner in Germany (5 days of activity)
 - enabled participants to: be familiar with verification methods and the state-of-the-art tools for verification of hybrid systems, be able to use some of these tools in order to verify safety properties of robotic systems.
- 4) Training in problem-based learning (pedagogical methods) and robotic algorithm verification and synthesis:
 - will be organized in March 2025 at the partner in Romania (5 days of activity),
 - will enable participants to: be familiar with robotic algorithm synthesis and certification methods, be able to use some tools in order to synthesize and

certify robotic algorithms, be familiar with student-centered pedagogical methods, such as problem-based learning [9].

After each training, the trained teachers from every partner organization will organize in their departments, for their interested colleagues, a training after training, with a total of 16 trainings after trainings.

The main result of these trainings will be the increased competence of more than 25 academic staff (teachers and researchers) from partner universities in the field of robotics, AI, formal verification, automated reasoning, and advanced student-centered pedagogical methods. The trained academic staff will:

- get information and advance knowledge,
- be aware of the state-of-the-art in current research in robotics and related fields,
- learn how to program robots,
- learn specifics of AI-based robotics,
- learn how to formally verify robotic algorithms and how to design robotic systems that behave safe,
- develop lecture material and novel pedagogical skills related to robotics, AI, robotic algorithm verification, automated reasoning, and other connected fields, with special attention to robotic applications,
- exchange information, knowledge and teaching experience.

IV. DISSEMINATION ACTIVITIES

Besides the publication of joint scientific papers and their presentation at international conferences, we will organize, at the end of the project, two important events (detailed below) for disseminating the project results.

These dissemination activities will assure that our AiRobo-Kit - including the book, AI-based robotic applications, videos and tutorials - can unfold its impact to improve the quality of teaching robotic courses

- at our partner universities, being used in teaching related courses, as well as
- in an international context beyond the project boundaries, being
 - freely available (on the website of the project), and
 - widely disseminated, within the lifetime of the project (on the project website, on social media, at the International Summer School, at the International Conference of the project, at other international conferences, in the interest group, in the industry), as well as after the end of the project.

A. The International Summer School

The International Summer School will be organized physically in June-July 2026 by academic staff from the partner institution in Greece as 12 full days of courses taught. Based on their applications, we will select from all the partner institutions 20 students at different levels (Bachelor, Master, and PhD) for participation at the summer school. The instructors will be 8 academic staff (teachers and researchers) from

partner universities, who played key roles in the development of the AiRobo-Kit.

The students will learn important notions from the book, the developed robotic applications, and tools. Furthermore, they will acquire skills for developing correct and safe robotic systems, including robot construction, programming, simulation, testing, verification, and certification.

The goal of the International Summer School is twofold: 1. teaching the students in practical exercises, based on the principles of problem-based learning, 2. practical evaluation of the learning material. This way, the school contributes to: 1. the dissemination of the project outcomes through the participating international students, and 2. a validation of the project's achievements.

B. The International Conference

The International Conference will be organized physically in November 2026 (the last month of the project period) by academic staff from the partner institution in France as 2 full days of sessions. We will host 20 participants (academic teachers and researchers, as well as people from industry) outside the partnership, who are interested in the results of our project. The presentations will be given by 7 academic staff (teachers and researchers) from partner universities, who co-developed the AiRobo-Kit.

The objective of the conference is to make the participants familiar with the results of the project, especially with the book and the developed robotic applications, tools, and the research material.

Our International Conference and the scientific papers published at external events will contribute to 1) the dissemination of the value of the project through the international participants (academic teachers, researchers, people from industry), and 2) the final evaluation of the results (as the participants of the International Conference, the reviewers of our scientific papers, and the participants to the conferences where we present the scientific papers will give us feedback concerning the quality of the results of the AiRobo-Kit).

