PRIFYSGOL ABERYSTWYTH UNIVERSITY

SEMESTER ONE 2025-2026

COMPUTER SCIENCE

CSM3620 : ROBOTIC APPLICATIONS

Time allowed: **2 HOURS**

Answer all **THREE** questions

All questions carry equal marks.

YOU MAY BRING THE FOLLOWING INTO THE EXAMINATION:
UP TO 3 SHEETS OF NOTES ON A4 PAPER (WHICH MAY BE DOUBLE-SIDED). THERE ARE NO ADDITIONAL RESTRICTIONS ON CONTENT OR FORMATTING OF THESE NOTES.
NO ELECTRONIC DEVICES.

CALCULATORS ARE PERMITTED (CASIO FX83 OR FX85 MODELS ONLY) Addendum: or CASIO FX991

STUDENTS MAY SUBMIT ANSWERS TO THIS PAPER IN EITHER WELSH OR ENGLISH

PHS 19/11/25

Once seated, students may complete the front cover of the answer book(s) and the attendance slip ONLY.

DO NOT TURN THE EXAMINATION QUESTION PAPER OVER UNTIL INSTRUCTED TO DO SO.

1. **This question examines the design of a robotic system for a specific application.**

Scientists are keen to learn more about an Emperor penguin colony living in the Antarctic. They have asked for a robot to be developed that can monitor the penguin population up-close, especially during the harsh winter months, 'living' along-side the penguins. Over winter, the temperatures can drop down to -80° C with blizzard winds up to 200km/h.

Emperor penguins are the largest of the various penguin species, with adults weighing up to 40 kg. They are flightless birds, but often described as flying in the water. Whilst on the ice they waddle or slide, but once in the water they can 'fly' at speeds of 10kph and dive to depths of 250m. They dive into the water from the edge of sea ice and jump back out of the water onto the ice.

Emperor penguins huddle together on the ice in tightly packed groups to protect themselves from the harsh environment, especially over the winter months. They can pack up to 10 penguins per square meter and continuously shuffle around so that each penguin takes a turn being on the outside of the huddle, whilst those from the outside warm back up on the inside. During a 49-hour blizzard, a huddle can easily move 200m. Colonies can consist of 1k–40k penguins.

Scientists would like to know more about the conditions inside a huddle. Specifically, scientists want to track the movement pattens, different types of communication between penguins and the temperatures at different depths within the huddle. To do this, the scientists have asked for multiple robot penguins to be produced to help track behaviours and motions. Emperor penguins are not typically territorial and therefore it is hoped they will accept robotic penguins into the colony.

a) Discuss the hardware considerations relevant to designing a robotic application for this scenario, with justification for the choices made. As part of your answer you should consider how the robot is adapted to its environment, its locomotion, power, morphology (structure and appearance) of the robot, and the hardware capabilities to perform the required task. [15 marks]

b) Discuss different behaviours the robot would need to generate within the scenario. This should consider the behaviours associated with the social interaction, and the task. [10 marks]

c) Discuss what ethical and safety considerations the designers should take into account, for a robot operating in this scenario. [8 marks]

2. This question examines the application of kinematics, and control theory.

a) Figure 1 shows the dimensions of the Turtlebot3 burger robot. If the robot is sent the linear velocity 0.225 m/s and the angular velocity 0.9375 rad/s, calculate the individual velocities for both the left (v_l) and right (v_r) wheels. Show all your working. [4 marks]

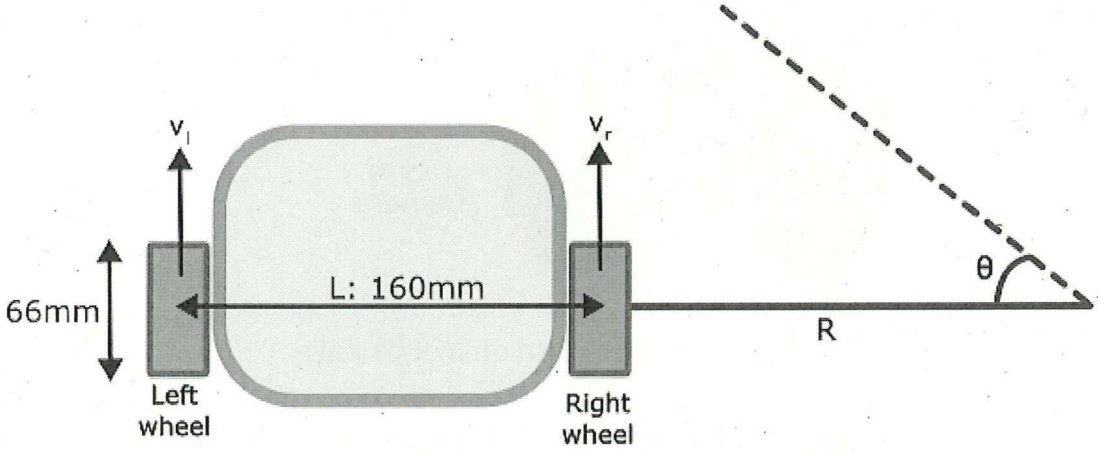


Figure 1: Turtlebot3 burger robot outline, not to scale

b) What is the radius of the turning circle for this set of velocities? [2 marks]

c) Explain how a PID controller can be used to maintain the calculated wheel velocities. As part of your answer you should consider limitations of PID controllers (overall and for each element) and how the different components contribute to the PID controller. [8 marks]

d) A mobile robot has a depth camera mounted on the chassis and an arm mounted just behind the camera, see Figure 2.

