ICSE Class 10 Robotics and Artificial Intelligence Specimen Paper 1

Written by the Future Topper subject team on the CISCE examination pattern. Not an official CISCE paper. Found a mistake? Write to contactfuturetopper@gmail.com

Maximum Marks: 100 | Time Allowed: Two hours | Reading Time: 15 minutes

Section A is compulsory. Attempt any four questions from Section B.

General Instructions

Write your answers on the separate answer paper provided. The first 15 minutes are for reading the paper, and you may not write during that time. Marks for each question, or part of a question, are shown in brackets. Section A carries 40 marks and must be attempted in full. Section B carries 60 marks, and you must answer any four of the six questions in it. Write all programs in Python, give meaningful names to your variables and add short comments where they help. Where a question gives a sketch for a single board computer written in Arduino C, you need only read it and explain what it does; you are not asked to write Arduino code. Where a question asks for a diagram, draw it yourself in pencil and label it; no printed figures are supplied, and every arrangement or set of data is described in words. Show the working for every calculation. This paper is the theory component of the subject and carries 100 marks. The internal assessment, also of 100 marks, is based on the Robotics, Artificial Intelligence and Python assignments completed in school during the year.

SECTION A (40 Marks)

Attempt all questions from this Section.

Question 1 [20]

Choose the correct answer for each of parts (i) to (xviii), and state whether each statement in parts (xix) and (xx) is True or False. Write only the answer; do not copy the question. Each part carries 1 mark.

(i) Unmanned aircraft that fly by themselves along a route planned in advance over farmland, using GPS to keep their position, and spray fertiliser on the crops below, are examples of:

(a) cobots (b) autonomous drones

(c) humanoid robots (d) industrial manipulators

(ii) The marks scored by 300 candidates in a test are to be grouped into the ranges 0 to 10, 10 to 20 and so on, to show how many candidates fall in each range. The most suitable chart for this is:

(a) a pie chart (b) a line graph (c) a scatter plot (d) a histogram

(iii) A driving gear with 12 teeth turns at 90 revolutions per minute and meshes with a driven gear of 36 teeth. The speed of the driven gear is:

(a) 270 rpm (b) 45 rpm (c) 30 rpm (d) 90 rpm

(iv) The type of gear pair normally used to transmit motion between two shafts whose axes meet at right angles is:

(a) a bevel gear pair (b) a spur gear pair

(c) a rack and pinion (d) an internal gear pair

(v) Which one of the following is an internal sensor of a robot?

(a) an ultrasonic sensor that measures the distance to a wall (b) a camera that recognises faces

(c) a rotary encoder that measures the angle of a joint (d) a bump switch on the front of a robot

(vi) Which one of the following actuators produces straight-line (linear) motion directly?

(a) a pneumatic cylinder (b) a DC motor

(c) a servo motor (d) a stepper motor

(vii) An air conditioner measures the room temperature and switches its compressor off when the room reaches the temperature set on the remote. This is an example of:

(a) open loop manual control (b) closed loop automatic control

(c) open loop automatic control (d) teleoperation

(viii) A robot arm that moves in one plane has a shoulder and an elbow, each of which is a revolute joint, and no other joint. The number of degrees of freedom of the arm is:

(a) 1 (b) 3 (c) 4 (d) 2

(ix) In the 4Ws problem canvas, the block that records the benefit the stakeholders will get once the problem is solved is:

(a) Who (b) What (c) Where (d) Why

(x) A line follower robot uses infrared sensors to follow a black line on a white floor. A sensor above the black line gives a different signal from one above the white floor because the black surface:

(a) absorbs most of the infrared light, so little is reflected back to the sensor (b) reflects more infrared light than the white floor

(c) gives out infrared light of its own (d) blocks the sound waves sent by the sensor

(xi) A robotic lawn mower in a park meets a bicycle left on the grass, decides by itself to steer around it and then carries on mowing. Such a system is best described as:

(a) manual (b) automated but not autonomous

(c) autonomous (d) remote controlled

(xii) Among the steps of machine learning, the step that comes immediately after collecting the data is:

(a) testing the model (b) preparing (cleaning) the data

(c) making predictions on new data (d) deploying the model

(xiii) An employee secretly changes the billing software of a company so that one rupee from every customer's bill goes into his own bank account. This is an example of:

(a) software piracy (b) computer fraud

(c) degradation of work (d) a disputed product right

(xiv) Copying a licensed design program from the school computer and installing it on friends' laptops without paying for it is:

(a) software theft (b) a virus attack (c) hacking (d) sabotage

(xv) After the statements a = [4, 1, 3], a.append(2) and a.insert(1, 9) are executed in that order, the output of print(a) is:

(a) [4, 1, 3, 2, 9] (b) [9, 4, 1, 3, 2] (c) [4, 9, 1, 3, 2] (d) [4, 1, 9, 3, 2]

(xvi) If s = "ROBOTICS", the output of print(s[2:5], s[-1]) is:

(a) OBO S (b) BOT C (c) BOTI S (d) BOT S

(xvii) Statement I: In supervised learning, the model is trained on examples that are labelled with the correct answer. Statement II: Grouping the customers of a shop by their buying habits, when no group names are given in advance, is an example of supervised learning.

