

ISC Class 12 Robotics Specimen Paper 1

Written by the Future Topper subject team on the CISCE examination pattern. Not an official CISCE paper.
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Maximum Marks: 70 | Time Allowed: Three hours | Reading Time: 15 minutes

Paper 1 (Theory) carries 70 marks. Part I is compulsory. Part II has five Sections, one for each unit of the syllabus; answer one question from each Section.

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. Part I is compulsory and carries 20 marks. Part II carries 50 marks and is divided into five Sections, one for each unit of the syllabus: Section A, Introduction (8 marks); Section B, Robotics in Healthcare (12 marks); Section C, Robotics in Agriculture (12 marks); Section D, Smart Manufacturing and Industry 4.0/5.0 (12 marks); and Section E, Space Robotics (6 marks). Each Section offers two questions, and you must answer one question from each Section. Marks for each question, or part of a question, are shown in brackets. Some questions ask you to apply the fundamentals studied in Class 11, such as sensors, motors, power and control, to the robots of the Class 12 syllabus; show all working for any calculation and give every final answer with its unit. No diagrams, block diagrams or robot sketches are printed in this paper. Where a question asks for one you are expected to draw it yourself in pencil and label it. This paper carries 70 of the 100 marks for the subject, the remaining 30 being for Paper 2, the practical examination together with the practical file of assignments assessed in school.

PART I (20 Marks)

Answer all questions. Question 1 carries 10 marks and Question 2 carries 10 marks.

Question 1 [10]

Each part carries 1 mark. For the parts that offer four choices, write only the option you choose. For the rest, answer in a single sentence or give the single word or name asked for.

- (i) A pick and place robot must put a component down on the same spot of a circuit board, cycle after cycle, to within 0.02 mm. When selecting the robot, the specification that matters most for this job is:
(a) payload (b) reach (c) repeatability (d) maximum speed
- (ii) A delivery robot in a hospital records video in the corridors and the wards and stores it on a cloud server. The ethical issue this raises most directly is:
(a) impact on employment (b) privacy and surveillance
(c) military and defence use (d) environmental impact
- (iii) A powered exoskeleton for a patient recovering from a stroke picks up the small electrical signals of the thigh muscles to judge when the patient means to stand. The sensor it uses is:
(a) an electromyography (EMG) electrode (b) a LIDAR scanner
(c) an ultrasonic range finder (d) a GPS receiver
- (iv) State one task that an assistance robot carries out in a hospital ward.
- (v) Name the improved form of satellite positioning that lets a seeding robot place seeds to within a few centimetres of the planned point.
- (vi) A wheeled robot drives between rows of cabbages, uses a camera to tell weeds from the crop, and pulls the weeds out with a small mechanical tool. It belongs to the type called:
(a) seeding and spraying robot (b) space station robot
(c) collaborative robot (d) ground mobile robot
- (vii) The feature that most clearly marks Industry 5.0 out from Industry 4.0 is:

- (a) production that is human centric, sustainable and resilient, with people and robots working together (b) the first use of steam power in factories
(c) the replacement of every worker by a fully automatic machine (d) the introduction of the moving assembly line
- (viii)** Expand the abbreviation AGV as it is used in a smart factory.
- (ix)** The suspension that NASA's recent Mars rovers use to keep all six wheels on the ground while climbing over rocks is called the:
(a) leaf spring suspension (b) rocker-bogie suspension
(c) air suspension (d) torsion bar suspension
- (x)** State the type of space robot to which Canadarm2 on the International Space Station belongs.

Question 2 [10]

Each part carries 2 marks.

- (i)** A cold store near Nashik needs a robot arm to stack cartons of 20 kg each on pallets at a temperature of -18 degrees Celsius. State two parameters the designer must fix when choosing the arm, and explain why each one matters for this particular job. [2]
- (ii)** A da Vinci system is set to a motion scaling of 3:1. The surgeon moves a hand control 18 mm to the right, and the surgeon's hand has a slight tremor of amplitude 0.9 mm. Calculate the distance the instrument tip moves and the tremor amplitude that would reach the tip if scaling alone acted. Name the further feature of the system that removes the tremor. [2]
- (iii)** A seeding robot drops one seed every 25 cm along a row 50 m long, the first seed falling at the very start of the row, and it travels at 0.5 m s^{-1} . Calculate the number of seeds it drops in the row and the time between one drop and the next. [2]
- (iv)** State two features that make a factory a smart factory in the sense of Industry 4.0. [2]
- (v)** On a certain day Mars is $2.25 \times 10^8 \text{ km}$ from the Earth. Taking the speed of radio waves as $3.0 \times 10^5 \text{ km s}^{-1}$, calculate the time in minutes that a command takes to reach a rover on Mars, and the least time between sending a command and seeing on the Earth the picture that shows its result. [2]

SECTION A: INTRODUCTION (8 Marks)

PART II (50 Marks). Answer one question from each of the five Sections. Answer one question from this Section. Each question carries 8 marks.

