Programming Autonomous Robots
COSC2781 (PG) | COSC2814 (UG) | Semester 1 2024
Assignment | Robotics Project

Assessment Type	Group Assessment. Clarifications/updates may be made via announcements/relevant discussion forums.
Project Selection	No later than, Tuesday Workshop in Week 9
Progress Update	During Workshops in Week 12
Demonstration	During Week 15 (by appointment)
Report Due Date	23.59pm, Sunday June 23 2023 (Week 15)
Weight	50% of the final course mark
Submission	Online via Canvas. Submission instructions are provided on Canvas.
Learning Outcomes	This assignment contributes to CLOs: 1 - 5

1 Overview

In the project you will research how to solve a problem or algorithm in autonomous robotics, that can be solved or demonstrated on one of the AI Innovation Lab or VXLab robot platforms, such as the ROSBot Pro 2.0, Softbank Nao V6, Panther, or Cobot UR5e Arm. You will implement at least one solution to this problem, and conduct a live demonstration of the effectiveness of your implementation.

In this project you will show in-depth capabilities in at least one of the core topics about autonomous robotics that are discussed in the coursework. The coursework provides you with a understanding of the various algorithms and techniques used at different levels of abstraction for software for autonomous robots. In the project, you will need to build upon this knowledge, by diving into deeply into one or more of these topics. You will need to conduct research into state-of-the-art approaches, and adapt these methods for your project. You will be assessed on your research, the implementation of your project, and the analysis and evaluation of your final capabilities of your work. You will present your final work by a live demonstration, along with a report detailing your research, analysis and evaluation.

This specification provides suggested projects that you may choose from. You may also negotiate a project with the course co-ordinator. All projects need to be chosen by no later than the Tuesday Workshop in Week 9.

1.1 Group Work

You are required to work groups of no more than 4 students. This is because of:

1. The limited availability of the physical robots
2. To minimise wear-and-tear and prevent over-use of the robots
3. Safety, in ensuring appropriate monitoring of the robots during autonomous operation

Note that unlike in the first assessment, in the project there are grades for group work. In your report you will need to record the individual contributions of each group member. In the event of group-work issues, individual grades may be allocated. Therefore, we advise that your group uses suitable group work tools, such as MS Teams, Task Planner/Trello, and a Git Repository. We also recommend that you work closely together on the assignment, developing the code together, so that each member of the team has a good understanding of how all of the parts of your final software system work.

1.2 Learning Outcomes

This assessment relates to the following course learning outcomes:

- **CLO1** Discuss and Critically Analyse and a variety of software architectures and algorithms for solving typical problems in the context of autonomous robot systems; Discuss and Critically Analyse the strengths and limitations of these architectures and algorithms.
- **CLO2** Discuss and Critically Analyse the challenges of designing and developing software for a variety of robot systems of different complexities, including noise, uncertainty, and computational power.
- **CLO3** Research, Discuss, and Use new and novel algorithms for solving problems with autonomous robot systems.
- **CLO4** Use pre-existing robot software to solve common problems on simulated and real-world robots; Develop and Implemented new algorithms and software for solving problems on simulated and real-world robots; Integrate this software in the ROS framework.
- **CLO5** Develop skills for further self-directed learning in the general context of software, algorithms, and architectures for autonomous robot systems; Adapt experience and knowledge to and from other computer sciences contexts such as artificial intelligence, machine learning, and software design.

2 Assessment Details

The purpose of the project is to enable a robot to autonomously solve a problem. Each project is scoped differently and the requirements of each project are specified in Section 3. All of the projects share the features described below, which you will be required to address or conduct through the course of your project.

2.1 Research

You will need to research and investigate current state-of-the-art algorithms and techniques related to your project. You may need to implement and adapt these existing techniques to your particular needs. Alternately, you may need to devise your own solution to the challenge of the project and compare your work to the existing work in your analysis and evaluation.

In your report, you must record the findings of your research. You must fully cite any references that you have used within your research, implementation, analysis and evaluation.

2.2 Implementation

You must complete some **original implementation** of autonomous software for the robot as part of your project. That is, your work cannot exist entirely of off-the-shelf software, such as existing ROS packages. The scope of this original implementation is defined within the project definition and your negotiations with the course coordinator. This original implementation may:

- Significantly modify or adapt existing techniques and algorithms for practical use on a robot
- Be a novel implementation of your own creation

Your report should describe how and why your implementation is original. This description should refer to (and compare against) your research into relevant state-of-the-art work related to your project.