(a) Both Statement I and Statement II are correct. (b) Both Statement I and Statement II are incorrect.

(c) Statement I is correct but Statement II is incorrect. (d) Statement I is incorrect but Statement II is correct.

(xviii) Statement I: Matplotlib is a Python library used mainly to draw graphs and charts. Statement II: After the statement import numpy as np, a programmer can write np.array() in place of numpy.array().

(a) Both Statement I and Statement II are correct. (b) Both Statement I and Statement II are incorrect.

(c) Statement I is correct but Statement II is incorrect. (d) Statement I is incorrect but Statement II is correct.

(xix) A tuple, once created, can have one of its elements changed by an assignment such as t[0] = 5.

(xx) Kaggle is a website from which publicly shared datasets can be downloaded for AI projects.

Question 2 [20]

(i) State two differences between an ordinary machine and a robot. **[2]**

(ii) Give two reasons why new-age robotic systems, such as warehouse robots and autonomous drones, have become possible in the last few years. **[2]**

(iii) What is an idler gear? State its effect on the direction of rotation of the driven gear and on the gear ratio of the train. **[2]**

(iv) Distinguish between contact and non-contact external sensors, giving one example of each. **[2]**

(v) Distinguish between a revolute joint and a prismatic joint, giving one example of each. **[2]**

(vi) A four-wheeled robot has its two left wheels driven by one motor circuit and its two right wheels driven by another. Explain how it can turn to the left on the spot. **[2]**

(vii) Distinguish between deterministic and probabilistic decision making, giving one example of each. **[2]**

(viii) What is meant by responsibility for the reliability of output as an ethical issue in computing? Give an example. **[2]**

(ix) Distinguish between a rule-based approach and a learning-based approach to building an AI model. **[2]**

(x) Give the output of the following code. **[2]**

```
s = "data science"
print(s.count("a"), s.find("sci"))
print(s.replace(" ", "_").upper())
```

SECTION B (60 Marks)

Attempt any four questions from this Section. Each question in this Section carries 15 marks.

Question 3 [15]

(i) A teacher has recorded, for each of 40 students, the number of hours spent practising and the marks scored in a Python test. Name the chart best suited to explore whether the two quantities are related, give a reason for your choice, and state what you would conclude if the points rise from the lower left to the upper right of the chart. **[3]**

(ii) State one use of each of the following Python packages: NumPy, Pandas and SciPy. **[3]**

(iii) A school in Jaipur has a rooftop solar plant. The units of electricity (kWh) it generated on the seven days of one week, Monday to Sunday, were 42, 47, 39, 51, 55, 30 and 44. Write a Python program that does the following.

1. Stores the names of the days, Mon to Sun, in one list and the units in another list.
2. Calculates and prints the total units and the average units per day, the average rounded to two decimal places.
3. Finds and prints the day on which the most units were generated, using max() and index().
4. Prints the name and the units of every day on which generation was below the average.
5. Imports matplotlib.pyplot and draws a line graph of the units against the days, with circle markers, the title Solar Generation in One Week and the axis labels Day and Units (kWh), and displays it.

State the values your program prints. **[9]**

Question 4 [15]

(i) Explain how a pair of gears can be used to increase the turning force (torque) at the joint of a robot arm, and state what is given up in exchange. Why does a small, fast motor usually need such a gear pair to lift an arm? [3]

(ii) Name, by its application, the type of sensor needed in each of the following situations, and give one example of a device of that type. (a) A robot vacuum cleaner must know that a wall is 10 cm ahead without touching it. (b) A greenhouse robot must know the air temperature. (c) A drone must know how far it has tilted and how fast it is turning. [3]

(iii) The elbow joint of a robot arm is driven by a motor through a compound gear train arranged as follows. Gear A, with 10 teeth, is fixed on the motor shaft and meshes with gear B, which has 40 teeth. Gear C, with 12 teeth, is fixed on the same shaft as gear B and turns with it. Gear C meshes with gear D, which has 36 teeth and is fixed on the elbow joint. The motor turns at 360 rpm and supplies a torque of 0.2 N m. Take the gear ratio of a pair as the number of teeth on the driven gear divided by the number of teeth on the driving gear, and ignore friction.

