

ISC Class 12 Robotics Specimen Paper 2

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) The number of independent movements a robot arm can make, which decides how freely it can place and turn its gripper, is called its:
 - (a) payload (b) degrees of freedom
 - (c) duty cycle (d) resolution
- (ii) An armed ground robot is designed to choose and fire on targets without a human approving each shot. Among the ethical headings below, this case falls most directly under:
 - (a) environmental impact (b) impact on employment
 - (c) autonomy versus human control, in military use (d) privacy of personal data
- (iii) State what is meant by minimally invasive surgery, the kind of surgery the da Vinci Surgical System is built for.
- (iv) A robot in a hospital pharmacy counts tablets into labelled packs for each ward. The main benefit it brings is:
 - (a) fewer dispensing errors (b) shorter operations
 - (c) clearer ultrasound images (d) faster wound healing
- (v) State one reason why a robot that harvests strawberries needs a soft gripper.
- (vi) A monitoring robot judges the health of a crop from how its leaves reflect red and near infrared light. The sensor it uses is:
 - (a) an ultrasonic sensor (b) a limit switch
 - (c) a thermocouple (d) a multispectral camera

- (vii) The hand-held unit with which an operator moves an industrial robot step by step and records the positions of a program is the:
 (a) end-effector (b) gearbox (c) power supply (d) teach pendant
- (viii) State one reason why a robotic welding system gives more consistent welds than a human welder.
- (ix) The electrical power of NASA's Curiosity rover on Mars comes from:
 (a) solar panels (b) hydrogen fuel cells
 (c) a radioisotope thermoelectric generator (d) non-rechargeable batteries alone
- (x) State one task that a robotic arm on a space station can do which saves astronauts from making a spacewalk.

Question 2 [10]

Each part carries 2 marks.

- (i) Explain one way in which robots harm the environment over their working life, and suggest one way in which a manufacturer of robots can reduce that harm. [2]
- (ii) A hospital in Hyderabad uses a robot to carry meal trays to the wards. State two ways in which it must behave differently from a robot that carries parts across an empty factory floor. [2]
- (iii) A harvesting robot in an apple orchard in Shimla picks one apple every 6 s and works 10 hours a day. Calculate the number of apples one robot picks in a day, and the number of robots needed to pick 72,000 apples in three days. [2]
- (iv) Name two types of robot used in a smart factory, other than the industrial robot arm, and state one job done by each. [2]
- (v) State two reasons why robots, rather than astronauts, are sent to explore the surfaces of other planets. [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 manufacturer in Coimbatore is choosing between two robot arms. Arm P has six axes, a rated payload of 7 kg, a reach of 0.9 m, a repeatability of 0.02 mm, a dust and water protection rating of IP69K and a price of 18 lakh rupees. Arm Q is a four axis SCARA arm with a rated payload of 3 kg, a reach of 0.6 m, a repeatability of 0.01 mm, a protection rating of IP20 and a price of 9 lakh rupees. Job 1 is inserting small components of 0.2 kg into circuit boards on a flat bench. Job 2 is lifting 5 kg packs of food off a conveyor that is washed down with water every shift, and tilting each pack into a carton. Using the payload, the protection rating, the repeatability and the price only, state which arm you would select for each job, giving two reasons in each case. [4]
- (b) For Job 2 the gripper itself has a mass of 1.5 kg. Calculate the load on the arm you chose as a percentage of its rated payload, and comment on the margin. [2]
- (c) Explain, in terms of degrees of freedom, why a four axis SCARA arm cannot tilt a pack into a carton while a six axis arm can. [2]

Question 4 [8]

- (a) A team building a spraying robot decides to develop its software with the Robot Operating System (ROS). Give four reasons why ROS helps such a team. [4]
- (b) The team first tests the robot in Gazebo. State two things about the robot and its surroundings that a simulator such as Gazebo models, and explain two reasons why results obtained in simulation may not hold in the field. [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 types of robot used in healthcare, and for each give one example of the work it does in a hospital. [4]
- (b) A hospital in Kochi uses an autonomous robot that disinfects empty isolation wards with ultraviolet light. Explain how such an assistance robot does its work. [3]
- (c) State two safety features the disinfection robot must have, giving the reason for each. [2]
- (d) Robots are increasingly used to look after elderly patients in care homes. Discuss two ethical concerns about human-robot interaction in such care, and suggest one safeguard. [3]