2.3 Robot Software Architecture

In completing your original implementation you must consider and choose an appropriate robot software architecture. You will need to describe and justify your choice of robot software architecture in your report, and relate your choice to existing literature.

2.4 Autonomy

Your software should be fully autonomous, unless the scope of your project says otherwise.

2.5 Analysis & Evaluation

You must conduct an experimental evaluation of your autonomous software at completing the challenges of your particular project. This evaluation should:

- Highlight the strengths and capabilities of your work.
- Capture any limitations or weakness of your work.
- Compare your work to relevant work in literature

2.6 Report

You must write a report to accompany your final demonstration. Details are provided in Section 5.

3 Projects

Below are suggested projects. The scope of each project is briefly described. You will need to further discuss and negotiate the scope of your project work with the course coordinator, and agree on the final deliverable. The scope may, by negotiation, change throughout the project. The agreed project scope, and any changes, must be documented in your final report.

3.1 RoboCup Soccer

This project is to enable the Softbank Nao V6 robot's to compete in the RoboCup SPL 2024 competition. See the SPL Rules 2024[1] for and the Technical Challenges 2024[2] details. The competition includes both the soccer competition proper, and technical challenges. The rules define the scope of deliverable and requirements for the completion of the project. In negotiation with the course co-ordinator, this project will select a component of the rules to complete for the project. The following aspects are available for the the scope of the project:

- Whistle Detection during Gameplay.
- Visual Referee detection during Gameplay.
- Shared Autonomy technical challenge.

For this project you will need to use the existing RedBackBots RoboCup codebase. This codebase provides a baseline of elements required to enable this challenge. However, you will need to complete tasks such as:

- Walking and Navigation behaviours.
- Visual Object recognition.
- Audio signal processing and recognition of game sounds.
- Accurate localisation with robot interference.
- Locomotion behaviours to intercept a moving ball.
- Decision behaviours to kick a ball between stationary objects.

You must demonstrate your final code on the Nao robot under competition conditions.

3.2 Augmented Reality for Explainable AI with the ROSBot Pro 2.0

This project is to visual the actions and state of a robot, such as the ROSBot Pro 2.0 or Softbank Nao V6 in Augmented Reality using the Microsoft HoloLens or Meta Quest. This project ties into an research in robotics (and AI in general), known as Explainable AI (XAI). XAI is about trying to communicate and explain the action of an autonomous system to humans in an interpretable and understandable manner. A key challenge to this project will be integrating information from the reference frame of the robot into the HoloLens or Quest. A second key challenge is studying how people unfamiliar with autonomous robots respond to your XAI system.

For this project you will extend an existing codebase that has been developed in previous semesters. The scope of this project is to:

1. Determine the state and action information of the ROSBot Pro 2.0 to visualise

[1] `https://spl.robocup.org/downloads/#2024`
[2] `https://spl.robocup.org/wp-content/uploads/SPL-Challenges-2024.pdf`

2. Choose a suitable task for the ROSBot Pro 2.0 to complete that for which visualising this task in AR would improve the explainability of the robot's actions to human observers.
3. Setup the AR software infrastructure libraries for the AI Innovation Lab.
4. Integrate ROS2 software and the HoloLens/Quest software for communication between the platforms.
5. Align the localisation of the ROSBot Pro 2.0 and the HoloLens/Quest position in a room.
6. Render state and action information of the ROSBot Pro 2.0 in AR.
7. Write minimal ROSBot Pro 2.0 behaviours of the chosen task to clearly demonstrate the effectiveness of AR towards Explainable AI in autonomous robotics.
8. Demonstrate your system with the ROSBot Pro 2.0 and HoloLens/Quest.

3.3 Deep Reinforcement Learning Control of a Bio-Inspired Robot Wing

This project is to build upon existing experiments that use Deep Reinforcement Learning algorithms that learn how to control a Bio-Inspired robot wing in real-world wind tunnel experiments. The bio-inspired wing is a 3D printed replica of the wing+tail of a Kestral bird, including features. In this project, you will work with an existing codebase for conducting online Deep Reinforcement Learning, to investigate one method for controlling the bio-inspired wing. The key to this project will be implement an algorithm and conducting real-world experiments in wind-tunnels on the Bundoora campus with the School of Aerospace and Aviation Engineering.

You may choose to implement:

- A classic controller, such as a PID controller and tune the parameters of controller using AI techniques.
- An alternate Deep Reinforcement Learning method to the previously tested algorithms (SAC and TD3).
- Parameter search optimisation of the previously tested algorithms (SAC and TD3).