Question 3 [8]

- (a)** A hospital in Lucknow wants a robot to carry medicines from its pharmacy to the wards. The route has smooth floors, ramps and lifts, and patients, visitors and staff are always about. Compare a wheeled robot with a legged robot for this job, state which you would choose and why, and name two sensors the robot you choose must carry. [4]
- (b)** An autonomous delivery robot working in a housing society in Bengaluru brushes against a six year old child who runs into its path. The child is unhurt but frightened. Discuss who should be held accountable for such an incident, and suggest two safety measures that would reduce the chance of it happening again. [4]

Question 4 [8]

- (a) A student builds a line following robot whose software runs on ROS. It has three nodes: camera_node, which reads the camera; line_detector, which finds the line in each image; and motor_controller, which drives the wheels. Using this project, explain what is meant by a node and a topic, and describe how data flows from the camera to the wheels. Draw the ROS graph of the project yourself, showing each node as an oval and each topic as a rectangle, and give each topic a suitable name. [4]
- (b) Explain what Gazebo is, and give three reasons why the student should test the robot in Gazebo before building the hardware. [4]

SECTION B: ROBOTICS IN HEALTHCARE (12 Marks)

Answer one question from this Section. Each question carries 12 marks.

Question 5 [12]

- (a) Name the four main components of the da Vinci Surgical System and state the part each plays. [4]
- (b) Explain the working principle of the system, and explain why it is described as a master and slave system rather than an autonomous surgical robot. [3]
- (c) State two advantages the system offers the patient and one advantage it offers the surgeon, compared with open surgery. [3]
- (d) A private hospital in Pune is deciding whether to buy the system. State two limitations of the system that the hospital should weigh against its advantages. [2]

Question 6 [12]

- (a) A district hospital in Odisha has no radiologist on duty at night. A robotic ultrasound system lets a radiologist in Bhubaneswar examine a patient there. Explain the working principle of such a system. [3]
- (b) Name four components of the system and state the part each plays. [3]
- (c) Explain why a force sensor at the probe is essential, and why the force limit must be applied by the robot itself rather than by the distant radiologist. [2]
- (d) State two advantages of the robotic system over a scan made by hand. [2]
- (e) State one concern about the patient's privacy or consent that is peculiar to a remote scan of this kind, and one safeguard the hospital should adopt. [2]

SECTION C: ROBOTICS IN AGRICULTURE (12 Marks)

Answer one question from this Section. Each question carries 12 marks.

Question 7 [12]

- (a) Explain the working principle of a seeding and spraying robot used for precision farming. [3]
- (b) Name three of its components and state the part each plays. [3]
- (c) Explain how the robot supports precision farming, reduces labour and benefits the environment, giving one point under each heading. [3]
- (d) Spraying a 2 hectare cotton field in Punjab by hand uses 400 litres of pesticide mixture, applied evenly over the whole field. A spraying robot whose camera finds pests sprays only the patches that need it, which make up 15 per cent of the field, at the same rate per square metre. Calculate the volume the robot uses, the volume saved and the saving as a percentage, and state one benefit of the saving other than cost. [3]

Question 8 [12]

- (a) A monitoring and sensing robot patrols a tea garden in Assam. Explain the working principle of such a robot. [3]
- (b) Name three of its components and state the part each plays. [3]

- (c) Explain how the robot helps the planter find a pest attack early. [2]
- (d) The robot takes one image of 4 MB every 5 m and covers 3.0 km of rows each day. Calculate the image data it collects in a day, and explain why it is better for the robot to examine the images on board and send only alerts over its radio link. [2]
- (e) State two ways in which the data from such a robot improves the yield or the quality of the tea. [2]

SECTION D: SMART MANUFACTURING AND INDUSTRY 4.0/5.0 (12 Marks)

Answer one question from this Section. Each question carries 12 marks.