Question 6 [12]

- (a) Explain the working principle of a powered lower limb exoskeleton. [3]
- (b) Name three components of the exoskeleton and state the part each plays. [3]
- (c) Exoskeletons are used both in rehabilitation wards and by workers who lift heavy loads. State two advantages they offer, one in each setting. [2]
- (d) The exoskeleton runs from a lithium-ion battery rated 25.2 V, 6.0 Ah. Only 80 per cent of the stored energy may be used, and the suit draws an average of 120 W while the patient walks. Calculate the energy stored in watt hours and the walking time the battery allows, in minutes. [2]
- (e) Explain what is meant by assist as needed in a rehabilitation robot. [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 ground mobile robot used in a field, and name three of its components. [4]
- (b) Explain how a harvesting robot finds the crop that is ready to be picked. [2]
- (c) Explain how a weeding robot removes weeds, and give two advantages of this method over spraying the whole field with weedkiller. [3]
- (d) A weeding robot clears a strip 1.5 m wide on each pass. It works a field 120 m long and 45 m wide, making passes along the length at 0.5 m s^{-1} , and each turn at the end of a pass takes 20 s. Calculate the number of passes, the number of turns and the total time taken, in hours. [3]

Question 8 [12]

- (a) Apple growers in Himachal Pradesh prune their trees every winter. Explain how a pruning robot decides where to cut and then makes the cut. [4]
- (b) Name three components of a pruning robot and state the part each plays. [3]
- (c) State two difficulties that make pruning harder for a robot than seeding or spraying. [2]
- (d) State three advantages that pruning robots could bring to the orchard owners. [3]

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 how a load-carrying automated guided vehicle works in a steel plant, describing two different ways in which it can find its route. [4]
- (b) A load-carrying AGV with a payload of 600 kg must move 4800 kg of steel coils from the store to a press 120 m away. It travels at 1.0 m s^{-1} in both directions and spends a total of 60 s loading and unloading on each trip, and it returns empty to the store after every trip, including the last. Calculate the number of trips and the total time in minutes. [3]
- (c) State two features that keep workers safe when AGVs share the floor with them. [2]
- (d) State three advantages of AGVs over forklifts driven by workers. [3]

Question 10 [12]

- (a) A security and sensing robot patrols a pharmaceutical plant in Baddi at night. Explain its working principle and name its main components. [4]
- (b) The robot raises a fire alarm only when two different signs of fire are detected together, never on the reading of one sensor alone. Explain why, and explain why it reports a fire ahead of an intruder when both are detected at once. [2]
- (c) The robot patrols a loop 360 m long at 0.8 m s^{-1} and stops for 30 s at each of four checkpoints. Calculate the time for one patrol, in minutes, and the number of complete patrols it can make in an eight hour night shift. [3]
- (d) The same plant uses a 3D printing robot to make spare parts. Explain how a 3D printing robot makes a part, and state two advantages of making spare parts this way. [3]

SECTION E: SPACE ROBOTICS (6 Marks)

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

Question 11 [6]

- (a) Vyommitra is a robot developed by ISRO and designed to fly in the uncrewed Gaganyaan mission. Describe what Vyommitra is and how it works. [2]
- (b) Name four of its components. [2]
- (c) Explain why such a robot is flown before a human crew. [2]

Question 12 [6]