(a) Find the overall gear ratio of the train and the speed of the elbow joint in rpm. [3]

(b) Find the torque available at the elbow joint, and explain in one sentence the trade-off the gear train makes. [3]

(c) If the motor shaft turns clockwise, state with reasons the direction in which the elbow joint turns, and find the time the joint takes to turn through 90 degrees. [3]

Question 5 [15]

(i) Distinguish between manual control and automatic control, giving one example of each from household appliances such as fans, refrigerators and air conditioners. [3]

(ii) Draw yourself, in pencil, a labelled block diagram of a closed loop control system for a robot, using the blocks input (desired value), controller, robot (with its actuators), output and sensor (feedback). State the purpose of the feedback path. [3]

(iii) A school robotics club builds a four-wheeled obstacle-avoiding robot. It has an ultrasonic sensor at the front, a single board computer (an Arduino Uno), a motor driver board and four DC motors; the two left motors are wired together and the two right motors are wired together, and a battery pack powers everything.

(a) State the role of the ultrasonic sensor, the single board computer and the motor driver board in this robot. [3]

(b) The robot must keep moving forward until an obstacle is closer than 20 cm, then stop, move back a little, turn right and carry on. Write this decision logic as a numbered list of steps that the single board computer repeats. [3]

(c) The sensor measures the time between sending a sound pulse and receiving its echo. Taking the speed of sound in air as 340 m/s, find the distance to an obstacle when the echo returns after 1.2 milliseconds, and state whether the robot will stop. Also find the echo time for an obstacle 17 cm away. [3]

Question 6 [15]

(i) Explain the progression from traditional industrial robots to cobots, giving three ways in which cobots differ from the robots that came before them. [3]

(ii) Give three reasons why a designer should visualise the motion of a robot component in software such as Tinkercad before it is 3D printed or cut. [3]

(iii) A planar RR arm is being designed in Tinkercad for a pick and place task on a table. Its base is fixed at a point O. The first link, 30 cm long, turns about a revolute joint at O, and the second link, 20 cm long, turns about a revolute joint at the far end of the first link. The links lie at slightly different heights,

so that each joint can turn through a full circle.

(a) Find the greatest and the least distance from O at which the end of the arm can be placed, and describe the shape of the region the end can reach. **[3]**

(b) Take O as the origin, with the x-axis along the first link when its angle is 0 degrees. The first link is at 0 degrees, and the second link is turned through 90 degrees anticlockwise relative to the first. Find the coordinates of the end of the arm and its distance from O. **[3]**

(c) State the number of degrees of freedom of the arm. The arm must also be able to raise the gripper straight up off the table and lower it again. Name the type of joint you would add, say where you would add it, and state the new number of degrees of freedom. **[3]**

Question 7 [15]

(i) In a cricket match an on-field umpire gives a batter out leg before wicket, and the decision is then reviewed using a ball-tracking system. Give three differences between the way the umpire decides and the way the ball-tracking system decides. **[3]**

(ii) Describe how the Turing Test is carried out, and state one limitation of the test. **[3]**

(iii) Read the following account of a coaching centre in Lucknow and answer the questions that follow. Situation 1: a former employee who still knows the administrator password logs into the student database from home and downloads the phone numbers of 2,000 students, which he sells to a marketing company. Situation 2: a pen drive brought from a cyber cafe is plugged into an office computer; soon files on all the office computers are deleted and the computers slow down. Situation 3: the centre buys software that marks the weekly tests automatically and records every keystroke of the office staff; two experienced teachers who used to set and mark the tests are now asked only to scan answer sheets all day, and the office staff feel they are being watched every minute.

(a) Name the cybersecurity or ethical issue shown in each of the three situations. **[3]**

(b) Explain the harm caused to the people affected in each of the three situations. **[3]**

(c) Suggest one precaution the centre should take against each of the three situations. **[3]**

Question 8 [15]

(i) Students of a school in Chennai notice that taps in the school washrooms are often left running. They plan an AI project to reduce this wastage of water. Write one line for each of the 4Ws (Who, What, Where and Why), and then use them to write a problem statement. **[3]**

(ii) An AI model, trained on data about used scooters between 1 and 7 years old, predicts the resale price in thousands of rupees by the straight line price = 62 – 7 x age, where age is in years. (a) Predict the resale price of a scooter that is 4 years old. (b) State what the number –7 tells you. (c) Explain why the model should not be used for a scooter that is 10 years old. **[3]**

(iii) An obstacle-avoiding robot records ten distance readings, in centimetres, from its ultrasonic sensor: 85, 0, 42, 18, 410, 27, 15, 63, 0 and 9. A reading of 0, or a reading above 400, is an error. Write a Python program that does the following.