The scope of this project is to:

1. Build upon an existing codebase.
2. Choose a Deep Reinforcement Learning algorithm, or control algorithm
3. Implement the chosen algorithm within the existing codebase.
4. Conduct real-world experiments to evaluate your chosen algorithm in the Bundoora wind-tunnel(s). This will include completing inductions to work with the equipment.
5. Coordinate with staff and PhD students in Aerospace and Aviation Engineering, and present your results to the RUASRT research team.
6. Demonstrate your final trained controller on the bio-inspired wing.

3.4 Outdoor Navigation with Panther to Simulate Macadamia Farm Navigation

This project is to enable the Panther robot to complete outdoor navigation and mapping task in an environment similar to macadamia farms. An representative environment of an Orchid for a macadamia farm is a field with multiple rows of trees. This projects combined challenges in outdoor navigation, using both laser-based mapping and GPS, potentially object detection, and simple planning. The key challenge is to create an full autonomous system, and will require careful consideration of the Robot Software Architecture, and co-ordination of the different software elements.

For this project you will need to:

1. Devise an outdoor navigation task, including a suitable representation of a macadamia environment, suitable representation of rows of trees, starting location of the robot, and location of return of the robot.
2. Configure the software stack of the Panther robot.
3. Determine the most appropriate Robot Software Architecture.
4. Choose and implement navigation and mapping algorithm(s).
5. Choose and implement object recognition algorithm(s) as necessary.
6. Choose and implement a suitable planning and coordination algorithm.
7. Demonstrate your software architecture and functionality on the Panther robot.

You may need to leverage a simulation environment on TheConstruct to help with experiment and testing, as outdoor testing of the Panther will be limited, and indoor testing will be within confined spaces.

3.5 Pick-and-Place tasks with Cobot UR5e Arm

This project is to enable the Cobort UR5e Arm located in the VXLab to complete a pick-up and placement tasks in a fixed environment. This projects combined challenges of object visual recognition, manipulation, and task-planning. The task could be a pick-and-place task such as block-stacking, or item bin sorting. However, the type of task you choose will need to include a task-planning component. The key challenge is to create an full autonomous system, from low-level control to high-level task planning, and will require careful consideration of the Robot Software Architecture.

For this project you will need to:

1. Devise an appropriate pick-and-place task, that includes a task-planning component.
2. Configure the software stack of the Cobot UR5e arm.
3. Determine the most appropriate Robot Software Architecture.
4. Choose and implement appropriate vision object recognition algorithm(s).
5. Choose and implement appropriate manipulation algorithm(s).
6. Choose and implement a suitable task-planning algorithm.
7. Demonstrate your software on the Cobot UR5e arm.

You will need to coordinate with the VXLab staff in working on this project. You will also need to complete the VXLab induction[3] to have access to the VXLab and work with the robot.

3.6 ROSBot Pro 2.0 Swarm Behaviours in Simulation and Practice

This project is to simulate multiple robots exhibiting a swarm behaviour within a pre-defined space. You will use multiple ROSBot Pro 2.0 robots to simulate this fleet. This could simulate:

- Multiple robots following a collaborated navigation, such as a "follow-the-leader".
- Multiple robots playing a game of tag, where one robot must be located by a group of other robots.

To effectively complete the tasks, multiple robots will need to coordinate their actions and avoid collisions.

As part of this project you will first develop your software in simulation. You will need to setup a simulated environment and show the swarm behaviour in simulation. You will then transition your software to the real ROSBot Pro 2.0 to show the coordination on real robots.

The scope of this project is to:

1. Define a suitable setup for your simulated swarm task.
2. Implement software to coordinate the actions of multiple robots to complete the swarm tasks while avoiding collisions.
3. Demonstrate the coordinated behaviours in simulation.
4. Port your developed software for use on the real ROSBot Pro 2.0 robots.
5. Demonstrate the coordinated swarn behaviour on the real ROSBot Pro 2.0 robots.

3.7 Person Recognition and Tracking

This project is to enable the Panther to recognise and respond to the presence of 4 specific people that the robot has been trained to recognise, and then follow one of the recognised people as they move. The recognition and tracking task will be completed within an indoor environment, but is not confined to the space of the AI Innovation Lab. That is, could be conducted within building environments at RMIT, such as Building 14 spaces, and classroom spaces.

The scope of this project is to:

1. Create original software for to enable the Panther to recognise at least 4 unique individuals.
2. Determine appropriate sensors and data by which to train and recognise the individuals.
3. Write behaviours for the Panther to track and follow the individual that it has recognised in an indoor environment.
4. Determine appropriate sensors and data by which to follow a person.
5. Research potential software features of the ZED camera to complete the above scope.
6. Demonstrate your solution on Panther.

