Design of a Multitask and Terrestrial Robot Challenge for Course Project of Intelligent Robots

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***Abstract*—Robotics is a highly practical, multidisciplinary, and rapidly developing field of study which lies at the intersection of computer science, automatic control, mechanical engineering, and materials science, as well as other disciplines. Designing a suitable yet challenging robotics course project is incredibly important and beneficial for teaching the subject effectively. Carrying out a practical robotics project helps students consolidate their knowledge and connect concepts across disparate areas of computer science and mechatronics engineering as they design and develop an integrated robotic system. Additionally, a practical project helps deepen a student's understanding of how recent ground-breaking results in Artificial Intelligence (AI) can be implemented in a real robotic system. This paper provides an overview of a project for the *Intelligent Robots* graduate course. In the proposed course project, each team programs a small-scale humanoid robot to carry out a multi-task robot challenge on a terrestrial map. The course project is organized into a series of milestones, each of which is related to the corresponding module of the robot (e.g., joint motion, visual servoing, etc.). The students' performance in the course project over the past three years has been summarized and reviewed. The evaluation results and the student feedback show that the proposed course project is interesting and engaging, and provides the students with a comprehensive opportunity to apply their theoretical knowledge in robotics, as well as to implement the findings of contemporary research in AI, to a real robotic system.**

***Keywords*—intelligent robot, course project, robot challenge, milestones**

I. Background and Significance

Rapid advances in computing and sensing technologies have extensively widened the applications of robotic systems to areas such as home care [1], medical health [2], and hazardous exploration [3]. Recent progress in merging Artificial Intelligence (AI) and robotics [4, 5] has accelerated the development of intelligent robots, which not only perform repetitive tasks automatically as directed by a program but can also learn new skills and generalize them to perform new tasks. Such a capability enables the robot to perform even more challenging and complex tasks [6, 7]. To realize the potential of intelligent robots, there is a growing demand for the cultivation of new talent in the field of robotics.

Robotics is a rapidly developing, highly practical, and multidisciplinary subject, which requires background knowledge in computer science, automatic control, mechanical and materials engineering. Hence, designing a practical course project is essential for teaching the subject effectively which ensures that students can successfully apply theory to develop a real, functioning robotic system. More importantly, a practical project provides students with a global overview and thorough understanding of the operation of an integrated robotic system (i.e., how different modules interact and collaborate in an integrated system), as well as providing them with extensive practical engineering and debugging experience.

However, existing robotics course projects focus more on automation and not on "intelligence", in the sense that the students have relatively few opportunities to explore the connection between AI and robotics or to apply the latest research findings in AI, such as deep learning for robot vision [8] and reinforcement learning for robot planning [9], to a real intelligent robotic system. To bridge this gap, this paper presents the design of a new course project for the *Intelligent Robots* graduate course, in which teams of students program small-scale humanoid robots to compete on a terrestrial map. Such a course project has several advantages.

(1) The humanoid robot possesses multiple Degrees of Freedom (DoFs), providing the flexibility required to perform complex tasks (e.g., crawling, dancing, grasping, etc.);
(2) The robot utilized has an open architecture, making it convenient for implementing various AI techniques (e.g., deep detection networks);
(3) The proposed robot challenge involves multiple modules (e.g., modeling, planning, perception, control) such that students have a broad opportunity to implement learned knowledge and to test innovative ideas.

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A. Robotics Course

Many universities and research institutes have designed similar courses in robotics.

CMU: There are three teaching modules for robotics (i.e., 16-811, 16-711, 16-642), "Math Fundamentals for Robotics", "Kinematics, Dynamic Systems, and Control", and "Manipulation, Estimation, and Control". Module 16-811 covers selected topics in applied mathematics, including "Solution of Linear Equations", "Polynomial Interpolation and Approximation", "Solution of Nonlinear Equations" [10]. Module 16-711 covers "*fundamental concepts and methods to analyze, model, and control robotic mechanisms which move in the physical world and manipulate it*" [11]. Module 16-642 provides "*an overview of the current techniques that allow robots to locomote and interact with the world*" [12].

