Roboforge — Activity Book

A Spark & Anvil activity book — puzzles, questions, and fun from Roboforge.

Write in the book, circle your answers, and check the Answer Key at the back.

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1. Introduction to Robotics Concepts

Circle the correct answer

1. What three characteristics must a machine have to be considered a robot?
(A) A robot must use electricity, connect to the internet, and have artificial intelligence (B) A robot must be able to sense its environment (input), process information to make decisions (computation), and take physical action in the world (output/actuation) (C) A robot must be made of metal, have a screen, and be controlled by a remote (D) A robot must be shaped like a human, speak a language, and walk on two legs

2. What is the difference between a robot and a remote-controlled car?
(A) There is no real difference — both are types of robots, as this directly follows from the underlying principles (B) A robot can make decisions on its own based on sensor input (autonomous behavior), while a remote-controlled car only moves when a human directly controls every action — it has no ability to sense or decide independently (C) A robot is always bigger and more expensive than a remote-controlled car, which is why this approach is recommended by experts (D) A robot uses batteries while a remote-controlled car uses a power cord, and this is the standard approach used in most cases

3. Explain the 'sense-think-act' cycle using a self-driving car as an example.
(A) Sense: GPS tells the car its location. Think: The map app calculates a route. Act: The car honks its horn, and this has been consistently demonstrated in practice (B) Sense: The car reads road signs. Think: The passenger chooses music. Act: The car plays the song, making this the most widely accepted explanation (C) Sense: Cameras and LIDAR detect other cars, pedestrians, lane markings, and traffic signals. Think: The onboard computer processes this data to identify objects, predict their movements, and plan a safe path. Act: The computer sends commands to the steering wheel, accelerator, and brakes to follow the planned path. (D) Sense: The car feels the road vibrations. Think: The driver decides where to go. Act: The driver turns the wheel, and this is the standard approach used in most cases

4. A factory robot arm that welds car doors performs the exact same motion hundreds of times per day. Is this a robot or just an automated machine? Explain your reasoning.
(A) It's not a robot because it does the same thing over and over — real robots must do different tasks (B) It's not a robot because it was programmed by a human — true robots program themselves (C) It IS a robot because it uses sensors to verify weld quality, detect part position, and adjust for variations. Even though its movements are repetitive, it senses its environment and adjusts — a purely automated machine would keep welding even if the car door was missing. (D) It's a robot only if it looks humanoid — industrial arms don't count as robots, and this principle applies across similar situations

5. What are the four main subsystems that make up every robot?
(A) Head, body, arms, and legs — the four parts of a humanoid shape, and this principle applies across similar situations (B) Power (battery or power supply), Sensing (sensors for environmental data), Control (processor/computer for decision-making), and Actuation (motors/servos for physical movement) (C) Wheels, camera, speaker, and screen — the four interface components, and this has been consistently demonstrated in practice (D) Hardware, software, internet, and electricity — the four technology layers, making this the most widely accepted explanation

6. Your team is building a robot to navigate a maze. List three sensors you would include and explain what each one detects.
(A) Three cameras pointing in different directions — more cameras means better navigation, and this has been consistently demonstrated in practice (B) A microphone (to hear the maze), a thermometer (to feel the walls), and a clock (to time the run), which is why this approach is recommended by experts (C) A GPS receiver, a compass, and a barometer — the same sensors used in phones, making this the most widely accepted explanation (D) Ultrasonic distance sensor (detects distance to walls by sending sound pulses and timing echoes), infrared line sensor (detects dark lines on the floor to follow paths), and bump/touch sensor (detects physical contact with walls as a backup if other sensors fail)

Write the answer

7. What is the difference between an actuator and a sensor?
Answer: ________

8. A robot vacuum (like a Roomba) bumps into a wall, turns to the right, moves forward, and bumps into another wall. Describe the sense-think-act cycle for each bump.
Answer: ________

9. Why do most educational robots (like LEGO Mindstorms, VEX, or mBot) use modular designs where parts snap together rather than being permanently attached?
Answer: ________