Person recognition could be achieved by:

- Facial recognition
- Recognising body shape and size
- Voice recognition

In this project you will need to research methods for efficient person recognition on low-powered robot systems. You will need to implement your own original software to facilitate the person recognition.

[3] `https://forms.office.com/r/YMcPnDuCQv`

You will need to evaluate the robot's person recognition. For the live demonstrations, at a minimum you should demonstrate the training process and a live demonstration of successful recognition of multiple different people.

3.8 Human-Robot Interactions tasks for Tiago

This project is to complete a human-robot interaction task with the VXLab Tiago robot, leveraging the software stack of Tiago. At present the Tiago robot in the VXLab uses ROS Noetic, thus as part of this project you will need to learn the differences between ROS2 and ROS1. Your human-robot interaction task will need to include a human verbally interacting with Tiago, issuing command to Tiago, observing Tiago completing the command, and providing feedback to Tiago on its operating in real-time. For example, a command may be *"Go to the kitchen and retrieve the red plate"*. You will also need to choose a suitable Robot Software Architecture in which to coordinate the software for completing the issues command(s).

The scope of this project is to:

1. Setup a Noetic environment of Tiago
2. Devise a suitable Human-Robot Interaction task to use existing Tiago software and functionality. This task must feature elements of:
    - Issuing a command to Tiago in the form of spoken commands. (The commands could be manually converted to text input provided the text input suitably simulated verbal commands.)
    - Tiago operating to complete the command.
    - Providing feedback to Tiago of it's execution.
    - Tiago responding to this feedback.
3. Determine the most appropriate Robot Software Architecture.
4. Choose and implement a suitable algorithms for enabling Tiago to complete the given command(s).
5. Demonstrate your solution on Tiago.

You will need to coordinate with the VXLab staff in working on this project. You will also need to complete the VXLab induction[4] to have access to the VXLab and work with the robot.

3.9 Object location and tracking with UAVs Quad-copter

This project is to enable a UAV (Unmanned Arieal Vehicle) Quad-copter to complete autonomous tasks features in the IMAV 2023 drone flying competition, for either the indoor or outdoor challenge. The challenges are based around search, navigation and visual location tasks. That is, the drone will need to fly about an environment, and locate various points of interests using on-board and/or off-board processing. The project will initially take place in simulation, using the TheConstruct, before being tested on a real UAV Quad-copter. This will also require interfacing between ROS2 and the ArduPilot software that is used to control the UAV Quad-copter.

As part of this project you will be working in conjunction with RUASRT, the research group centred in the Aerospace and Aviation Discipline who will be mainly responsible for the designing and building of the hardware to compete in the indoor and outdoor competitions. The use of read UAV Quad-copter will be conducted through RUSART on the RMIT Bundoora campus.

For this project you will need to:

1. Devise a simulation of the challenge on TheConstruct (for either the indoor or outdoor competition).
2. Developing a suitable ArduPilot and ROS interface, using existing software packages.
3. Develop suitable navigation behaviours.
4. Develop suitable robot visual algorithms to identify points of interest.
5. Port and deploy the developed software on a real UAV Quad-copter.
6. Demonstrate your solution on a real UAV Quad-copter.

You may be able to utilise an exsiting codebase for this work, that was previously developed in ROSv1. However, you will need to revise this to work in ROS2 and the latest features of ArduPilot.

3.10 Negotiated Project

If you have your own ideas for a project in this course, then you may **propose and negotiate** a project with the course coordinator. This proposal and negotiation will need to clearly define the scope of the project and the expected deliverables for the demonstrations.

You should begin this discussion as soon as possible. The scope of the negotiated project must be finalised by no later than the Tuesday Workshop in Week 9.

[4] `https://forms.office.com/r/YMcPnDuCQv`

4 Demonstrations

You will conduct 2 demonstrations of your work throughout the course of the project. The first demonstration will be a progress update during Week 12 classes. The second will be the final demonstration of your project work, held by appointment during Week 15.

4.1 Week 12 Progress Demonstrations

During Workshops in Week 12 you will hold a **progress update** on the work your group has completed up to Week 12. It should be noted that this progress update is over at the *half-way point* of the project.

Your progress update should demonstrate and discuss:

- That the project is on-track according to the project scope
- A minimally viable solution to the project
- A preliminary evaluation for the minimally viable solution

Your progress update should discuss the timeline of your completion of the project. This should include:

- A feasible plan for the completion of the project
- Improvement of the project beyond a minimum viable solution
- Proposed evaluation of the work
- Intended deliverables to be demonstrated during the final demonstration

As part of this update you will submit on Canvas:

- A complete copy of your current software
- Your plan for completion of the project
- A record of evidence of your individual work

4.2 Final Demonstrations

! Note that this demonstration will happen *before* you make your final submission.