- (a) Distinguish between a space probe and a lander, giving one example of each. [2]
- (b) Explain how a lander uses its sensors and engines to make a soft landing on the Moon or Mars. [2]
- (c) Explain why probes and landers must be able to act on their own for long periods. [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) (b) degrees of freedom. Each independent joint motion adds one degree of freedom; six are needed to place and orient a tool fully in space.
- (ii) (c) autonomy versus human control, in military use. Removing the human from the decision to fire is the central question.
- (iii) Surgery carried out through a few small cuts, using a camera and long thin instruments, instead of one large opening.
- (iv) (a) fewer dispensing errors. The robot reads each prescription and counts and labels exactly, without the slips of tired staff.
- (v) A strawberry is soft and bruises easily, so it must be held with a gentle, spread out force. Accept that the fruit varies in size and shape, so a gripper that moulds round it is needed.
- (vi) (d) a multispectral camera. Healthy leaves reflect strongly in near infrared and absorb red light.
- (vii) (d) teach pendant.
- (viii) The robot repeats the same torch speed, angle, distance and heat on every weld and does not tire. Any one such reason.
- (ix) (c) a radioisotope thermoelectric generator, which turns the heat of decaying plutonium-238 into electricity day and night and through dust storms.
- (x) Any one: capturing a visiting cargo spacecraft and berthing it; moving equipment or a large module into place outside the station; inspecting or replacing an outside part.

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) Harm, any one: robots use much electricity over their life, often from fossil fuels; their batteries and electronics contain toxic and scarce materials that become electronic waste; mining the metals for motors and batteries damages land. Remedy, any one: design robots for low energy use; make them repairable and their parts recyclable; take back old robots and batteries for recycling.

One way robots harm the environment 1. One remedy 1.

- (ii) Any two: it must move slowly and give way to patients, visitors and staff, who walk unpredictably; it must detect and stop for people, including a patient on a wheelchair or a child, at close range; it must signal its presence quietly with lights or gentle sounds so as not to disturb patients; it must use lifts and doors safely alongside people; it must keep the food clean and covered.

First difference 1. Second difference 1.

- (iii) Apples per day = $10 \times 3600/6 = 6000$. In three days one robot picks 18000, so the number of robots = $72000/18000 = 4$.

6000 apples a day 1. 4 robots 1.

- (iv) Any two: a collaborative robot, which works beside people on assembly; an automated guided vehicle, which carries materials between stations; a 3D printing robot, which builds parts layer by layer; a robotic welding system, which joins metal parts; a security and sensing robot, which patrols for faults and intruders.

First type with its job 1. Second type with its job 1.

- (v) Any two: robots can survive radiation, extreme cold and the lack of air, which would kill a person; they need no food, water or return journey, so the mission is far cheaper; the long travel times and signal delays are no threat to a robot's life; a lost robot does not mean a lost life.

First reason 1. Second reason 1.

Question 3 [8]

- (a) Job 1: Arm Q. Reasons, any two: the parts weigh 0.2 kg, well within its 3 kg payload; its repeatability of 0.01 mm suits inserting components; it costs half as much as Arm P; IP20 is enough on a dry bench. Job 2: Arm P. Reasons, any two: the pack and gripper weigh more than Arm Q's 3 kg payload but within Arm P's 7 kg; IP69K means it is dust tight and protected against the high pressure, high temperature water jets of the daily wash down, while IP20 gives no protection against water; the higher price is justified because Arm Q cannot do the job. The ability to tilt the pack is not credited here, since it is asked in part (c).

Arm Q for Job 1 1. Two reasons for Job 1 1. Arm P for Job 2 1. Two reasons for Job 2 1.

- (b) Load = gripper + pack = 1.5 + 5.0 = 6.5 kg. Percentage of rated payload = $6.5/7 \times 100 = 92.9$ per cent. The margin is only 0.5 kg, which is small: a heavier pack, a change of gripper, quick accelerations or a pack held far from the wrist could take the arm beyond its rating.

6.5 kg and 92.9 per cent 1. Margin judged small with a reason 1.

- (c) Placing a tool anywhere and turning it to any orientation needs six degrees of freedom, three for position and three for orientation. A SCARA has four: two revolute joints moving the arm in a horizontal plane, one prismatic joint moving it up and down, and a wrist rotation about a vertical axis, so it can only turn the pack about the vertical and keep it level. A six axis arm has the extra wrist joints that rotate the tool about horizontal axes, so it can tip the pack.

SCARA's four axes, all keeping the tool level 1. Six axis arm's extra rotations about horizontal axes 1.