V. CONCLUSIONS

The AiRobo project creates the possibility to significantly improve the teaching of AI-based robotics. In a cross fertilization manner, we exploit the experiences of 5 excellent European computer science departments, in order to

- strengthen the usage of AI in robotics;
- employ formal methods for robot design and verification, and demonstrate the employment of tools for the formal synthesis, verification and certification of robotic algorithms;
- provide robotic applications and video tutorials, to drive innovation in different domains like education, industry, healthcare, agriculture, etc., paying special attention to people with disabilities and migrant background;
- publish a book with innovative material that supports teaching and learning subjects like, e.g., AI, robotics, automated reasoning, formal verification, graph theory,

automated theorem proving, or verification of hybrid systems;

- train academic staff;
- employ novel pedagogical student-centered methods, such as problem-based learning, instead of traditional teaching methods in the process of teaching a larger variety of courses addressed by the project;
- publish the project outcomes in scientific papers;
- provide a platform for the communication and exchange of good practices and expertise between the partner universities, in an international context in related fields including AI, robotics, and formal verification.

The project has a strong potential to create synergies in the higher education sector. The developed materials (the book, the tools, the video tutorials and the concrete robotic applications) are based on several disciplines, covered in our partner universities' curricula, that are related to computational logic (for example mathematical logic, artificial intelligence, automated theorem proving, algorithm synthesis and mathematical theory exploration, modelling and certifying algorithms, verification of hybrid systems, graph theory, satisfiability checking, etc.). In a similar way, the project has a potential impact on most of the subjects that are in the computer science curricula of the partners universities, like for instance software engineering or programming. The impact further extends to robotic application domains, for example agriculture or medicine.

Besides theoretical aspects, AiRobo has also a strong focus on applications. The AiRobo-Kit aims to support the inclusion of robotics examples (both from the book as well as from the robotic applications) in the lectures mentioned above, as illustrations of applications of theoretical disciplines. This is quite important since a large number of students tend to have little interest in theoretical courses, because they are uncertain how useful these are for their future career.

The higher education robotic materials for courses, tools, applications, and research materials will contribute to the inclusiveness of people with disabilities and with migrant backgrounds by providing accessibility, promoting diversity and inclusion, offering valuable technical skills, building confidence and self-esteem, and promoting ethical considerations in the development and use of these technologies.

ACKNOWLEDGEMENTS

This work is co-funded by the European Union through the Erasmus+ project *AiRobo: Artificial Intelligence-based Robotics*, 2023-1-RO01-KA220-HED-000152418.

REFERENCES

- [1] European Union, Erasmus+ project AiRobo: Artificial Intelligence based Robotics, 2023-1-RO01-KA220-HED000152418. www.airobo.info.uvt.ro, 2023 - 2026.
- [2] European Union, Erasmus+ project ARC: Automated Reasoning in the Class, 2019-1-RO01-KA203-063943, 2019 - 2022. www.arc.info.uvt.ro.
- [3] Michael Batty. Digital twins. *Environment and Planning B: Urban Analytics and City Science*, 45(5):817–820, 2018.
- [4] Bruno Buchberger, Tudor Jebelean, Temur Kutsia, Alexander Maletsky, and Wolfgang Windsteiger. Theorema 2.0: Computer-assisted natural-style mathematics. *Journal of Formalized Reasoning*, 9(1):149–185, 2016.