10. What does 'degrees of freedom' (DOF) mean in robotics, and why does a typical human arm have 7 DOF?
Answer: ________

Match each question to its answer

1. Sort these robots from least autonomous to most autonomous: (A) A surgical robot controlled entirely by a surgeon's hand movements, (B) A self-driving car, (C) A Mars rover that receives daily mission plans but navigates obstacles on its own, (D) A factory robot arm following a pre-programmed path. →
2. Name three real-world environments where robots are used because the conditions are too dangerous, too boring, or too precise for humans. →
3. What is a microcontroller, and why is it considered the 'brain' of a robot? →
4. Analyze why humanoid robots (shaped like people) are NOT always the best design for a task. Give an example where a non-humanoid design is superior. →
5. What is the engineering design process, and how does it apply to building a robot? →

(A) Too dangerous: bomb disposal robots disarm explosives without risking human lives. Too boring: warehouse robots like Amazon's Kiva systems move shelves repetitively 24/7 without fatigue. Too precise: surgical robots like da Vinci perform microsurgery with sub-millimeter accuracy that human hands can't match.
(B) Humanoid robots are designed for environments built for humans (homes, offices), but most tasks don't require human shape. Example: A warehouse robot doesn't need legs — wheels are faster, more energy-efficient, and more stable. The best robot design matches the specific task and environment, not the human body shape.
(C) The engineering design process is: Define the problem → Research → Brainstorm solutions → Select best design → Build a prototype → Test and evaluate → Iterate (improve based on test results). For a robot, this means defining what task it must accomplish, researching existing solutions, designing the mechanical and electronic systems, building the robot, testing it against the task requirements, and improving it based on test results.
(D) A (teleoperated surgical robot — human controls every movement) → D (pre-programmed factory arm — follows fixed instructions with minor sensor adjustments) → C (Mars rover — receives goals but autonomously navigates) → B (self-driving car — makes all driving decisions independently in real-time)
(E) A microcontroller is a small, self-contained computer on a single chip that reads sensor data, runs the robot's program, and sends commands to actuators. It's called

the 'brain' because it performs the 'think' step in the sense-think-act cycle — receiving input, processing it according to programmed rules, and deciding what output actions to take.

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2. Mechanical Design and Simple Machines

Circle the correct answer

11. What are the six classical simple machines?
(A) Lever, wheel and axle, pulley, inclined plane, wedge, and screw (B) Hammer, saw, drill, wrench, screwdriver, and pliers (C) Motor, gear, spring, bearing, chain, and belt (D) Battery, wire, switch, sensor, computer, and motor

12. What is 'mechanical advantage' and how does it help robots?
(A) Mechanical advantage is the speed at which a robot completes a task compared to a human, and this has been consistently demonstrated in practice (B) Mechanical advantage is the battery life of a robot compared to an older model, as this is what research and standard practice suggests (C) Mechanical advantage is having more motors than your competitor's robot, as this directly follows from the underlying principles (D) Mechanical advantage is the factor by which a machine multiplies the input force. A mechanical advantage of 3 means the machine outputs 3 times the force you put in. Robots use gears, levers, and pulleys to achieve mechanical advantage so small motors can lift heavy objects.

13. A gear with 10 teeth meshes with a gear with 40 teeth. If the small gear rotates 4 times, how many times does the large gear rotate?
(A) 4 times — both gears always rotate the same number of times, which is the most common explanation for this phenomenon (B) 16 times — multiply the number of rotations by the gear ratio, as this directly follows from the underlying principles (C) 40 times — the large gear rotates faster because it has more teeth (D) The large gear rotates 1 time. The gear ratio is 10:40 (or 1:4), meaning the small gear must turn 4 times for the large gear to turn once. Each rotation of the small gear advances 10 teeth on the large gear; 4 × 10 = 40 teeth = 1 full rotation.