1. Stores the ten readings in a tuple named readings and converts the tuple into a list.
2. Using a loop and the append() method, builds a list named valid that holds only the readings that are not errors, counts the error readings, and prints that count.
3. The robot then takes two more readings, 33 and 71, both valid. Adds them to valid using the extend() method.
4. Sorts valid in ascending order and prints it, together with its smallest and largest values.
5. Counts and prints how many valid readings are below 20 cm.
6. Accepts a distance from the user and, using the in operator, reports whether it is present in valid and, if it is, its index in the sorted list.
7. Converts valid into a tuple and prints it.

Write the output of your program when the user enters 27. **[9]**

ANSWER KEY AND MARKING SCHEME

A full model answer is given for every part. Marks shown in italics are the step marks an examiner would award. Accept any other correct point of equal value, and accept answers in the candidate's own words; where a question asks for a set number of points, credit only that number, taking the best of those offered. For a Python program, credit correct logic and the correct use of the list, tuple, string or library feature the question names; accept any sensible variable names and any correct alternative logic that gives the same output, and do not deduct for a different but consistent layout. A minor slip of syntax that does not change the logic loses at most one mark in a program. In a calculation, a correct method with an arithmetic slip loses only the mark for the final value, and a wrong value carried forward correctly is not penalised twice.

Question 1 [20]

(i) (b) autonomous drones. They navigate and carry out the task without a pilot controlling each movement.

(ii) (d) a histogram. A histogram shows how continuous data is distributed over class intervals.

(iii) (c) 30 rpm. The speed falls in the ratio 12 : 36, so 90 x 12 / 36 = 30 rpm.

(iv) (a) a bevel gear pair. Bevel gears have cone-shaped faces and join intersecting shafts.

(v) (c) a rotary encoder that measures the angle of a joint. It measures the state of the robot itself; the other three sense the surroundings.

(vi) (a) a pneumatic cylinder. Compressed air pushes a piston along the cylinder; the three motors all produce rotation.

(vii) (b) closed loop automatic control. The measured temperature is fed back and compared with the set value without a person acting.

(viii) (d) 2. Each revolute joint adds one independent motion.

(ix) (d) Why. It states why the problem is worth solving and how the stakeholders gain.

(x) (a) absorbs most of the infrared light, so little is reflected back to the sensor.

(xi) (c) autonomous. It senses a situation it was not told about in advance and chooses its own action without a person.

(xii) (b) preparing (cleaning) the data. Missing, duplicate and wrong values are removed before a model is trained.

(xiii) (b) computer fraud. A computer is used to deceive people for money.

(xiv) (a) software theft, also called software piracy.

(xv) (c) [4, 9, 1, 3, 2]. append() adds 2 at the end, then insert(1, 9) puts 9 at index 1 and shifts the rest to the right.

(xvi) (d) BOT S. The slice [2:5] takes indexes 2, 3 and 4, and index -1 is the last character.

(xvii) (c) Statement I is correct but Statement II is incorrect. Grouping unlabelled data is unsupervised learning (clustering).

(xviii) (a) Both Statement I and Statement II are correct. The keyword as gives the module a short alias.

(xix) False. A tuple is immutable, and the assignment raises a TypeError.

(xx) True.

1 mark for each correct answer. No mark is deducted for a wrong answer.

Question 2 [20]

(i) An ordinary machine, such as a mixer grinder or a ceiling fan, does one fixed job when a person switches it on, and it does not sense what is happening around it. A robot, such as a robot vacuum cleaner, senses its surroundings through sensors, processes that information in a controller and decides how to act. A machine has to be rebuilt or redesigned for a new job, while a robot can be reprogrammed to do a different task with the same hardware.

Note for the examiner: Accept also: a robot can work with some independence from a person, a machine needs an operator.

Robot senses and decides, machine does not 1. Robot can be reprogrammed for new tasks 1.

(ii) Sensors such as cameras, ultrasonic sensors, GPS receivers and inertial sensors have become small, accurate and cheap. Small but powerful processors and single board computers can now run the software,

including AI programs, that lets a robot decide for itself. Other acceptable reasons are light rechargeable lithium batteries, wireless and internet connectivity, and progress in machine learning.