MIT: The "Robotics" (2.165) course [13] at MIT includes an introduction to robotics and machine-learning, kinematics and dynamics of rigid body systems, adaptive control, system identification, sparse representations, and more. Another course "Robotic Manipulation" (6.4212) introduces "*the fundamental algorithmic approaches for creating robot systems that can autonomously manipulate physical objects in unstructured environments such as homes and restaurants*" [14].

UPenn: The course "Robotics" at UPenn is given by the General Robotics, Automation, Sensing and Perception (GRASP) Laboratory. The program provides "*an ideal foundation for what today's experts in robotics and intelligent systems need to know – from artificial intelligence, computer vision, control systems, dynamics, and machine learning to design, programming and prototyping of robotic systems*" [15].

Northwestern University: There are three courses on robotics at Northwestern University [16], "Intro to Mechatronics" (ME333), "Robotic Manipulation" (ME449), and "Embedded Systems in Robotics" (ME495). ME333 includes an "*Introduction to microprocessor controlled electromechanical systems*" [17]. ME449 discusses "*Robotic Manipulation Representations of the configuration and spatial motion of rigid bodies and robots based on modern screw theory*" [18]. Finally, ME495 [19] is a project-based course aimed at teaching Robot Operating Systems (ROS) [20].

KTH: Three relevant mandatory courses are provided for first-year Master's students in Systems, Control, and Robotics at KTH [21]. "Introduction to Robotics" (DD2410) delivers a very broad introduction to the field of robotics. "*The course consists of lectures, lab assignments, and a wide selection of reading materials. The course is examined with assignments and a larger project, and a written exam*" [22]. "Control Theory and Practice" (EL2520) is a more challenging course which "*Introducing basic theory and methods for analysis and design of advanced multivariable control systems*" [23]. "Modelling of Dynamical Systems" (EL2820) teaches "*Systematic method for building mathematical models of technical systems from basic physical relations and measured data*" [24].

In summary, it is common for robotics courses at universities around the world to include a practical course project, which aims to provide students with a comprehensive overview of integrated robotic systems, to give them the opportunity to apply theory in developing real robotic systems, and to gain experience implementing the latest research findings in AI.

B. Overall Assessment

The *Intelligent Robots* graduate course consists of three parts: 1) theoretical sessions – lectures on core concepts such as robot kinematics, dynamic modelling, control and planning methods, 2) seminars – discussions on the latest research progress in a specific area (e.g., surgical robots, micro/nano robots), 3) lab sessions – training on the operation of the robot and potential methods of achieving the project milestones. In summary, the course provides a balance between theoretical studies and practical experience, as well as between fundamental principles and state-of-the-art research. Specifically, the course has two main features that make it unique.

First, the latest research progress is delivered by presenting papers which have won the "Best Paper Award" in the top-tier conferences and journals in the field of robotics, including *IEEE Transactions on Robotics* [25], *The International Journal of Robotics Research* [26], and *ICRA/IROS* [27, 28]. Second, the lab sessions are organized into a series of milestones, each of which corresponds to a different functional module of the robot (e.g., the perception, control, and motion modules). Therefore, achieving all the milestones naturally guarantees that the robot has the basic ability to carry out multiple tasks in the challenge.

The composition of the final mark is given as follows:

$$Final = 5\%Part. + 30\%HW + 25\%Mid. + 40\%Proj. \quad (1)$$

where *Final* denotes the final mark, *Part.* represents participation, *HW* denotes homework, and *Proj.* is the mark for the course project. Hence, the course project is the most significant part of the course. The final mark composition also balances the students' time in the classroom and the lab.

C. Intended Outcomes

The intended outcomes of the course can be summarized as follows: 1) the students have an excellent understanding of fundamental concepts in robotics, including kinematics, dynamics, control, and planning, 2) the students can run the simulation environments and understand how typical control algorithms are implemented in such an environment, 3) the students are proficient in operating the small-scale humanoid robot, in implementing cutting-edge technologies, and have demonstrated the ability to explore and test innovative ideas.

The remainder of this paper is organized as follows. Section II presents the details of the course project, including the robot model, the challenge map, and the project milestones. Section III introduces the evaluation methods and several sample project results. Section IV shows the students' performance in the course project, as well as their feedback. Section V concludes the paper with a discussion on training and education in the field of robotics.