Question 9 [12]

- (a) Explain the working principle of an industrial manipulator used for spot welding in the body shop of a car plant in Chennai, and name its main components. [4]
- (b) Each car body is clamped in a fixture before the manipulator welds it. Explain why the fixture is needed, and state what would happen to the welds if a body were clamped 5 mm out of place. [2]
- (c) A two wheeler factory in Hosur uses robotic welding systems on its frame line. Name four components of such a welding cell, other than the robot arm, and state two advantages of robotic welding over manual welding. [3]
- (d) Describe three measures that keep the workers of the Hosur factory safe from the welding cell. [3]

Question 10 [12]

- (a) Explain the working principle of a collaborative robot (cobot) and name its main components. [3]
- (b) Explain the two safety methods called power and force limiting, and speed and separation monitoring. [3]
- (c) A cobot in an electronics plant in Noida works beside people who may walk towards it at up to 1.6 m s^{-1} . Its sensors and controller take 0.1 s to recognise a person, and the arm then takes 0.4 s to come to rest. Calculate the least distance at which a person must be detected if the arm is to be at rest before the person reaches it, and the distance at which the detection zone should be set if a further safety margin of 0.2 m is added. [3]
- (d) A small firm that makes switchboards in short batches is choosing between a cobot and a conventional industrial arm for screwing on covers. Give three reasons why a cobot may suit it better. [3]

SECTION E: SPACE ROBOTICS (6 Marks)

Answer one question from this Section. Each question carries 6 marks.

Question 11 [6]

- (a) Describe the working principle of a Mars rover of the kind sent under NASA's Mars rover programme, explaining how it is commanded from the Earth and how it moves safely between commands. [3]
- (b) A rover drives at 0.04 m s^{-1} while it is moving. In autonomous mode it stops after every 2.0 m for 30 s to take stereo images and plan the next stretch, including a stop after the final stretch. Calculate the time it takes to cover 120 m in this way, in minutes, and its average speed, and state why it stops so often. [3]

Question 12 [6]

- (a) Name the three elements that made up the Chandrayaan-2 mission and state the job of each. [3]
- (b) State what happened to the lander in September 2019, and name the element that went on returning scientific data afterwards. [1]
- (c) State two advantages that India gained from the Chandrayaan-2 mission. [2]

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. Every calculation has been worked by machine and the working shown is the working that was checked. Accept any correct alternative method that reaches the same result. For a descriptive answer, credit the idea rather than the exact words, accept any correct example from a real system in place of the one given, and give credit to a well reasoned answer that applies the system to the situation in the question rather than reciting a general list. For a drawing accept any clear and correctly labelled version.

Question 1 [10]

- (i) (c) repeatability. Repeatability is the closeness with which the robot returns to the same taught point under the same conditions, which is what placing a part on the same spot every cycle needs.
- (ii) (b) privacy and surveillance. Patients are filmed in a place where they expect privacy, and the recordings are held by a third party.
- (iii) (a) an electromyography (EMG) electrode. Surface EMG electrodes on the skin pick up the electrical activity of a muscle a moment before it contracts.
- (iv) Any one: carrying medicines, meals, linen or samples between the wards and the pharmacy or laboratory; helping staff lift or turn a patient; guiding visitors; disinfecting rooms.
- (v) RTK (real time kinematic) GPS, which corrects the satellite position with signals from a fixed base station. Accept differential GPS.
- (vi) (d) ground mobile robot. It moves over the field on wheels and works on the crop, here weeding.
- (vii) (a) production that is human centric, sustainable and resilient, with people and robots working together.
- (viii) Automated guided vehicle.
- (ix) (b) rocker-bogie suspension. Its linked rockers and bogies let each wheel rise and fall over a rock while all six stay in contact with the ground.
- (x) Space station robotics. Canadarm2 is a robotic arm that works on the outside of the station.

1 mark for each correct part. No mark is deducted for a wrong option, and a one-line answer that carries the correct idea gains the mark even if it is loosely worded.

Question 2 [10]

- (i) Any two, each with a reason tied to the job. Payload: the arm must be rated for the carton together with the gripper, so somewhat above 20 kg, or it will be overloaded and lose accuracy. Operating environment: at -18 degrees Celsius ordinary lubricants thicken, cables stiffen and condensation forms when the arm is moved in and out, so a freezer rated arm with suitable seals and grease is needed. Reach and workspace: the arm must reach the far corner and the top layer of a full pallet. Speed or cycle time is also accepted if justified by the number of cartons to be stacked.