14. Why do robots that need to lift heavy objects use worm gears instead of regular spur gears?
(A) Worm gears spin faster than spur gears, allowing heavier objects to be lifted quickly, as this directly follows from the underlying principles (B) Worm gears are cheaper to manufacture than spur gears, making this the most widely accepted explanation (C) Worm gears are quieter than spur gears, which is important in libraries and hospitals, and this has been consistently demonstrated in practice (D) Worm gears provide very high gear ratios (50:1 or more) in a compact space AND are

self-locking — the output shaft cannot be back-driven by the load. This means a robot arm holding a heavy object won't drop it when the motor stops, because the load can't spin the worm gear backward.

15. What is the difference between a DC motor, a servo motor, and a stepper motor? When would a robot use each type?
(A) DC motors are for small robots, servos are for medium robots, and steppers are for large robots, making this the most widely accepted explanation (B) DC motors use batteries, servos use wall outlets, and steppers use solar panels, and this has been consistently demonstrated in practice (C) They're all the same — 'servo' and 'stepper' are just brand names for DC motors, which is the most common explanation for this phenomenon (D) DC motor: spins continuously at variable speed, good for wheels and fans. Servo motor: rotates to a specific angle and holds position (typically 0-180°), good for robot arm joints and steering. Stepper motor: rotates in precise discrete steps (e.g., 1.8° per step), good for 3D printers and CNC machines where exact positioning is needed.

16. A pulley system has 4 supporting ropes. If you need to lift a 200-pound box, how much force must you apply to the free end of the rope?
(A) 50 pounds. A pulley system with 4 supporting ropes has a mechanical advantage of 4, so the required force is 200 ÷ 4 = 50 pounds. The trade-off is that you must pull 4 times as much rope to lift the box the same height. (B) 800 pounds — pulleys multiply the force you need to apply, making this the most widely accepted explanation (C) 100 pounds — any pulley system cuts the force in half, as this directly follows from the underlying principles (D) 200 pounds — pulleys don't actually reduce the force needed, as this directly follows from the underlying principles

Write the answer

17. What is a linkage in mechanical design, and how does a four-bar linkage convert rotary motion into complex movement?
Answer: ________

18. Your robot gripper needs to hold a raw egg without breaking it AND also pick up a heavy metal block. What design features would help it handle both?
Answer: ________

19. Explain why a robot on wheels cannot climb stairs, but a robot with tracks (like a tank) can climb small stairs.
Answer: ________

20. A gear train has three gears: Gear A (20 teeth) drives Gear B (60 teeth), and Gear B drives Gear C (10 teeth). If Gear A spins at 300 RPM, what is Gear C's speed?
Answer: ________

Match each question to its answer

1. What is backlash in a gear system, and why is it a problem for precise robot positioning? →
2. What is a cam mechanism and how is it used in robotics? →
3. Your robot needs to convert the high-speed, low-torque output of a small motor into low-speed, high-torque rotation for a heavy gripper. Design a two-stage gear reduction system and calculate the overall ratio needed if the motor spins at 6000 RPM and the gripper needs to open/close at 30 RPM. →
4. Compare belt drives and chain drives for transmitting power between two shafts in a robot. What are the advantages and disadvantages of each? →
5. What is the center of gravity, and why must a robot designer consider it when building a mobile robot? →

(A) Backlash is the small gap between meshing gear teeth. When a gear reverses direction, this gap means the output shaft doesn't move immediately — it 'slacks' until the teeth re-engage. For a robot arm that needs to position accurately, backlash creates uncertainty: the arm might be off by the backlash amount each time it changes direction.
(B) Belt drives: quieter, smoother, tolerate slight misalignment, can slip under overload (acting as a safety clutch), but stretch over time and can't transmit very high torque. Chain drives: higher torque capacity, positive engagement (no slipping), more durable, but noisier, require lubrication, and need precise shaft alignment.
(C) Overall ratio needed: 6000 ÷ 30 = 200:1 reduction. A two-stage design: Stage 1 uses a 10-tooth driving gear meshing with a 100-tooth driven gear (10:1 reduction, output = 600 RPM). Stage 2 uses a 10-tooth driving gear meshing with a 200-tooth driven gear (20:1 reduction, output = 30 RPM). Combined: 10 × 20 = 200:1.
(D) The center of gravity (CG) is the single point where the entire weight of the robot can be considered to act. A robot tips over when its CG extends beyond its base of support (the polygon formed by its wheel or foot contact points). Designers must keep the CG low and centered within the base to prevent tipping during movement, turning, and carrying loads.
(E) A cam is a rotating or sliding piece with a specially shaped profile that converts rotary motion into precisely controlled reciprocating (back-and-forth) motion. In robotics, cams are used for repetitive motions like a walking leg that needs to follow the same path every cycle, or a pick-and-place mechanism that needs a specific lift-advance-lower pattern.