II. Course Project

Note that the assessment of the course project takes up *40%* of the final mark. The breakdown of the course project mark is as follows:

$$40\%Proj.=9\%Milestone+21\%Match+10\%Report \quad (2)$$

where *Milestone* represents the three milestones before the robot challenge, *Match* denotes the robot's performance in the challenge match, and Report denotes the mark given to the project report. Specifically, the main content of the course project is to program a small-scale humanoid robot to carry out a series of tasks on a terrestrial map (including stairs, slopes, obstacles, narrow aisles, etc.).

A. Robot Challenge

The humanoid robot used in the course project is the *Yanshee* robot from UBTECH Robotics [29]. The *Yanshee* robot can be used as an open-source platform, supporting both ROS and the programming language Python [30], such that many open-source AI and machine-learning algorithms can be conveniently transplanted or tailored. A diagram of a *Yanshee* robot is shown in Fig. 1. A Raspberry Pi is running as the main processor, connected to the built-in sensors (i.e., the camera, microphone, speaker) and the motion control module. The motion control module includes an STM32 processor, sending commands to control the servo motors. The STM32 processor can also communicate with more external sensors via a series of universal interfaces.

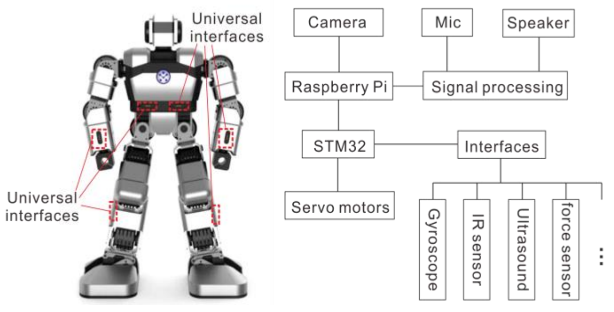


Fig. 1. The humanoid robot of *Yanshee* is used as the teaching platform of the course project. It is an open-source platform, has built-in sensors, and also supports multiple external sensors via a series of universal interfaces.

A total of six universal interfaces are present around the wrist, waist, and knee joints of the robot. The interfaces are magnetic such that sensors can be easily attached (instead of plugged in) to the robot. The sensor can be selected from a set, which includes an Infrared (IR) sensor, an ultrasound sensor, a tactile sensor, a force sensor, and more. The IR and ultrasound sensors are used to measure distance, while the tactile and force sensors are used to monitor the contact status. Note that those sensors can be attached to any one of the six universal interfaces. The Yanshee robot's specifications are summarized in Table I.

TABLE I. The Specification of *Yanshee* Robot

Specification	Value
Size	370×192×176 mm
Weight	2.05kg
Degrees of freedom	17 (neck, should, elbow, waist, knee, ankle, etc.)
Voltage	9.6V
Sensing capability	Contact, distance, temperature, humidity, etc.

In addition, the robot also integrates two categories of built-in functions for human-robot interaction: 1) voice – the robot can recognize a human's voice, answer human's questions accordingly (information inquiry, stories, translation, etc.), and convert text into voice, 2) vision – the robot can recognize a human's face and track it, and can also identify a human's facial expression, as well as several gestures (e.g., thumb up, "V" pose).

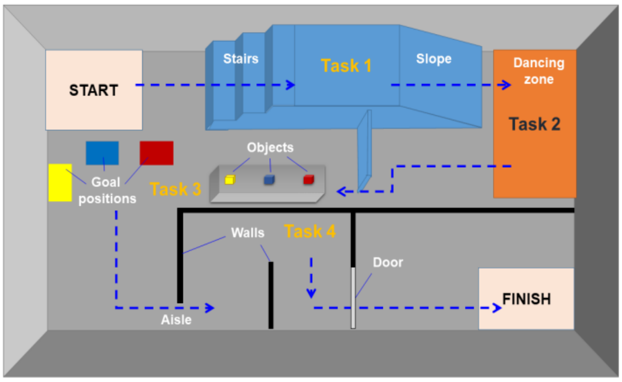


Fig. 2. The robot is required to autonomously complete four tasks on a terrestrial map, which includes a set of stairs, a slope, a narrow aisle, and a door.