First parameter with a reason tied to this job 1. Second parameter with a reason tied to this job 1.

- (ii) With a scaling of 3:1 the tip moves one third of the hand movement, so tip movement = $18/3 = 6$ mm. The tremor would also be scaled down, to $0.9/3 = 0.3$ mm. The feature that removes it is tremor filtering, which strips out the rapid, small oscillations of the hand before the movement is passed to the instrument.

Tip movement 6 mm and tremor 0.3 mm 1. Tremor filtering named 1.

- (iii) Number of spacings = $50/0.25 = 200$, so the number of seeds = $200 + 1 = 201$, counting the seed at the start. Time between drops = distance/speed = $0.25/0.5 = 0.5$ s.

201 seeds 1. 0.5 s between drops 1.

- (iv) Any two: machines, robots and products are connected through the internet of things and share data continuously; the data is collected and analysed, often with artificial intelligence, to control and improve production; machines and their digital control form cyber-physical systems that adjust themselves; maintenance is predicted from sensor data rather than done after a breakdown; production can be changed quickly to make customised products.

First feature 1. Second feature 1.

- (v) Time = distance/speed = $2.25 \times 10^8 / 3.0 \times 10^5 = 750$ s = 12.5 minutes. The command takes 12.5 minutes to reach the rover and the picture of the result takes as long to come back, so the least time is $2 \times 12.5 = 25$

minutes, ignoring the time the rover takes to act.

12.5 minutes 1. 25 minutes for the round trip 1.

Question 3 [8]

- (a) A wheeled robot suits this route. Smooth floors, ramps and lifts are what wheels handle best; a wheeled base is simpler, cheaper, steadier with a load and more efficient on battery power. A legged robot can climb steps and cross rough ground, but none of that is needed here, and it is costlier, harder to control and less stable when people bump into it. So a wheeled robot is chosen. Two sensors it must carry: a LIDAR or depth camera to map the corridors and detect people and obstacles, and ultrasonic or infrared proximity sensors and bump sensors for close range safety. Wheel encoders and an inertial measurement unit for tracking its position are also accepted.

Wheeled robot assessed for this route 1. Legged robot assessed for this route 1. Choice of wheeled robot justified 1. Two suitable sensors 1.

- (b) Accountability is shared and must be settled before such a robot is used. The manufacturer answers for the design and for the safety of its sensing and stopping; the software developer for the behaviour of the program, for example whether it was tested for a small child who appears suddenly; the operating company or housing society for where and when the robot is allowed to run, its maintenance and its speed settings. A robot cannot itself be held responsible, which is why a clear line of human responsibility is an ethical requirement. Safety measures, any two: limit the robot's speed in areas where children play and at blind corners; fit sensors with a wide, low field of view that can detect a small child and stop the robot within a short distance; add lights and a sound warning; restrict its routes or hours; and keep a log of incidents so they can be investigated.

Responsibility of the manufacturer and developer 1. Responsibility of the operator, with the robot itself not answerable 1. First safety measure 1. Second safety measure 1.

Question 4 [8]

- (a) A node is a single program that does one job: here camera_node, line_detector and motor_controller are three nodes. A topic is a named channel that carries data of one type, for example /camera/image_raw and /cmd_vel; a node publishes messages on a topic and any node that subscribes to it receives them. Data flow: camera_node publishes image messages on /camera/image_raw; line_detector subscribes to that topic, finds the line in each image and publishes a velocity command on /cmd_vel; motor_controller subscribes to /cmd_vel and turns each command into wheel speeds. The graph should show three ovals in a row with the rectangle /camera/image_raw between the first two and /cmd_vel between the last two, with arrows running from camera_node to line_detector to motor_controller. Accept any sensible topic names.

Node explained with this project 1. Topic explained with this project 1. Data flow from camera to wheels 1. ROS graph with ovals, rectangles and named topics 1.