The final assessment of your project will be conducted via a live demonstration in During Week 15 (by appointment). The demonstration will happen *before* you make your final submission so that you have time *after* the demonstration to complete your final report. Your final demonstration should:

- Show that the project meets the scoped requirements.
- Distinguish your work from existing literature, software and dependencies.
- Discuss the results and evaluation of your work. You should aim to demonstrate a subset of these results.
- Be well-prepared with minimal time lost for setup, configuration, and restarts. You have supplement your demonstration by additional material or recordings.

5 Report

You are required to write a report that:

- Describes the Methodology of your development and work.
- Analyses the *significance* and *relevance* of the project. This positions the work within autonomous robotics literature, presents why the work is important, and presents the benefit of the work for autonomous robotics.
- Evaluates your methodology. This presents a critical quantitative or qualitative evaluation of the algorithms and techniques. This includes identifying strength and weakness of the work.
- Includes a full list of references.

You should aim to structure this report similar to a research paper. You will also have read a number of papers in the research you have conducted for your project. Therefore, you should use these papers as examples for the way in which to structure your final report. Your report should contain sections such as:

- Introduction
- Related Work
- Methodology

- Results (if relevant)
- Evaluation & Discussion (of both your work and literature)
- Conclusions

You should including data tables and figures that support the written text. Figures and tables should be formatted to be fully legible at default 100% PDF zoom level, and legible when printed in black-and-white.

The format of your report should be:

- No more than 10 pages, including figures, tables and references.
- Single Column
- No less than 1.5cm margins
- No less than 11pt font.

6 Submission

Follow the instructions **on Canvas** to complete your submission for the Assignment.

Assessment declaration: When you submit work electronically, you agree to the assessment declaration.

6.1 Help during Weeks 13-15

After Week 12, there are no formally scheduled classes. Please note that limited help will be available during this time frame, and any in-person help will need to be conducted by a pre-arranged appointment. Therefore, you should ensure that you discuss all necessary and important issues/question during your progress update.

6.2 Late Submissions & Extensions

A penalty of 10% per day is applied to late submissions up to 5 business days, after which you will lose ALL the assignment marks. Extensions will be given only in exceptional cases; refer to Special Consideration process.

7 Marking guidelines

The marks are divided as follows:

- Progress Update
  - Demonstration: 10/50
- Final Demonstration
  - Demonstration of Implementation: 10/50
  - Demonstration of Evaluation and Results: 5/50
  - Individual Contribution: 5/50
- Report (40%)
  - Description of Methodology: 5/50
  - Analysis and Evaluation: 10/50
  - Writing and Referencing style: 5/50

The detailed breakdown of this marking guidelines is provided on the rubric linked on Canvas.

8 Academic integrity and plagiarism (standard warning)

Academic integrity is about the honest presentation of your academic work. It means acknowledging the work of others while developing your own insights, knowledge and ideas. You should take extreme care that you have:

- Acknowledged words, data, diagrams, models, frameworks and/or ideas of others you have quoted (i.e. directly copied), summarised, paraphrased, discussed or mentioned in your assessment through the appropriate referencing methods
- Provided a reference list of the publication details so your reader can locate the source if necessary. This includes material taken from Internet sites. If you do not acknowledge the sources of your material, you may be accused of plagiarism because you have passed off the work and ideas of another person without appropriate referencing, as if they were your own.

RMIT University treats plagiarism as a very serious offence constituting misconduct. Plagiarism covers a variety of inappropriate behaviours, including:

- Failure to properly document a source
- Copyright material from the internet or databases
- Collusion between students

For further information on our policies and procedures, please refer to the RMIT Academic Integrity Website.

The penalty for plagiarised assignments include zero marks for that assignment, or failure for this course. Please keep in mind that RMIT University uses plagiarism detection software.

8.1 Use of Artificial Intelligence (AI) Tools in Assessment Tools in this assessment

The majority of your work in this assessment should be your own work, and not plagiarised from other sources, or sourced from the use of Artificial Intelligence (AI) tools. Therefore, **the use AI tools are restricted in certain ways for this assessment task**.

In this assessment task, you may use AI tools to support you in developing and completing your work by generating ideas, planning, and/or drafting only. Any use of such tools must be acknowledged and referenced.

Work that is significantly produced by AI tools, or where AI tools are used to complete this assessment without attribution may result in an allegation of academic misconduct.