(i) How does the number of joints on the robot arm affect its reach space? [3 marks]

(ii) The location of an object in front of the robot can be perceived from the depth camera. With reference to inverse kinematics and the transform tree, describe how the robot can pick up the object. [4 marks]

(iii) Write out the forward kinematic chain for the robot arm, starting from the base link of the arm to the end effector, $T_W \rightarrow \mathit{eff}$. [2 marks]

(iv) A tree based planner is a commonly used approach for arm path planning in high-dimensional spaces. Describe how this samples the

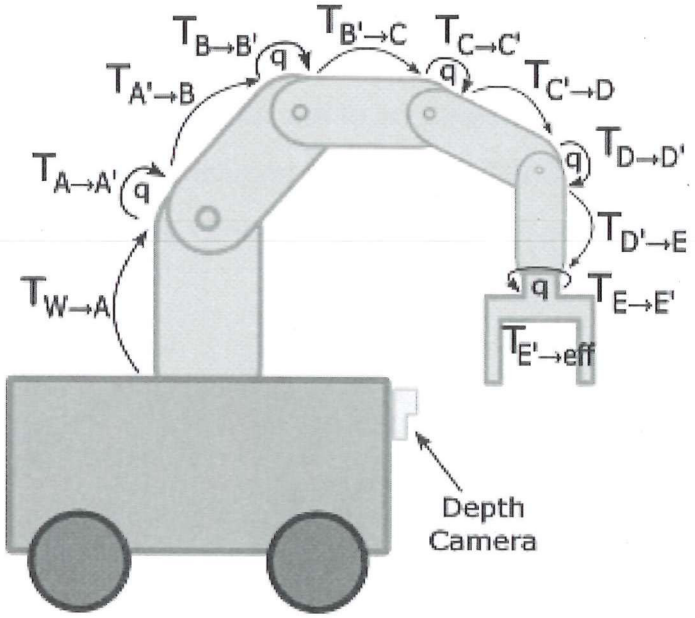


Figure 2: Robot arm on mobile base

space to find a valid path to a goal location. You should draw a diagram to support the explanation. [10 marks]

3. This question is about mapping and navigation, around the following scenario. You are working for a company building bespoke robotic solutions and have been assigned to a new project: a mining robot that needs to work in an open cast mine (a large pit with access ramps and specific extraction points, see Figure 3). The bottom of the pit is a mostly, but not totally, flat area while the ramps allow vehicles to drive down to the pit from the outside of the mine, and back up/out. Some ramps are steeper than others. Some areas of the mine can be muddy, depending on the weather.

The robot you are working on is a dumper truck, i.e. a vehicle that transports the rocks extracted from the mine to the outside of the mine, navigating from specific locations in the pit and along the ramps. The vehicles will behave differently whether they are loaded or not.

a) You first look at well established existing mapping and navigation methods, such as that provided by standard ROS 2 packages.

(i) Given that the open cast mine is definitely a three-dimensional world, how would you represent the world using a standard mapping technique? Make sure you discuss what aspects of the world you represent and how each is represented in the map. [6 marks]



Figure 3: An open cast mine

(ii) Explain how multiple aspects of the mine can be combined in the map for each location of the mine and should be combined in this particular example. Give numerical examples. [6 marks]

(iii) Describe how a standard planning algorithm (such as Wavefront) would use the data in the map from the previous part of the question to plan a path for the robot from a loading location to the top of the mine. You are not required to give the steps of a specific algorithm. Discuss the properties and potential limitations of the generated path. [6 marks]

(iv) The mine is a dynamic environment with temporary changes (other vehicles move) and more permanent changes (new parts are excavated, ramps are destroyed and built). Discuss how these two types of change can be dealt with in your map of the mine, how they can be combined with the base map and how the relevant data can be acquired. [5 marks]

b) For a second version of the navigation system, you look at potentially more efficient ways of representing the environment of the robots and how they could navigate using this alternative representation.

(i) For a robot to drive on a track, no map of the track is required. Briefly discuss this statement. Explain what information is needed about the track for mapping of the overall mine to be possible. [5 marks]

(ii) Given the distinct parts of the mine (pit, ramps), what alternative

representation of the mine overall could be used? Describe how each part of the mine would be represented and what information would be stored in the map. [5 marks]

END OF PAPER