- (b) Gazebo is a three dimensional robot simulator that works with ROS. It contains a physics engine, so a model robot in it has mass, friction and gravity acting on it, and it simulates sensors such as cameras, LIDAR and encoders, so the same ROS nodes can be run against the simulated robot as against the real one. Reasons to test there first, any three: mistakes in the program cannot damage the hardware or injure anyone; the design can be changed and tried again in minutes, at no cost in parts; a test can be repeated in exactly the same conditions, which helps debugging; difficult or rare situations, such as poor lighting or a broken line, can be set up at will; and the software can be developed before the hardware has arrived.

Gazebo described as a physics based simulator working with ROS 1. First reason 1. Second reason 1. Third reason 1.

Question 5 [12]

- (a) The surgeon console is where the surgeon sits, looks at a magnified three dimensional view of the operating field and moves hand controls and foot pedals. The patient-side cart stands beside the operating table and carries the robotic arms that hold the instruments and the camera through small cuts. The vision system, with its endoscope camera and image processing equipment, gives the high definition three dimensional view. The EndoWrist instruments are the small tools at the tips of the arms, with a wrist that bends and turns more freely than a human wrist.

Surgeon console 1. Patient-side cart 1. Vision system 1. EndoWrist instruments 1.

- (b) The surgeon operates from the console, through a few small cuts in the patient. Each movement of the surgeon's hands on the controls is measured, scaled down and filtered to remove tremor, and then reproduced by the instruments inside the patient, while the surgeon watches the magnified 3D image. It is a master and slave system because the console is the master and the instruments are the slave: every movement of the instruments is a copy of a movement the surgeon makes, and the robot makes no decisions and does nothing on its own.

Surgeon's movements measured and reproduced through small cuts 1. Scaling, tremor filtering and 3D view 1. Master and slave explained, with no independent action 1.

- (c) For the patient, any two: smaller cuts and so less pain and blood loss, less scarring, a lower risk of infection, and a shorter stay in hospital and a quicker return to normal life. For the surgeon, any one: a comfortable seated position that reduces fatigue in long operations; a steadier and more precise movement through motion scaling and tremor filtering; a magnified 3D view.

First patient advantage 1. Second patient advantage 1. One surgeon advantage 1.

- (d) Any two: the very high cost of the system and of its instruments and maintenance; the long training the surgeons and theatre staff need; the surgeon gets little or no sense of touch from the tissue on many models; setting up the system adds time to each operation; a fault in the system during surgery must be planned for.

First limitation 1. Second limitation 1.

Question 6 [12]

- (a) The ultrasound probe is held by a robotic arm beside the patient. The radiologist, far away, moves a dummy probe or joystick, and the arm copies the movement, positioning and tilting the probe on the patient's body, while the images are sent back over the network in real time. The system can also move the probe through a set scan automatically, the radiologist watching and correcting.

Probe held and moved by a robotic arm 1. Remote control by the radiologist 1. Images returned in real time, or automatic scan 1.

- (b) Any four: the robotic arm, which holds and moves the probe; the ultrasound probe, which sends and receives the sound waves; the control system with the remote operator's console, which turns the radiologist's movements into commands for the arm; the display and image processing unit, which forms and shows the image; and the communication link that joins the two ends.

Two components with their parts 1. Third component with its part 1. Fourth component with its part 1.

- (c) The probe must press on the body firmly enough to give a clear image but never hard enough to hurt the patient, and the force sensor lets the controller keep the contact force within a safe limit. The limit must be applied on the spot because signals to and from the radiologist are delayed and the link may drop, so a person far away cannot react quickly enough.

Force kept within a safe limit 1. Delay or loss of the link as the reason for a local limit 1.

- (d) Any two: the images are consistent, because the robot holds the probe steadily and repeats a scan exactly; diagnostic precision is better, since the position and pressure are controlled and recorded; the technician is spared the strain of holding a probe for long periods; and a specialist can examine patients in distant places.

First advantage 1. Second advantage 1.

- (e) Concern, any one: the images and the patient's body are seen by someone who is not in the room, and the images travel over a network, where they could be intercepted or stored without the patient's knowledge; the patient may not understand that a distant doctor is controlling the machine. Safeguard, any one: explain the

remote nature of the scan and take written consent; encrypt the link and the stored images; keep a chaperone or nurse with the patient; limit who can view the records.

Concern 1. Safeguard 1.

Question 7 [12]

- (a) The robot moves along the field using GPS and its sensors to follow rows laid out as stored coordinates. At each planned point it places a seed at the set depth and spacing, and its spraying system releases a measured dose of water, fertiliser or pesticide, often only where a sensor or camera shows the plant needs it.