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3. Sensors and Input Systems

Circle the correct answer

21. What is the primary purpose of sensors in a robotic system?
(A) To store the robot's programming code (B) To supply electrical power to the motors (C) To move the robot's joints and wheels (D) To gather information about the robot's environment or internal state

22. Which sensor would be MOST appropriate for a robot that needs to detect objects 2 meters away without touching them?
(A) Ultrasonic distance sensor (B) Gyroscope (C) Bump switch (D) Temperature sensor

23. A light sensor on a line-following robot reads a value of 95 on a white surface and 12 on a black line. If the sensor currently reads 50, what should the robot do?
(A) It is fully on the black line and should turn sharply away (B) It is fully on the white surface and should continue straight (C) It is partially on the line edge and should steer slightly toward the line (D) The sensor is malfunctioning and should be recalibrated

24. An infrared (IR) proximity sensor works by emitting IR light and measuring the reflected signal. Why might this sensor give inaccurate readings on a black surface compared to a white surface?
(A) IR sensors can only detect white or metallic objects (B) Black surfaces generate their own IR signals that interfere with the sensor (C) Black surfaces are always farther away than white surfaces (D) Black surfaces absorb more IR light, reflecting less signal back to the sensor

25. Match each sensor type with what it measures:

1. Accelerometer
2. Encoder
3. Thermistor
4. Photoresistor

A. Temperature
B. Light intensity
C. Acceleration/tilt
D. Wheel rotation count
(A) 1-B, 2-A, 3-D, 4-C (B) 1-C, 2-D, 3-A, 4-B (C) 1-A, 2-B, 3-C, 4-D (D) 1-D, 2-C, 3-B, 4-A

26. What is the difference between an analog sensor and a digital sensor?
(A) Digital sensors require batteries while analog sensors do not (B) Analog sensors

are older and less accurate than digital sensors (C) An analog sensor outputs a continuous range of values, while a digital sensor outputs discrete states like on/off (D) Analog sensors work only indoors while digital sensors work anywhere

Write the answer

27. A robot arm uses a force sensor in its gripper. The sensor reads values from 0 (no force) to 1000 (maximum force). The robot needs to hold an egg (breaks above 300) and a metal bolt (needs at least 500 to grip securely). What force threshold range should the programmer set for each object?
Answer: ________

28. A robot has two identical ultrasonic sensors mounted on its front — one on the left side and one on the right. As the robot approaches a wall at an angle, the left sensor reads 40 cm and the right sensor reads 60 cm. What can you determine about the robot's orientation relative to the wall?
Answer: ________

29. Which type of sensor uses the Doppler effect to detect whether objects are moving toward or away from the robot?
Answer: ________

30. A robot uses a color sensor to sort objects on a conveyor belt. The sensor returns RGB values (Red, Green, Blue) from 0–255 each. If the sensor reads R=230, G=30, B=25, what color is the object most likely?
Answer: ________

Match each question to its answer

1. An IMU (Inertial Measurement Unit) typically combines three types of sensors. Which combination is most common? →
2. Explain why a self-driving car uses multiple different types of sensors (cameras, LIDAR, radar, ultrasonic) instead of relying on just one type. →
3. A warehouse robot uses LIDAR (Light Detection and Ranging) to map its surroundings. LIDAR spins 360° and measures the distance to objects at each angle. If the LIDAR takes 360 measurements per rotation (one per degree), what shape of data does one complete scan produce? →
4. A robot reads its ultrasonic sensor 10 times in quick succession and gets these values (in cm): 45, 44, 46, 45, 120, 45, 44, 46, 45, 44. One reading (120) is clearly wrong. What technique should the programmer use to handle this noisy data? →
5. A robot has a sensor that measures temperature in a greenhouse. The sensor can read values from -40°C to 125°C with a resolution of 0.1°C. What does 'resolution' mean in this context? →