First valid reason 1. Second valid reason 1.

(iii) An idler gear is a gear placed between the driving gear and the driven gear, meshing with both, that does no work of its own on any shaft. Because each external mesh reverses the direction, the idler makes the driven gear turn in the same direction as the driving gear. It does not change the gear ratio, which still depends only on the numbers of teeth on the driving and the driven gears; an idler is also used to bridge a gap between two shafts that are some distance apart.

Meaning: a gear between driver and driven 1. Same direction as the driver, gear ratio unchanged 1.

(iv) A contact sensor must physically touch an object to detect it, for example a limit switch or the bump switch on the front of a robot vacuum cleaner. A non-contact sensor detects an object from a distance without touching it, for example an ultrasonic sensor, an infrared proximity sensor or a camera.

Contact sensor explained with an example 1. Non-contact sensor explained with an example 1.

(v) A revolute joint allows one link to rotate about a fixed axis relative to the other, as at the elbow of a robot arm or the hinge of a door. A prismatic joint allows one link to slide in a straight line along the other, as in a sliding drawer, a lift cabin moving in its shaft or the jaws of a parallel gripper.

Revolute joint with an example 1. Prismatic joint with an example 1.

(vi) The controller runs the right-side wheels forward and, at the same time, runs the left-side wheels backward at the same speed. The two sides push in opposite directions, so the robot spins to the left about its centre without moving forward. This way of steering by changing the speeds of the two sides is called differential (skid) steering.

Note for the examiner: If a candidate says the left wheels are stopped while the right wheels run forward, award 1 mark, since the robot then turns left about the left side rather than on the spot.

Right wheels forward 1. Left wheels backward at the same time 1.

(vii) In deterministic decision making the system follows fixed rules, so the same input always gives exactly the same output, for example a calculator, or a lift that always goes to the floor whose button is pressed. In probabilistic decision making the system works out how likely each outcome is from patterns in data and chooses the most likely one, so its answer carries some uncertainty, for example a weather app that reports a 70 per cent chance of rain, or a spam filter.

Deterministic with an example 1. Probabilistic with an example 1.

(viii) It is the question of who must answer when a computer system produces a wrong result that harms someone: the people who wrote the program, those who supplied the data, or the organisation that used the output without checking it. For example, if a faulty electricity billing program sends a family a bill ten times too large, the company cannot simply blame the computer; it remains responsible for checking and correcting the bill.

Meaning 1. Suitable example 1.

(ix) In a rule-based approach people write the rules, usually as if-then statements, and the system only follows them, for example a chatbot that gives fixed replies to fixed questions; it cannot handle a case its rules do not cover. In a learning-based approach the system is given data and finds the patterns or rules for itself, for example a spam filter trained on thousands of labelled e-mails; it can deal with new cases and improves as it gets more data.

Rule-based explained 1. Learning-based explained 1.

(x) 2 5 on the first line and DATA_SCIENCE on the second line. The letter a occurs twice, both in data. The substring sci begins at index 5, counting the space at index 4. replace() changes the space to an underscore and upper() then turns every letter into a capital.

Note for the examiner: Output machine checked by running the code in Python 3.

2 5 1. DATA_SCIENCE 1.

Question 3 [15]

(i) A scatter plot. Each student is shown as one point, with the hours on the x-axis and the marks on the y-axis, so the pattern of all 40 points shows at a glance whether the two quantities are related. If the points rise from the lower left to the upper right, there is a positive relationship: students who practise for more hours tend to score higher marks.

Scatter plot 1. Reason 1. Positive relationship concluded 1.

(ii) NumPy works with arrays of numbers and carries out fast numerical calculations on them, such as the mean of a thousand sensor readings. Pandas stores and handles data arranged in rows and columns (a DataFrame); it can read a CSV file, clean it, filter it and summarise it. SciPy is built on NumPy and provides scientific tools such as statistics, optimisation, interpolation and signal processing.

NumPy 1. Pandas 1. SciPy 1.