Question 4 [8]

- (a) Any four: ROS provides ready made, tested packages for common jobs such as navigation, mapping and drivers for cameras and GPS, so the team need not write them; the software is split into separate programs, the nodes, which can be written, tested and replaced one at a time by different members; standard message formats let parts from different makers work together; tools are provided for viewing and recording the robot's data, which helps debugging; the same software runs on the simulated robot in Gazebo and on the real one; it is free, open source and supported by a large community; nodes can run on different computers linked by a network.

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

- (b) Things modelled, any two: the physics acting on the robot, such as gravity, its mass, friction and collisions; its moving parts and motors; its sensors, such as cameras, GPS and range finders, which give simulated readings; the surroundings, such as the ground, the crop rows and obstacles. Reasons, any two: real soil is uneven, muddy and slippery in ways the model does not capture; real sensors give noisy readings, and sunlight, dust and spray affect the camera; motors and batteries do not behave exactly as modelled; real plants and weather vary from day to day.

First thing modelled 1. Second thing modelled 1. First reason 1. Second reason 1.

Question 5 [12]

- (a) Surgical robots help surgeons operate with greater precision through small cuts, for example the da Vinci system. Assistance robots help staff and patients with everyday tasks, for example carrying medicines and meals or helping to lift a patient. Diagnostic robots help examine patients, for example a robotic ultrasound system or a robot that draws blood samples. Rehabilitation and therapy robots help patients regain movement, for example exoskeletons and arm training robots after a stroke.

Surgical with example 1. Assistance with example 1. Diagnostic with example 1. Rehabilitation and therapy with example 1.

- (b) The robot carries ultraviolet C lamps on a mobile base. It maps the ward with LIDAR or cameras, or uses a stored map, and drives by itself to a series of positions round the room. At each it stops long enough to give every surface the dose of ultraviolet light needed to kill bacteria and viruses, the time being worked out from the distance to the surfaces, and it then reports the room as done.

Autonomous navigation round the ward 1. Stops at positions to give the dose 1. Dose time set by distance, with completion reported 1.

- (c) Ultraviolet C light harms skin and eyes. Any two, each with its reason: motion or body heat sensors that switch the lamps off at once if a person enters; a door interlock; warning lights or a spoken warning; starting only by remote command after staff confirm the room is empty; an emergency stop.

First feature with reason 1. Second feature with reason 1.

- (d) Any two, discussed: elderly people may become attached to a robot or lonely if robots replace human contact, so care must stay human centred; a patient with failing memory may not understand that the robot is a machine, or may be deceived by it; the robot's cameras and microphones record private moments; a frail person may be hurt if the robot moves or lifts wrongly, and it must be clear who is responsible; the patient's right to refuse the robot's help must be respected. Safeguard, any one: robots support but do not replace human carers; the patient or family gives informed consent; recordings are limited and protected; a named person is responsible for each robot.

First concern 1. Second concern 1. One safeguard 1.

Question 6 [12]

- (a) An exoskeleton is a wearable powered frame strapped along the legs. Sensors detect the movement the wearer is making or intends to make, through joint angle sensors, foot pressure sensors or EMG signals. The control system then drives motors at the hip and knee to give just the help needed to stand, step or climb, while the frame carries part of the body weight.

Sensing of the wearer's movement or intent 1. Motors driven by the control system to help 1. Frame carrying part of the weight 1.

- (b) Any three: the structural frame, which carries the load and is strapped to the limbs; motors and actuators at the joints, which supply the movement; the control system, which reads the sensors and decides how much help to give; the sensors, which measure joint angles, foot pressure or muscle signals; the battery, which powers the suit.

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

- (c) Rehabilitation: a patient who cannot walk unaided can stand and walk, improving mobility and allowing many repetitions of walking practice. Industry: the suit takes part of the load, adding strength and endurance and reducing back and shoulder injuries among workers.

Rehabilitation advantage 1. Industrial advantage 1.

- (d) Energy stored = $25.2 \times 6.0 = 151.2$ Wh. Usable energy = $0.80 \times 151.2 = 120.96$ Wh. Walking time = $120.96/120 = 1.008$ h = 60.5 minutes, about one hour.

151.2 Wh 1. About 60.5 minutes 1.

- (e) The robot gives only as much help as the patient cannot provide: it lets the patient do the work while they can, steps in when they fall short of the target movement, and reduces its help as the patient recovers, so that the patient's own effort is always exercised.