In the course project, two students form a team to program the robot to autonomously perform multiple tasks on a terrestrial map without, or with minimal human assistance or remote control. The robot challenge map is shown in Fig. 2 and consists of four tasks:

- *Task 1*: The robot climbs upstairs and then walks down a slope without falling;
- *Task 2*: The robot dances with multiple joints;
- *Task 3*: The robot picks a target object and places it onto a corresponding goal position;
- *Task 4*: The robot travels down a narrow aisle, avoids walls, opens a door, and walks through.

Therefore, completing all the tasks presents challenges for the robot's performance in a number of areas, including locomotion, visual perception, and interaction control. During the course project, the students are encouraged to apply techniques or methods from the latest research in AI to further improve the robot's performance in terms of movement speed, accuracy, and autonomy.

B. Milestones

Before the formal challenge, all teams must achieve three milestones. Each milestone corresponds to a specific functional module of the robot which is essential for the autonomous operation of the robot. Achieving the milestones guarantees that the students possess the necessary knowledge to program/control the robot, such that the robot can at least meet the basic requirements of the challenge. The design of the milestones also encourages the students to begin work on the project earlier and save more time for fine-tuning their approach to the formal challenge.

Milestone 1: The whole-body movement with all the joints. The movement duration should be longer than 1 minute. After Milestone 1 is achieved, the students will have gained proficiency in programming the robot's motion, including coordinating the movement of multiple joints. They will also have learned how to use the robot's built-in functions to generate the motion.

Milestone 2: Grasping and placement of a target object. The spatial relationship between the object and the robot is not calibrated beforehand. Therefore, the robot should use sensors (e.g., vision) to detect the object and then adjust its motion accordingly. For this challenge, hard-coded methods will not suffice. After Milestone 2 is achieved, the students will have become experts in the principles and implementation of visual servoing [31] to address the problem of unknown positions and to deal with unforeseen changes, e.g., re-grasping.

Milestone 3: locomotion inside constrained space. Due to the narrow width of the aisle, the robot has to walk sideways; Due to the narrow width of the aisle, the robot has to walk sideways. After Milestone 3 is achieved, the students will be skilled at applying methods of customizing the robot's pose and adjusting the robot's movement (by using pre-calibration and internal or external sensors such as IMUs or vision).

The milestones are summarized in Table II. Effectively, the three milestones correspond to *Task 2–4* discussed in the previous section. However, achieving the milestones only meets the basic requirements of the course project, and the tasks involved in the formal challenge will require more improvement and effort, which will be discussed in the subsequent section. The reasons why *Task 1* is not reflected in any milestone are because 1) it is more comprehensive, in the sense that the students need to use the knowledge and skills acquired from more than one milestone to complete it, and 2) it is also more challenging, and the students will need more time (than the regular lab session) to address it. Additionally, by spending more time on *Task 1* the students will have more opportunity to develop and test innovative solutions.

TABLE II. MILESTONES OF COURSE PROJECT

No.	Mission	Mastered Skill
1	Whole-body movement	Motion control, joint coordination
2	Grasping-and-placement	Visual perception, visual servoing
3	Locomotion	Balance, pose adjustment

III. EVALUATION METHOD

The robot's performance in the multi-task challenge is evaluated according to three main criteria: 1) the overall timing, where the faster the robot can complete the task, the higher the mark granted to the team, 2) the completeness of each task, where all compulsory steps of each task should be accomplished, 3) the involvement of humans, where the less human assistance is required (i.e., greater autonomy), the higher the mark a team obtains. The three performance criteria are discussed in greater detail in the following section.

A. Criteria

Total Time: Each team has to complete the challenge within 30 minutes. Two trials are allowed in total. However, if the second trial is conducted, the results in the first trial will be overwritten.

Human Involvement: Fewer manual operations and less human assistance will lead to higher marks granted. For example, the full autonomous pipeline (with the automatic connection between each task) guarantees the full mark. A deduction in marks is applied every time human assistance is provided.

Task Assessment: There are specific requirements for each task.