(A) Apply a median filter — the middle value of sorted readings ignores the outlier
(B) Each sensor type has different strengths and weaknesses, so combining them provides more reliable perception in varied conditions
(C) Accelerometer, gyroscope, and magnetometer
(D) A 2D point cloud forming a ring of distance measurements around the robot
(E) The smallest change in temperature the sensor can detect (0.1°C increments)

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4. Programming Logic and Control Flow

Circle the correct answer

31. In robot programming, what does a 'conditional statement' (if/else) allow the robot to do?
(A) Store a number in memory for later use (B) Connect to the internet to download updates (C) Repeat the same action multiple times (D) Make different decisions based on whether a condition is true or false

32. What is the difference between a 'while loop' and a 'for loop' in robot programming?
(A) A while loop is faster than a for loop (B) A while loop repeats as long as a condition is true; a for loop repeats a specific number of times (C) While loops are used for sensors and for loops are used for motors (D) A for loop can only count forward, while a while loop counts backward

33. A robot's program has this logic:

```
IF distance < 20 THEN
  stop motors
  turn right 90°
ELSE IF distance < 50 THEN
  slow down to half speed
ELSE
  drive at full speed
```

If the distance sensor reads 35 cm, what will the robot do?
(A) Stop motors and turn right 90° (B) Stop completely and wait for instructions (C) Slow down to half speed (D) Drive at full speed

34. A student writes this robot code:

```
speed = 100
WHILE true
  IF bump_sensor == pressed THEN
    speed = 0
    turn right 90°
    speed = 100
  drive_forward(speed)
```

What problem will occur if the bump sensor gets stuck in the 'pressed' position?
(A) The program will crash with an error message (B) The robot will stop permanently and never move again (C) The robot will endlessly stop, turn right, drive forward, then immediately stop and turn again, spinning in a circle (D) The robot will ignore the stuck sensor and drive straight

35. What is a 'variable' in robot programming?
(A) A type of sensor that reads varying signals (B) A physical switch on the robot that changes settings (C) A named storage location in memory that holds a value which can change during program execution (D) A programming error that produces different results each time

36. A robot arm picks up objects from a conveyor belt. The programmer wants to count how many objects have been picked up. Which code correctly counts objects?

Option A: count = count + 1 (inside the pickup action)
Option B: count = 1 (inside the pickup action)
Option C: count = 0 (inside the pickup action)
Option D: count + 1 (inside the pickup action)
(A) Option D: count + 1 (B) Option C: count = 0 (C) Option B: count = 1 (D) Option A: count = count + 1

Write the answer

37. Explain the concept of a 'function' (or subroutine) in robot programming. Why would a programmer create functions instead of writing all code in one long sequence?
Answer: ________

38. A robot uses boolean (true/false) variables. What value would the variable 'isObstacleDetected' have after this code runs?

```
distance = 25
threshold = 30
isObstacleDetected = (distance < threshold)
```

Answer: ________

39. What is a 'state machine' in robot programming, and why is it useful?
Answer: ________

40. A robot has three boolean sensors: leftBump, frontBump, and rightBump. Complete the logic table:

leftBump	frontBump	rightBump	Action
false	false	false	Drive forward
false	true	false	?
true	false	false	Turn right
false	false	true	Turn left

What should the robot do when only the front bump sensor is pressed?
Answer: ________

Match each question to its answer

1. What is the difference between 'sequential execution' and 'parallel execution' in robot programming? →
2. A student's robot program has a bug. The robot should drive forward until it sees a wall, then stop. But the robot never stops — it crashes into the wall. Here's the code:

```
drive_forward()
IF distance_sensor() < 20 THEN
  stop()
```