(iii) The program is as follows.

```
import matplotlib.pyplot as plt

# Step 1: the data in two lists
days = ["Mon", "Tue", "Wed", "Thu", "Fri", "Sat", "Sun"]
units = [42, 47, 39, 51, 55, 30, 44]

# Step 2: total and average
total = sum(units)
average = round(total / len(units), 2)
print("Total units:", total)
print("Average units per day:", average)

# Step 3: the best day
best = max(units)
print("Highest generation on", days[units.index(best)], "with", best, "units")

# Step 4: days below the average
print("Days below average:")
for i in range(len(days)):
    if units[i] < average:
        print(days[i], units[i])

# Step 5: the line graph
plt.plot(days, units, marker="o")
plt.title("Solar Generation in One Week")
plt.xlabel("Day")
plt.ylabel("Units (kWh)")
plt.show()
```

Output: Total units: 308, then Average units per day: 44.0, then Highest generation on Fri with 55 units, then Days below average:, followed by Mon 42, Wed 39 and Sat 30, each on a line of its own. A line graph with seven circle markers then opens. Sunday, with exactly 44 units, is not below the average and is not printed.

Note for the examiner: Program run in Python 3 and the printed values machine checked. Accept marker="o" written as "o" in the format string, for example plt.plot(days, units, "o-"). Accept the average stated as 44, 44.0 or 44.00; a candidate who formats it to two places, for example with format(average, ".2f"), prints 44.00 and loses no mark.

Two lists correctly created 1. Total with sum() and rounded average 1.5. Best day found with max() and index() 1.5. Loop printing the days below the average 1.5. Import and plt.plot() with markers 1.5. Title, axis labels and plt.show() 1. Printed values stated correctly 1.

Question 4 [15]

(i) A small gear on the motor shaft drives a larger gear on the joint. The larger gear turns more slowly, and, ignoring friction, the torque is multiplied by the gear ratio, so a gear ratio of 5 gives about five times the torque. The price paid is speed: the joint turns five times more slowly than the motor. Small DC motors spin fast but produce little torque, which is not enough to lift the weight of an arm and its load, so a reduction gear pair converts the fast, weak rotation into the slow, strong rotation the joint needs.

Small driver and large driven gear multiply torque 1. Speed is reduced in exchange 1. Motor alone is fast but weak 1.

(ii) (a) A range or proximity sensor, such as an ultrasonic sensor or an infrared proximity sensor. (b) A temperature sensor, such as a thermistor, an LM35 or a DHT11 module. (c) A motion or navigation sensor, such as a gyroscope together with an accelerometer, the pair often sold as an inertial measurement unit (IMU).

(a) range or proximity sensor with an example 1. (b) temperature sensor with an example 1. (c) motion or navigation sensor with an example 1.

(iii)

(a) Ratio of the first pair = 40 / 10 = 4. Ratio of the second pair = 36 / 12 = 3. Gears B and C share a shaft, so the overall ratio is the product, 4 x 3 = 12. Speed of the joint = 360 / 12 = 30 rpm.

Ratios 4 and 3 of the two pairs 1. Overall ratio 12 as the product 1. Joint speed 30 rpm 1.

(b) Torque at the joint = 0.2 x 12 = 2.4 N m. The gear train multiplies the torque twelve times but divides the speed by the same factor, so the arm gains lifting force and loses speed.

Torque multiplied by the gear ratio 1. 2.4 N m 1. Trade-off explained 1.

(c) Two gears in external mesh turn in opposite directions. Gear A turns clockwise, so gear B turns anticlockwise; gear C is on the same shaft as B and also turns anticlockwise; gear D meshes with C and turns clockwise. The joint therefore turns clockwise, the same way as the motor. At 30 rpm the joint makes 0.5 revolution per second, which is 180 degrees per second, so 90 degrees takes 90 / 180 = 0.5 second.

Note for the examiner: All values machine checked with exact fractions.

Reversal at each mesh, same direction on a shared shaft 1. Clockwise 1. 0.5 second 1.

Question 5 [15]

(i) In manual control a person watches the result and makes every adjustment, while in automatic control the system measures the result and adjusts itself without a person. An ordinary ceiling fan with a regulator is manually controlled: its speed changes only when someone turns the knob. A refrigerator is automatically controlled: its thermostat switches the compressor on and off to keep the set temperature.

Difference stated 1. Manual example 1. Automatic example 1.

(ii) The diagram is a row of blocks joined by arrows: input (desired value) to the controller, the controller to the robot with its actuators, and the robot to the output. A sensor measures the output, and an arrow runs from the sensor back to the controller, closing the loop. The feedback path tells the controller what the robot has actually done, so that the controller can compare it with the desired value and correct any error until the two match.

Forward blocks in the right order with arrows 1. Sensor and feedback arrow back to the controller 1. Purpose of feedback 1.

(iii)

(a) The ultrasonic sensor measures the distance to whatever is in front of the robot. The single board computer runs the program: it reads the distance, decides what the robot should do and sends control signals. The motor driver board takes these low-power signals and switches the larger battery current to the motors, setting their direction and speed, because the pins of the board cannot supply enough current to run a motor.