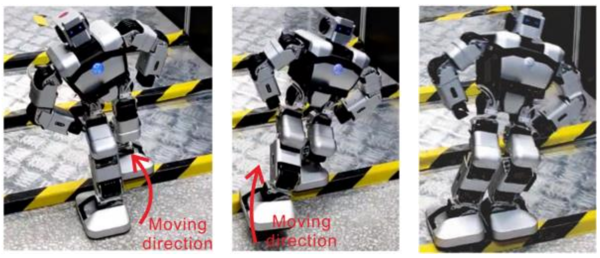
- *Task 1*: Any pose is allowed (e.g., walking or crawling);
- *Task 2*: At least 10 joints should be used and the whole movement should last for 1–2 minutes;
- *Task 3*: A target object with a random color is assigned and its exact position is unknown;
- *Task 4*: Side-walking, door pushing, and threshold crossing are required.

Overall Performance: Additional marks will be given to solutions which involve the full autonomous pipeline, as well as to particularly innovative solutions (for example, solutions in which the robot refers to external sensors or artificial markers to self-calibrate its position).

B. Sample Project Results

Several videos for the robot challenge can be found at https://youtube.com/playlist?list=PLZRqmAirNcTLVUArYihvCmIKd913Uwpyz.

Task 1: There are two main challenges in this task: 1) the servo motors have relatively low accuracy, and so the robot cannot walk straight without calibration, 2) the robot should adjust its pose to maintain balance while climbing stairs. To address the first issue, one team used the robot's gyroscope to calibrate the robot's orientation, and another team controlled the robot to actively make contact with the stairs to make its feet align. To realize better balance, one team controlled the robot to climb the stairs backwards (see Fig. 3), and another team controlled the robot to crawl down the slope (see Fig. 4).



(a) (b) (c)

Fig. 3. Snapshots of *Task 1*, where the robot moves backwards to climb a set of stairs: (a) lift the left leg, (b) lift the right leg, (c) stay on the step.

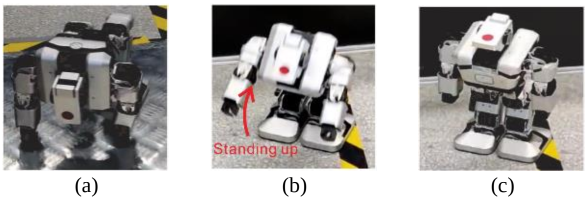


Fig. 4. Snapshots of *Task 1*, where the robot crawls down the slope: (a) crawling, (b) sit to stand, (c) stand up.

Task 2: A dance video is played before the formal task. Then, the main challenge in the task is to analyze the dance video and call the built-in functions to control the robot to reproduce the dance movements. To further improve fluency, one team fine-tuned the time step between two actions. Several snapshots of *Task 2* are shown in Fig. 5. Another team also considered the automatic transition from *Task 1* to *Task 2*, where the robot used the IR sensor and the magnetic sensor to navigate itself to the dance zone.

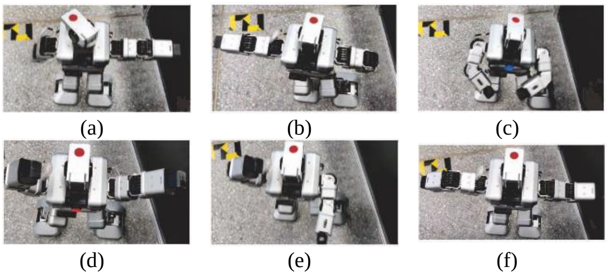


Fig. 5. Snapshots of *Task 2*: (a)–(f) dance actions.

Task 3: The formal task differs from the milestone in that there are a total of three objects with different colors, and the positions of each object are unknown. Additionally, their positions will also be randomly re-arranged before each team starts the task. The whole task is comprised of a series of steps: 1) detect the target object, 2) grasp the object, 3) detect the goal position, 4) move to the goal position, and 5) place the object onto the goal position. While all the initial positions are unknown, the goal positions are fixed, and an object with a specific color should be precisely placed onto a corresponding goal position. Unstable grasping (i.e., dropping) or incorrect placement (e.g., not on the corresponding goal position) will result in a deduction in marks. There are several challenges associated with this task: 1) the robot's vision should always be used in a control loop to detect the object, measure distance, and monitor the robot's status, 2) the robot's motion towards the object should be properly planned to generate a feasible grasping pose and to avoid collision with other objects, 3) the goal position is too large to be determined using vision, that is, it is outside the Field-of-View (FOV) of the robot.