Help only where the patient falls short 1. Help reduced as recovery proceeds 1.

Question 7 [12]

- (a) A ground mobile robot travels across the field by itself on wheels or tracks, using GPS and its cameras or LIDAR to follow the rows and avoid obstacles. As it goes it collects data on the soil and the crop and does a job such as weeding, harvesting or pruning. Components, any three: a mobility system of wheels or tracks with motors; a control unit; a GPS module; imaging and sensing equipment; a communication module.

Autonomous travel on wheels or tracks 1. Navigation by GPS and sensors, collecting data 1. Three components, 1 mark for any two 1. Third component 1.

- (b) Its cameras photograph the plants and image processing, often using machine learning, picks out the fruit or vegetables among the leaves and judges ripeness from colour and size; a depth camera then gives the position of each ripe item so that the arm can reach it.

Crop found and ripeness judged from images 1. Position found for the arm 1.

- (c) The robot's camera tells weeds from crop plants by their shape and colour, and the weed is then removed by a small hoe or blade, pulled out, burnt with a laser or given a tiny dot of weedkiller. Advantages, any two: little or no herbicide is used, so costs and harm to soil and water fall; the crop is not touched by chemicals; it

suits organic farming; weeds do not become resistant to herbicides.

Weeds recognised by the camera 1. Method of removal 1. Two advantages 1.

- (d) Number of passes = $45/1.5 = 30$, each 120 m long, so distance = 3600 m and driving time = $3600/0.5 = 7200$ s. Number of turns = $30 - 1 = 29$, taking $29 \times 20 = 580$ s. Total time = $7200 + 580 = 7780$ s = 2.16 hours.

Note for the examiner: Values checked by machine. A candidate who counts 30 turns gets 7800 s, 2.17 hours; award the last mark but not the second.

30 passes 1. 29 turns 1. 2.16 hours 1.

Question 8 [12]

- (a) The robot scans the tree from several sides with stereo or depth cameras, or LIDAR, and builds a three dimensional model of the trunk and branches. Software, set up with the grower's pruning rules, picks out the branches to remove, such as crossing, crowded or old wood, and the points at which to cut. The robot arm then guides its cutting tool to each point, checking its position with the camera, and closes the cutter.

Tree scanned and modelled in 3D 1. Pruning rules used to choose cut points 1. Arm guides the cutter to the point 1. Position checked with the camera before the cut 1.

- (b) Any three: cameras or LIDAR, which see the tree; a processing unit, which builds the model and chooses the cuts; a robot arm, which reaches the branches; a cutting end-effector such as powered shears or a saw, which makes the cut; a mobile base, which carries it from tree to tree; a power source.

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

- (c) Any two: every tree is different, so there is no fixed pattern to follow; branches hide each other, so the robot cannot see the whole tree; the decision which branch to cut needs judgement; outdoor light, wind and cold make sensing harder; the arm must reach into a tangle of branches without damaging them.

First difficulty 1. Second difficulty 1.

- (d) Any three: a shortage of skilled pruners in winter is overcome; every tree is pruned to the same standard; work can go on for long hours; workers avoid ladders and cold, tiring work; a record of each tree is kept to plan the next season.

First advantage 1. Second advantage 1. Third advantage 1.

Question 9 [12]

- (a) The AGV is a driverless vehicle that receives a transport task from the plant's control system, drives along a route to the pick-up point, loads, carries the load to its destination and unloads, reporting back and charging when needed; scanners make it slow or stop for people and obstacles. Route finding, any two: following a magnetic tape, wire or painted line in the floor; reading QR codes or markers on the floor at intervals; laser navigation using reflectors fixed on walls; natural navigation, in which a LIDAR compares what it sees with a stored map.

Task received and carried out without a driver 1. Slows or stops for obstacles 1. First route finding method 1. Second route finding method 1.

- (b) Number of trips = $4800/600 = 8$. Each trip = 120 m there and 120 m back at 1.0 m s^{-1} , 240 s, plus 60 s, = 300 s. Total = $8 \times 300 = 2400$ s = 40 minutes.