Ultrasonic sensor 1. Single board computer 1. Motor driver 1.

(b) Step 1: read the distance d from the ultrasonic sensor. Step 2: if d is 20 cm or more, run all four motors forward and go back to step 1. Step 3: otherwise stop all the motors. Step 4: run all the motors backward for a short time, say half a second, then stop. Step 5: turn right by running the left motors forward and the right motors backward for a short time. Step 6: go back to step 1.

Note for the examiner: Accept a flow chart or pseudocode in place of numbered steps. Arduino code is not required.

Reading the distance at the start of every cycle 1. Correct test with forward motion when clear 1. Stop, reverse and right turn in order, then repeat 1.

(c) The sound travels to the obstacle and back, so distance = speed x time / 2 = 340 x 0.0012 / 2 = 0.204 m = 20.4 cm. This is not closer than 20 cm, so the robot keeps moving forward, though it is about to stop. For 17 cm: time = 2 x distance / speed = 2 x 0.17 / 340 = 0.001 s = 1 millisecond.

Note for the examiner: Values machine checked. A candidate who forgets to halve (40.8 cm) loses the first mark only if the decision follows correctly from the value found.

Halving for the return journey 1. 20.4 cm and the robot does not yet stop 1. 1 millisecond 1.

Question 6 [15]

(i) The first industrial robots were large, fast and powerful arms that did one task, such as welding car bodies, and they had to work inside safety cages away from people. Cobots grew out of the need for robots that people could work beside. First, cobots carry force, torque or vision sensors and stop or slow down when they touch or come near a person, so no cage is needed. Second, they are light, have rounded edges and limited speed and force. Third, they can be taught a task by a worker who guides the arm by hand or uses a simple tablet app, so small factories can change their task quickly without expert programmers. They combine the human's judgement with the robot's strength and precision.

First difference 1. Second difference 1. Third difference 1.

(ii) First, moving the parts on screen shows whether any part collides with another during its motion. Second, it shows the range of movement and the reach, so the designer can check that the component can do its job. Third, the sizes of holes, pins and slots can be checked for fit, and a mistake can be corrected in minutes instead of wasting material, money and printing time on a part that will not work. Designs can also be shared and improved easily.

First reason 1. Second reason 1. Third reason 1.

(iii)

(a) Greatest distance, with both links in a straight line: 30 + 20 = 50 cm. Least distance, with the second link folded back over the first: 30 – 20 = 10 cm. The end can reach every point of a ring (annulus) centred at O, between a circle of radius 10 cm and a circle of radius 50 cm.

50 cm 1. 10 cm 1. Ring between the two circles 1.

(b) The first link ends at (30, 0). The second link points in the direction of the y-axis, so the end of the arm is at (30, 0 + 20) = (30, 20). Distance from O = square root of (30^2 + 20^2) = square root of 1300 = 36.1 cm, correct to one decimal place.

Note for the examiner: Value machine checked: the square root of 1300 is 36.06 to two decimal places.

End of first link at (30, 0) 1. (30, 20) 1. 36.1 cm 1.

(c) The arm has 2 degrees of freedom, one for each revolute joint. To lift objects, add a prismatic joint at the end of the second link, sliding up and down to raise and lower the gripper (as in a SCARA robot). The arm then has 3 degrees of freedom.

Note for the examiner: Accept a prismatic joint at the base that raises the whole arm. A candidate who adds a revolute joint with a horizontal axis (a shoulder pitch joint) has given a valid way to lift the gripper, though along an arc rather than straight up: award the joint mark if this is explained, and the mark for 3 degrees of freedom.

2 degrees of freedom 1. Prismatic joint giving vertical motion, placed sensibly 1. 3 degrees of freedom 1.

Question 7 [15]

(i) First, the umpire uses his eyes, experience and judgement in a split second, while the system uses several high-speed cameras and calculates the path of the ball. Second, the umpire may be affected by his viewing angle, tiredness or the pressure of the crowd, while the system gives the same result every time for the same data. Third, the umpire can weigh the spirit of the game and the context, while the system only predicts where the ball would have gone, with a small margin of error, which is why close calls are left with the umpire.

First difference 1. Second difference 1. Third difference 1.

(ii) A human judge holds typed conversations with two hidden participants, one a person and the other a machine, without knowing which is which. If, after the conversations, the judge cannot reliably tell the machine from the person, the machine is said to have passed the test and to show intelligent behaviour. The test was proposed by Alan Turing in 1950. One limitation is that it tests only whether a machine can imitate human conversation, not whether it really understands; a program can pass by clever tricks or evasive replies, and the test ignores other kinds of intelligence such as vision or movement.