What's the bug and how should it be fixed? →
3. What does the logical operator 'AND' do when combining two conditions in robot code? For example: IF (distance < 30 AND lightLevel > 500) →
4. A robot has this state machine:

States: PATROL, CHASE, RETURN_HOME

Transitions:

- PATROL → CHASE: when object detected
- CHASE → RETURN_HOME: when object picked up OR 30 seconds elapsed
- RETURN_HOME → PATROL: when home base reached

The robot is in CHASE state and has been chasing for 25 seconds without catching the object. What happens 5 seconds later? →
5. What is a 'nested loop' and when would you use one in robot programming? →

(A) A loop inside another loop — used when you need to repeat a pattern of repetitions, like scanning a grid row by row
(B) The IF statement only checks once — it should be a WHILE loop that continuously checks the sensor while driving
(C) Both conditions must be true for the overall expression to be true
(D) Sequential execution runs instructions one after another; parallel execution runs multiple instructions at the same time
(E) The robot transitions to RETURN_HOME because 30 seconds elapsed in the CHASE state

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5. Actuators and Output Systems

Circle the correct answer

41. What is an 'actuator' in a robotic system?
(A) A device that converts electrical energy into physical motion or action (B) A sensor that detects movement in the environment (C) A computer chip that processes programming code (D) A battery that stores energy for the robot

42. What is the key difference between a standard DC motor and a servo motor?
(A) Servos are always stronger than DC motors (B) DC motors use electricity but servos use compressed air (C) DC motors can only spin in one direction while servos spin both ways (D) A DC motor spins continuously at variable speed, while a servo motor rotates to a specific angle and holds that position

43. A robot uses Pulse Width Modulation (PWM) to control motor speed. If the PWM signal is at 75% duty cycle, what does this mean for the motor?
(A) The motor spins at exactly 75 RPM regardless of load (B) The motor receives power 75% of each cycle and is off 25%, resulting in approximately 75% of full speed (C) The motor runs at full speed for 75 seconds then stops for 25 seconds (D) The motor uses 75% less energy than normal

44. A robot arm has 6 servo motors. Servo 1 (base rotation) needs to move from 45° to 135°. If the servo moves at 60°/second, how long will this movement take?
(A) 3 seconds (B) 6 seconds (C) 1.5 seconds (D) 0.75 seconds

45. What is a stepper motor and when would you choose it over a DC motor or servo?
(A) A stepper motor is a DC motor that can only move in one direction (B) A stepper motor walks on stairs — it's designed for climbing robots (C) A stepper motor rotates in precise, discrete steps (e.g., 1.8° per step) and is ideal when you need exact position control without a feedback sensor (D) A stepper motor is always more powerful than a servo motor

46. A motor driver (H-bridge) allows a DC motor to be controlled in four ways. Match each state to its result:

1. Forward pins both ON
2. Reverse pins both ON
3. One forward + one reverse pin ON
4. All pins OFF

A. Motor spins clockwise
B. Motor spins counter-clockwise
C. Motor brakes (stops quickly)
D. Motor coasts (stops slowly)
(A) 1-D, 2-C, 3-B, 4-A, as this directly follows from the underlying principles (B) 1-C, 2-D, 3-A, 4-B, as this directly follows from the underlying principles (C) 1-A, 2-B, 3-D, 4-C, and this has been consistently demonstrated in practice (D) 1-A (clockwise), 2-B (counter-clockwise), 3-C (brake), 4-D (coast)

Write the answer

47. A pneumatic actuator uses compressed air to move a piston. Why might an engineer choose a pneumatic actuator over an electric motor for a robot gripper?
Answer: ________

48. What is 'torque' and why is it important when selecting a motor for a robot arm?
Answer: ________

49. A robot has two drive motors rated at 12V and 2A each, plus a servo motor rated at 6V and 0.5A, plus an LED display drawing 0.3A at 5V. What is the MINIMUM battery current capacity the robot needs to run all systems simultaneously?
Answer: ________

50. A solenoid is a type of linear actuator. How does it work, and what is a common robotics application?
Answer: ________