One team used the visual servoing method to grasp the object. This method involved programming the robot to walk a short distance, scan the environment, modify its trajectory, and then repeat until it is close to the object. They also controlled the robot to maintain a squatting pose to ensure that the target object was always visible within the robot's FOV during grasping. Another team programmed different goal positions into the robot in advance, such that the robot could quickly move there in an open-loop manner once it successfully grasped the object. Several snapshots of the task are shown in Fig. 6.

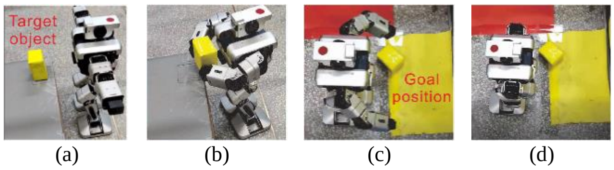


Fig. 6. Snapshots of *Task 3*: (a) initial pose, (b) grasp object, (c) place it onto the desired region, (d) final pose.

Task 4: Besides walking through a narrow aisle (i.e., Milestone 3), the robot needs to be able to open a door and step over the threshold, which is the primary challenge of Task 4. To achieve the task, it is important to keep the robot in the middle of the door, minimizing the chance of collision with the gate posts. It is also important to control the whole body of the robot to push the door while stepping over the threshold at the same time. One team used the feedback control method to keep the robot in the middle of the door and also used the whole-body planning scheme to generate the striding action. Several snapshots of the task are shown in Fig. 7.

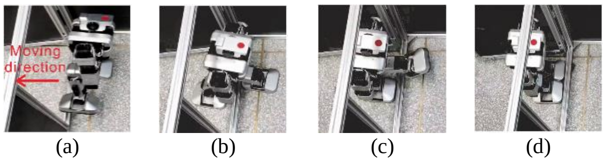


Fig. 7. Snapshots of *Task 4*: (a) initial pose, (b) lift up the left leg, (c) step over the threshold, (d) final pose.

IV. Results

The constructed challenge map is shown in Fig. 8. The *Intelligent Robots* graduate course has been conducted for three years, from 2020 to 2022. This section analyzes the efficacy of the course based on assessment results and student feedback.

Fig. 8. The constructed terrestrial map.

A. *Arrangement of Course Project*

At the beginning of the course project, several tutorials are provided to train the students in programming, including teaching them how to call the robot's built-in functions and calibrate the robot's servo motors. These tutorials will help students by providing them with the essential skills that are necessary to carry out the course project.

The robot challenge is defined and discussed at the very beginning of the course project, such that the students stay self-motivated as they progress through the project milestones. The lab sessions are given twice every week, with a one-day gap between two sessions (e.g., Wednesday and Friday). At the beginning of every first session of the week, a different milestone is introduced. By the end of the second session of the week, the students' progress is assessed to check if they have achieved that week's milestone. Such an arrangement gives the students ample spare time to work on the course project and achieve each milestone within a week.

The setting of milestones is useful to push the students to set up their study goals sequentially, build confidence, and find particular interests within the project. By having weekly milestones and practical sessions, students can gauge their performance in each aspect of the project, receive feedback, and see how they can apply their learned knowledge to solve practical problems. Thus, as the students progress through the project they'll feel a great sense of achievement with every milestone achieved and be more likely to remain motivated. It has been shown in prior years of the *Intelligent Robots* course that such a teaching structure enables all the students to accomplish their designs and experiments quickly and efficiently. Similar teaching structures can also be used in other course projects. In general, the students are encouraged to think critically and divide a large, complex system into several subsystems, each with its own individual experiments and specific goals. This enables them to deepen their understanding of core concepts and to form connections between theoretical principles and real-world applications.

B. Motivation during Course Project

The proposed course project is designed to motivate students to think creatively and come up with innovative ideas and solutions. The students are not expected to receive information from the teacher passively. Instead, they are encouraged to pose questions to the teacher during classes and to get deeply involved in lab sessions, where students and teachers can connect and interact more closely.

Several novel solutions developed by the students and implemented in the robot are summarized as follows.