- [5] Shih-Ting Chu, Gwo-Jen Hwang, and Yun-Fang Tu. Artificial intelligence-based robots in education: A systematic review of selected SSCI publications. *Computers & Education: Artificial Intelligence*, 3:100091, 2022.
- [6] The Coq Development Team. *The Coq Reference Manual*. INRIA, 2020.
- [7] Kenny Daniel, Alex Nash, Sven Koenig, and Ariel Felner. Theta*: Any-angle path planning on grids. *Journal of Artificial Intelligence Research*, 39, 01 2014.
- [8] Edsger W. Dijkstra. A note on two problems in connexion with graphs. *Numerische mathematik*, 1(1):269–271, 1959.
- [9] Diana H. J. M. Dolmans, Willem De Grave, Ineke H. A. P. Wolfhagen, and Cees P. M. van der Vleuten. Problem-based learning: Future challenges for educational practice and research. *Medical Education*, 39(7):732–741, 2005.
- [10] Isabela Drămnesc, Tudor Jebelean, and Sorin Stratulat. Certification of Tail Recursive Bubble-Sort in Theorema and Coq. In *LPAR 2024 Complementary Volume*, volume 18 of *Kalpa Publications in Computing*, pages 53–68. EasyChair, 2024.
- [11] Isabela Drămnesc, Erika Ábrahám, Tudor Jebelean, Gábor Kusper, and Sorin Stratulat. Experiments with automated reasoning in the class. In *Proc. of the 15th International Conference on Intelligent Computer Mathematics (CICM'22)*, volume 13467 of *LNCS*, pages 287–304. Springer, 2022.
- [12] Isabela Drămnesc and Tudor Jebelean. Synthesis of list algorithms by mechanical proving. *Journal of Symbolic Computation*, 68:61–92, 2015.
- [13] Isabela Drămnesc and Tudor Jebelean. Synthesis of sorting algorithms using multisets in Theorema. *Journal of Logical and Algebraic Methods in Programming*, 119:100635, 2020.
- [14] Isabela Drămnesc and Tudor Jebelean. AICons : Deductive synthesis of sorting algorithms in Theorema. In *Proc. of the 18th International Colloquium on Theoretical Aspects of Computing (ICTAC'21)*, volume 12819 of *LNCS*, pages 314–333. Springer, 2021.
- [15] Isabela Drămnesc and Tudor Jebelean. Mechanical verification of Insert-Sort and Merge-Sort using multisets in Theorema. In *Proc. of the IEEE 21st International Symposium on Intelligent Systems and Informatics (SISY'23)*, pages 55–60. IEEE Xplore, 2023.
- [16] Isabela Drămnesc, Tudor Jebelean, Erika Ábrahám, Sorin Stratulat, Gábor Kusper, Mircea Marin, Adrian Crăciun, Csaba Bíró, Gergely Kovászai, and Nikolaj Popov. *Computational Logic: A Practical Approach*. Editura Universitatii de Vest, 2022.
- [17] Isabela Drămnesc, Tudor Jebelean, and Sorin Stratulat. Certification of sorting algorithms using Theorema and Coq. In *Proc. of the 10th International Symposium on Symbolic Computation in Software Science (SCSS'24)*, volume 14991 of *LNCS*, pages 38–56. Springer, 2024.
- [18] <https://www.autodesk.com/products/fbx/>.
- [19] <https://fme-teaching.github.io/>.
- [20] Daniel Harabor and Alban Grastien. Online graph pruning for pathfinding on grid maps. *Proc. of the AAAI Conf. on Artificial Intelligence*, 25(1):1114–1119, Aug. 2011.
- [21] Donald Erwin Knuth. *The Art of Computer Programming, Volume 3: Sorting and Searching*. Addison Wesley, 2 edition, 1998.
- [22] Krzysztof Kozłowski and Dariusz Pazderski. Modeling and control of a 4-wheel skid-steering mobile robot. *International journal of applied mathematics and computer science*, 14(4):477–496, 2004.
- [23] Wm. C. Mitchell, Allan Staniforth, and Ian Scott. Analysis of Ackermann steering geometry. Technical report, SAE Technical Paper, 2006.
- [24] <https://github.com/Unity-Technologies/ml-agents>.
- [25] Alex Nash, Sven Koenig, and Craig A. Tovey. Lazy Theta*: Any-angle path planning and path length analysis in 3D. In *Proc. of the 3rd Annual Symposium on Combinatorial Search (SOCS'10)*, pages 153–154. AAAI Press, 2010.
- [26] Nils J. Nilsson. *Principles of Artificial Intelligence*. Symbolic Computation. Springer, 1982.
- [27] Chiara Panciroli, Anita Macaudo, and Luca Ferrari. Artificial intelligence and robotics in education. In *Proc. of the Italia Intelligenza Artificiale Workshop (Ital IA 2023)*, volume 3486 of *CEUR Workshop Proceedings*, pages 472–477. CEUR-WS.org, 2023.
- [28] <https://www.ros.org/>.
- [29] Stefan Schupp, Erika Ábrahám, Md Tawhid Bin Waez, Thomas Rambow, and Zeng Qiu. On the applicability of hybrid systems safety verification tools from the automotive perspective. *International Journal on Software Tools for Technology Transfer*, 26(1):49–78, 2024.
- [30] <https://unity.com/>.