Navigation along stored coordinates by GPS and sensors 1. Seed placed at set depth and spacing 1. Controlled spraying where needed 1.

- (b) Any three: the GPS module, which fixes the robot's position so that seeds and spray go to the right places; the sensors, such as cameras and soil sensors, which detect the rows, obstacles, plants and pests; the spraying system of tank, pump and nozzles, which delivers the dose; the seeding mechanism, which meters and places the seeds; the power source, a battery or solar panel, which runs it all.

First component with its part 1. Second component with its part 1. Third component with its part 1.

- (c) Precision farming: each seed and each dose goes to an exact place in the right amount, so germination is even and nothing is wasted. Labour: the robot works for long hours without a team of workers, which matters when farm labour is scarce at sowing time. Environment: less pesticide and fertiliser reaches the soil, the groundwater and nearby streams, and workers are not exposed to the chemicals.

Precision farming point 1. Labour point 1. Environment point 1.

- (d) Volume used by the robot = $0.15 \times 400 = 60$ litres. Volume saved = $400 - 60 = 340$ litres, which is $340/400 \times 100 = 85$ per cent. Benefit other than cost, any one: less chemical reaches the soil and water; less harm to bees and other useful insects; less pesticide residue on the crop; pests are less likely to become resistant.

60 litres 1. 340 litres and 85 per cent 1. Benefit other than cost 1.

Question 8 [12]

- (a) The robot moves along the rows of bushes on wheels or tracks, or flies over them, carrying cameras and environmental sensors. It records images of the leaves together with readings such as soil moisture, temperature and humidity, tags each with its GPS position, and processes them to judge the health of each patch, sending the results to the planter.

Moves through the garden carrying cameras and sensors 1. Readings tagged with position 1. Data processed to judge crop health and reported 1.

- (b) Any three: imaging sensors, such as ordinary, multispectral or thermal cameras, which photograph the leaves; environmental sensors, which measure soil moisture, temperature and humidity; a data storage and processing unit, which keeps and analyses the readings; a communication system, which sends alerts and data to the planter; a power source, which runs the robot.

First component with its part 1. Second component with its part 1. Third component with its part 1.

- (c) Image analysis can spot the first discoloured or damaged leaves, or the insects themselves, in a few bushes long before a person walking the garden would notice, and it marks exactly where they are, so the planter can treat that patch at once rather than spraying the whole garden later.

Early signs detected by image analysis 1. Location marked for prompt local treatment 1.

- (d) Number of images = $3000/5 = 600$. Data = $600 \times 4 = 2400$ MB, about 2.4 GB a day. Sending so much over a field radio link would take a long time and use much battery power, and coverage in a hilly garden may be poor. If the robot examines the images itself and sends only short alerts with the location of a problem, the planter gets the message at once.

Note for the examiner: Accept 2404 MB from a candidate who counts an image at the start of the rows as well, giving 601 images.

2400 MB 1. Reason for on-board processing 1.

- (e) Any two: watering and fertiliser are given according to measured soil moisture and plant health, so the bushes grow evenly; pests and disease are treated early, before they damage the leaf; the planter can see which sections give the best leaf and plan plucking rounds accordingly; records over seasons show which practices raise quality.

First way 1. Second way 1.

Question 9 [12]

- (a) The manipulator is an arm of several links joined by revolute joints, each driven by a servo motor under a controller. The path is programmed in advance, by teaching points with a teach pendant or offline, and the controller moves all joints together so that the welding gun follows the path with precise positioning and controlled force, using feedback from sensors at every joint. Components: actuators at the joints, a controller, an end-effector such as a spot welding gun, sensors such as encoders and force sensors, and a power supply.

Joints driven by servo motors under a controller 1. Programmed path followed with feedback 1. Two components 1. Remaining components 1.

- (b) The manipulator replays a path taught in fixed positions in space and does not itself see the car body, so the body must be held in exactly the position used when the path was taught; the fixture does this. If a body were clamped 5 mm out of place, every weld would land 5 mm away from its proper spot, possibly at the edge of or off the flanges to be joined, giving weak or missing joints, unless a vision or touch sensor were used to find the body and correct the path.

Robot follows a fixed taught path, so the body must be located exactly 1. All welds shifted by 5 mm, giving weak or missed joints 1.