- As the servo motors have low resolution, many laborious works are required to calibrate their model. To improve the accuracy of the robot's motion, the AprilTag [32] was posted on the challenge map and set as a landmark (with an exactly calibrated location), and the vision-based control scheme was used to compensate for the uncertainties in the robot's position by referring to the landmark;
- A simulation environment has been developed, where the students trained a reinforcement learning model [33] and then transferred it to the actual robot based on techniques from Sim2Real [34], such that the robot has the ability to carry out intelligent planning;
- A target object with a random color is assigned and its exact position is unknown; Deep detection networks [35] were constructed and employed for the detection of the target object in *Task 3*. This guaranteed a high accuracy in identifying the target object even when subjected to changes in the environment (e.g., illumination, object locations, etc.);
- Additional hardware (or end effectors) can be fabricated with the 3D printer and added to the robot to customize its body.

The improvements developed by the students are well supported by the facilities in the lab (see Fig. 9). The developed experimental platform can also be used for research on multi-agent systems [36], heterogeneous robots [37], and neuromorphic computing [38]. For example, multiple robots (e.g., wheeled robots, quadruped robots, and humanoid robots) carry neuromorphic chips and form a desired pattern for collaboration works [39]. This will provide an opportunity for students to gain experience applying the latest research findings in their practical projects.

(a) (b) (c)

Fig. 9. Facilities in the lab: (a) 3D printer, (b) server, (c) simulation environment.

C. Student Performance

The student's grades in the Intelligent Robots course over the past three years are summarized in Fig. 10, which demonstrates that the module setting and the overall assessment are reasonable.

Specifically, the results of the course project in 2020 are shown in Table III. In 2020, there were a total of eight teams, and three of them had conducted a second trial. For *Task 1*, most of the teams completed the task within 5 minutes, with limited human intervention (i.e., 1–3 human interventions). For *Task 2*, all the teams completed the task within 3 minutes. Some of them also designed several interesting poses, such as standing on one foot, playing basketball, performing a handstand, and more. For *Task 3*, the best team completed the entire pick up-transport-place task within 5 minutes. One team failed because the robot could not stably grasp the object. All of the teams required several instances of human assistance to calibrate the robot's position. For *Task 4*, most of the teams completed the task within 5 minutes, with few collisions with the wall and minimal human assistance.

TABLE III. PROJECT RESULTS IN THE YEAR 2020

Team no.	Trials	Task 1			Task 2		Task 3			Task 4		
		Stairs	Slope	HA[1]	Free motion	Features	Pick	Place	HA	Walking	Collision	HA
1	1	2'35"	1'40"	0	1'53"	Standing on one foot	5'14"	1'57"	3	9'30"	2	1
2	1	4'31"	1'08"	3	2'14"		1'18"	3'36"	2	5'28"	2	1
3	1	1'28"	1'26"	0	1'35"		1'08"	1'50"	1	3'37"	2	0
4	2	1'09"	0'47"	2	0'59"	Splits		Fail		2'20"	0	1
5	2	3'06"	0'41"	3	1'00"	Playing basketball	0'50"	1'51"	5	2'55"	2	1
6	1	1'49"	1'30"	0	1'09"		1'46"	2'28"	2	4'40"	2	2
7	1	1'51"	0'56"	1	1'19"	Handstand, One-hand push-ups	1'16"	1'51"	1	3'53"	2	0
8	2	1'36"	1'24"	0	1'12"		1'17"	1'49"	2	4'22"	1	0

[1] HA: The number of human assistance applied to.

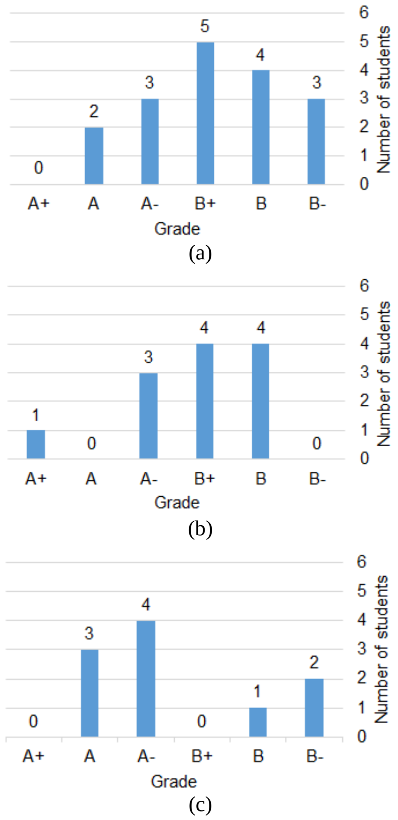


Fig. 10. Course grades in the past three years, where the horizontal axis denotes the grade and the vertical axis represents the corresponding number of students: (a) Year 2020 (17 students), (b) Year 2021 (12 students), (c) Year 2022 (10 students).