Judge, hidden human and machine, text conversation 1. Pass condition 1. Limitation 1.

(iii)

(a) Situation 1: hacking and data theft, that is unauthorised access to a computer system and stealing personal data. Situation 2: sabotage of computer systems by a virus (malware). Situation 3: degradation of work, as skilled work is reduced to a dull, repetitive task and staff are closely monitored by the computer.

Situation 1 1. Situation 2 1. Situation 3 1.

(b) Situation 1: the students' private phone numbers are now with a marketing company without their consent, so they may receive unwanted calls or fraud attempts, and the centre loses their trust. Situation 2: records and work are lost, and the centre loses time and money in restoring its computers. Situation 3: the teachers lose the use of their skill and judgement and may lose interest in their work or fear for their jobs, and constant keystroke monitoring causes stress and harms the staff's sense of being trusted.

Harm in Situation 1 1. Harm in Situation 2 1. Harm in Situation 3 1.

(c) Situation 1: change all passwords, and cancel the access of an employee on the day he leaves; use strong passwords with two-factor authentication. Situation 2: install and update antivirus software, scan every pen drive before it is opened, and keep regular backups. Situation 3: let the teachers check and moderate the marks the software gives and use the time saved for teaching and feedback, train them for the new tasks, and limit monitoring to what is really needed, explaining it openly to the staff.

Precaution for Situation 1 1. Precaution for Situation 2 1. Precaution for Situation 3 1.

Question 8 [15]

(i) Who: the students, the teachers and the maintenance staff of the school, who are the stakeholders. What: taps are left running and a large amount of water is wasted every day. Where: in the school washrooms, mostly during the breaks. Why: saving water lowers the school's water bill and conserves water in a city that often faces shortages. Problem statement: our students and staff have a problem of taps being left running, which wastes water in the school washrooms during the breaks; an ideal solution would detect running taps and alert the staff or close the taps, so that water and money are saved.

Who and What 1. Where and Why 1. Problem statement combining the four 1.

(ii) (a) price = 62 – 7 x 4 = 62 – 28 = 34, that is Rs 34,000. (b) –7 is the slope of the line: the predicted price falls by Rs 7,000 for every extra year of age. (c) A 10-year-old scooter is outside the range of the training data, and the line gives 62 – 70 = –8, a negative price, which is impossible; a linear regression model is reliable only within the range of data it was trained on.

Note for the examiner: Accept 34 thousand rupees.

Rs 34,000 1. Meaning of the slope 1. Outside the training range, negative price 1.

(iii) The program is as follows.

```
# Step 1: the readings in a tuple, then a list
```

```
readings = (85, 0, 42, 18, 410, 27, 15, 63, 0, 9)
data = list(readings)

# Step 2: keep the good readings, count the errors
valid = []
errors = 0
for r in data:
    if r == 0 or r > 400:
        errors = errors + 1
    else:
        valid.append(r)
print("Error readings:", errors)

# Step 3: two more readings
valid.extend([33, 71])

# Step 4: sort, smallest and largest
valid.sort()
print("Valid readings:", valid)
print("Smallest:", valid[0], "Largest:", valid[-1])

# Step 5: readings closer than 20 cm
close = 0
for r in valid:
    if r < 20:
        close = close + 1
print("Readings below 20 cm:", close)

# Step 6: search
d = int(input("Enter a distance: "))
if d in valid:
    print(d, "is present at index", valid.index(d))
else:
    print(d, "is not present")

# Step 7: back to a tuple
final = tuple(valid)
print("Final tuple:", final)
```

Output for the input 27: Error readings: 3, then Valid readings: [9, 15, 18, 27, 33, 42, 63, 71, 85], then Smallest: 9 Largest: 85, then Readings below 20 cm: 3, then the prompt with 27 typed in, then 27 is present at index 3, then Final tuple: (9, 15, 18, 27, 33, 42, 63, 71, 85). The three readings below 20 cm are 9, 15 and 18; 0 does not count because it was rejected as an error.

Note for the examiner: Program run in Python 3 with the inputs 27 and 50 and the output machine checked. Accept min() and max() in place of valid[0] and valid[-1], and sorted() followed by assignment in place of sort().

Tuple created and converted with list() 1. Loop with the error test, append() and the error count 2. extend() used correctly 1. sort() with smallest and largest printed 1. Count of readings below 20 cm 1. Search with in and index() 1.5. tuple() conversion printed and the output stated 1.5.