8 trips 1. 300 s per trip 1. 40 minutes 1.

- (c) Any two: laser safety scanners that slow the AGV and then stop it when someone is in its path; emergency stop buttons on the vehicle; flashing lights and warning sounds; bumpers that stop it on contact; marked lanes kept clear for AGVs.

First feature 1. Second feature 1.

- (d) Any three: they can run round the clock without breaks; they follow the same safe route at a steady speed, so there are fewer accidents and less damage to goods; they reduce the cost of drivers; they are linked to the plant's control system, so material arrives exactly when needed and every move is recorded; they free workers from tiring, repetitive driving.

First advantage 1. Second advantage 1. Third advantage 1.

Question 10 [12]

- (a) The robot patrols the plant on a planned route by itself, using its navigation system, and watches with cameras and sensors for unauthorised people, fire, gas leaks, water leaks and machines that are overheating or making unusual sounds. Its processor, often using AI, decides when a reading is abnormal and it sends an alert, with images and location, to the security room. Components: sensors such as cameras, thermal cameras, flame, smoke, gas and motion sensors; a navigation system; an AI processor; a communication module; a power source.

Autonomous patrol of a planned route 1. Watching for intruders, fire and faults 1. Alerts sent with location 1. Components 1.

- (b) A flame sensor alone can be set off by sunlight, a hot lamp or a welding arc, so requiring smoke or a high temperature as well cuts false alarms. Fire is reported first because it is the greater danger to life and to the plant, and its alarm must not wait behind the intruder alarm.

Reason for two conditions 1. Reason for giving fire priority 1.

- (c) Driving time = $360/0.8 = 450$ s. Stops = $4 \times 30 = 120$ s. One patrol = $450 + 120 = 570$ s = 9.5 minutes. Eight hours = 28800 s, and $28800/570 = 50.53$, so 50 complete patrols.

Driving time 450 s and stops 120 s 1. 9.5 minutes 1. 50 complete patrols 1.

- (d) The robot builds the part layer by layer from a computer model: its nozzle or tool moves along the outline of each thin slice of the part, laying down molten plastic or metal, or fusing powder, and then rises to the next layer until the part is complete. Advantages, any two: a spare part can be made on site within hours instead of waiting for delivery; one-off and complex shapes cost no more to make than simple ones; no stock of rarely used spares need be held; little material is wasted.

Layer by layer from a computer model 1. First advantage 1. Second advantage 1.

Question 11 [6]

- (a) Vyommitra is a half humanoid robot, with a head, torso and arms but no legs, that sits in the crew module. It responds to commands from mission control, monitors conditions in the module such as air pressure and the life support systems, reports and gives alerts, operates panel switches and can speak.

Half humanoid in the crew module 1. Responds to mission control and monitors the module 1.

- (b) Joints and actuators; end-effectors, that is its hands; sensors and cameras; a power source. Accept the controller or processor in place of any one.

Two components 1. Two further components 1.

- (c) The crew module and its life support systems must be proved in a real flight, with a human-like occupant reporting on conditions inside, before any astronaut is put at risk. Its records show how a person would have been affected, and any fault can be put right first.

Systems tested in flight first 1. No astronaut put at risk 1.

Question 12 [6]

- (a) A space probe flies past, orbits or travels on through space to study distant bodies, for example Voyager 1. A lander sets down on the surface of a body and works from that one spot, for example NASA's InSight on Mars or the Vikram lander of Chandrayaan-3. Accept any correct examples.

Probe with example 1. Lander with example 1.

- (b) As it descends the lander measures its height and speed with a radar or laser altimeter and its inertial sensors, and fires throttled engines against its fall to slow down, often after a heat shield and parachute on Mars. Near the ground its cameras check for rocks and slopes and it moves sideways to a safe spot, then touches down gently on shock absorbing legs.

Height and speed sensed and engines used to slow down 1. Hazard avoidance and gentle touchdown 1.

- (c) They work far from the Earth, so radio signals take minutes or hours each way and a descent or an emergency is over before any command could arrive; contact may also be lost for long periods. They must therefore sense, decide and act for themselves.

Signal delay or loss of contact 1. Must sense, decide and act for themselves 1.