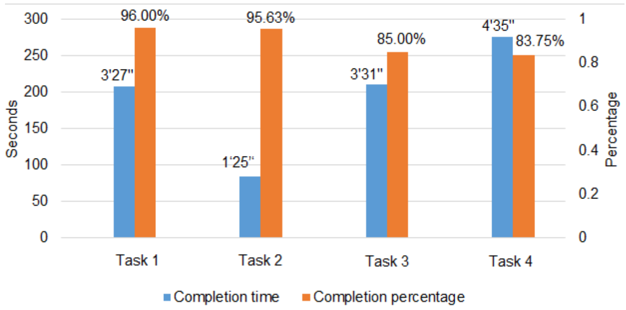


Fig. 11. The average completion time and percentage for each task.

The average time and the average completion percentage are shown in Fig. 11, where the completion percentage is defined as the score obtained by the team divided by the total score. Specifically, the completion times for *Task 1*, *2*, *3*, *4* are *3'27"*, *1'25"*, *3'31"*, and *4'35"* respectively. Hence, the total time limit of 30 minutes was shown to be reasonable for the robot challenge. In addition, the completion percentage of all of the tasks was above 80%, so the task content of the challenge was also reasonable.

D. Student Survey

One team said: "...In summary, this course includes the research and experiment on the locomotion and visual perception of the humanoid robot, which helps us master the knowledge of the robot and also gain some experience about hardware and software algorithm...".

Another team said: "...We obtained much achievement, and we were able to apply the learned knowledge to the practice. By the end, we would like to share a photo taken by the robot to appreciate the efforts spent on the course...".

V. DISCUSSION

An open loop control scheme cannot ensure stability and performance in robotics, which is also true in teaching. The proposed course project with its milestones allows the teacher to have timely and explicit feedback on the progress of their students. This provides the teacher with an idea of how well the students are understanding the taught concepts, and where students are having difficulties. As such, this presents the teacher with an opportunity to adjust the teaching plan to adapt to the students' progress. It is important for robotics courses that require strong, multidisciplinary background knowledge.

In general, the *Intelligent Robots* course is an interdisciplinary course open to all engineering schools, where students have diverse backgrounds and interests (e.g., their majors can vary from ocean engineering and computer science to microelectronics). Diverse criteria are established in the course project to help students find and develop their own motivations and interests within the project. They will also be able to combine the robotic system design project with their own academic backgrounds. Communication and interaction beyond the classroom is also offered throughout the project, allowing teachers to become more familiar with the students' ideas and personalities. Moreover, teachers can build reasonable and diverse grading criteria to ensure all students enjoy the course project, while also understanding the significance and value of robotic technologies in tackling practical problems.

VI. CONCLUSION

This paper systematically reports on the design of the course project for the *Intelligent Robots* graduate course. The unique feature of the project is the use of a series of milestones, aimed at helping the students become familiar with the robotic system and proficient in the essential modules required for the final challenge. Such a robot challenge effectively balances learned theoretical knowledge and practical engineering skills. In other words, it helps students understand robotics and gives them the knowledge and power to pursue their true passions. Meanwhile, the challenge also provides the teacher with an opportunity to combine their teaching with the latest robotics research and to gain a sense of accomplishment as they help students realize their potential. In summary, this robotics course can be used as a highly collaborative and interdisciplinary teaching platform that inspires students to realize their potential and motivates them to explore the scientific world.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Xiang Li initiated the project and designs the milestones; Yana Shu involved in the teaching and collected the data; Xiangjie Yan carried out the data analysis. All the authors contributed to the paper writing and they also had approved the final version.

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