- (c) Components, any four: a welding torch as the end-effector; a welding power source and wire feeder; a positioner or fixture that holds and turns the frame; a seam tracking sensor or camera; the robot controller and teach pendant; safety guarding and fume extraction. Advantages, any two: every weld is made with the same speed, angle and heat, so quality is consistent; the cell works faster and for longer than a person; less filler wire is wasted; workers are kept away from heat, fumes and arc light.

Two components 1. Two further components 1. Two advantages 1.

- (d) Any three: a fence or screen round the cell so that no one can walk into the reach of the arm; light curtains or interlocked gates that stop the robot at once if anyone enters; emergency stop buttons outside the cell; screens that block the arc light, and fume extraction; training, and a rule that only trained staff enter, after locking the robot off.

First measure 1. Second measure 1. Third measure 1.

Question 10 [12]

- (a) A cobot works in the same space as a person. Its sensors detect a person nearby or an unexpected contact, and its control algorithms reduce speed or stop so that the interaction stays safe; between times it carries on with its task. Components: sensors such as force and torque sensors at the joints, proximity sensors and cameras; an AI driven control unit; an end-effector; feedback systems; and a power supply.

Senses people or contact 1. Slows or stops through its control 1. Components 1.

- (b) Power and force limiting: the cobot's speed, force and power are kept low, and it stops or backs off as soon as its joint sensors feel a contact force above a set limit, so a collision cannot injure anyone. Speed and separation monitoring: sensors measure the distance to the nearest person, and the robot slows as the person comes nearer and stops altogether inside a set protective distance.

Power and force limiting: low force, stop on contact above a limit 1. Speed and separation monitoring: distance to the person measured 1. Slowing as the person nears and stopping inside the protective distance 1.

- (c) The person keeps walking during the time to recognise the person and the time to stop, $0.1 + 0.4 = 0.5$ s. Distance walked = $1.6 \times 0.5 = 0.8$ m, so the person must be detected at least 0.8 m away. With the margin, the detection zone should be set at $0.8 + 0.2 = 1.0$ m.

Total time 0.5 s 1. 0.8 m 1. 1.0 m with the margin 1.

- (d) Any three: a cobot needs no safety fence, so it fits into a small workshop beside the workers; it can be taught a new task by leading it by hand or through a simple interface, which suits short batches that change often; it is cheaper to buy and install; it is light and can be moved from one bench to another; a worker and the cobot can share the job, the worker placing the cover and the cobot driving the screws, which raises output without replacing the worker.

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

Question 11 [6]

- (a) A Mars rover is semi-autonomous. Each Martian day the team on the Earth studies the images and data sent back and uploads a plan of drives and science tasks, often relayed by an orbiter. The rover then carries out the plan by itself. While driving it takes stereo images with its hazard and navigation cameras, builds a map of the ground ahead, picks a safe path round rocks and steep slopes, and stops if something is wrong.

Daily plan uploaded from the Earth 1. Plan carried out by the rover itself 1. On-board hazard detection and path choice 1.

- (b) Number of stretches = $120/2.0 = 60$. Driving time per stretch = $2.0/0.04 = 50$ s, so each stretch takes $50 + 30 = 80$ s. Total time = $60 \times 80 = 4800$ s = 80 minutes. Average speed = $120/4800 = 0.025 \text{ m s}^{-1}$. It stops often because it can only see a short way ahead reliably, so it must look again and re-plan before each stretch to avoid driving into a hazard.

80 minutes 1. Average speed 0.025 m s^{-1} 1. Reason for the stops 1.

Question 12 [6]

- (a) The orbiter circles the Moon carrying instruments to map the surface and study its minerals, and relays signals. The lander, Vikram, was to make a soft landing near the lunar south pole and study the surface around it. The rover, Pragyan, carried inside the lander, was to roll out and analyse the soil near the landing site.

Orbiter with its job 1. Lander Vikram with its job 1. Rover Pragyan with its job 1.

- (b) During its descent on the night of 6 to 7 September 2019 the lander lost contact with the ground station and made a hard landing. The orbiter went on working in lunar orbit and returning data.

Hard landing of the lander with the orbiter continuing 1.

- (c) Any two: detailed study of the lunar surface and its minerals from the orbiter; experience in landing and rover design that fed into later missions; national pride and the inspiration of young people; scientific results obtained at low cost compared with similar missions elsewhere.

First advantage 1. Second advantage 1.