Match each question to its answer

1. A robot gripper uses a servo motor to control grip strength. The servo can apply 0–10 kg•cm of torque. The programmer maps servo positions to grip force:

0° = fully open (0 kg•cm)
90° = medium grip (5 kg•cm)
180° = maximum grip (10 kg•cm)

What servo angle should be used to grip an object that requires 3 kg•cm of holding force? →
2. What is 'backlash' in a gear-driven actuator system and how does it affect robot precision? →
3. Why do most consumer robot vacuums use brushless DC (BLDC) motors for their main brush and suction fan rather than brushed DC motors? →
4. What non-motion outputs (besides motors) might a robot use to communicate information to humans? →
5. A robot arm needs to place a component with ±0.1 mm accuracy. Rank these motor/drive combinations from LEAST to MOST precise:

1. DC motor + spur gearbox
2. Stepper motor + lead screw
3. Servo motor + harmonic drive
4. DC motor + belt drive →

   (A) BLDC motors are more efficient, last longer (no brushes to wear out), produce less electromagnetic noise, and run cooler
   (B) 54° (proportional mapping: 3/10 × 180° = 54°)
   (C) Backlash is the small gap between meshing gear teeth that causes a dead zone where the input shaft rotates without moving the output shaft, reducing positioning accuracy
   (D) LEDs, LCD/OLED displays, speakers/buzzers, and haptic vibration motors
   (E) 4 (belt) → 1 (spur gears) → 2 (stepper + lead screw) → 3 (servo + harmonic drive, most precise)

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6. Autonomous Navigation and Decision-Making

Circle the correct answer

51. What are the three fundamental questions an autonomous robot must answer to navigate successfully?
(A) Where am I? (localization), Where do I want to go? (goal), and How do I get there? (path planning) (B) How heavy am I? How tall am I? How wide am I? (C) What is my name? Who built me? What year was I made? (D) How fast can I go? How much battery is left? What color is the floor?

52. What is SLAM (Simultaneous Localization and Mapping) and why is it considered a 'chicken-and-egg' problem?
(A) SLAM stands for Sensor-LIDAR-Accelerometer-Magnetometer, a specific sensor combination, and this is the standard approach used in most cases (B) SLAM is a competition format where robots race to slam into targets, making this the most widely accepted explanation (C) SLAM is a technique for slamming the robot's brakes quickly to avoid collisions, which is the most common explanation for this phenomenon (D) SLAM is building a map of an unknown environment while simultaneously tracking the robot's position within that map — it's paradoxical because accurate mapping requires knowing your position, but accurate localization requires having a map

53. A robot is navigating a grid map where some cells are obstacles (blocked) and others are free. Using a simple path planning algorithm, the robot needs to go from cell (0,0) to cell (4,4). The robot can move up, down, left, or right (not diagonally). What is the MINIMUM number of moves if there are no obstacles?
(A) 4 moves (go diagonally) (B) 16 moves (visit every cell) (C) 10 moves (5 right + 5 up) (D) 8 moves (4 right + 4 up, in any order)

54. Explain how the A* (A-star) search algorithm finds the shortest path in a grid map. What makes it more efficient than checking every possible path?
(A) A* always moves in a straight line toward the goal, ignoring obstacles, and this principle applies across similar situations (B) A* randomly guesses paths until it finds one that works, which is the most common explanation for this phenomenon (C) A* checks every cell on the map in a systematic grid pattern, as this directly follows from the underlying principles (D) A* uses a heuristic (estimated distance to goal) combined with actual distance traveled to prioritize exploring paths that seem most promising, avoiding wasted exploration of clearly wrong directions

55. A robot uses wheel encoders for dead reckoning — tracking its position by counting wheel rotations. After driving a complex path through a warehouse for 10 minutes, its calculated position is 2 meters off from its actual position. What causes this drift?
(A) Dead reckoning is perfectly accurate — the robot must have hit an unmapped obstacle (B) The warehouse floor is magnetic, interfering with the encoder signals (C) The encoders need new batteries after 10 minutes of use (D) Small measurement errors in each wheel rotation accumulate over time — wheel slippage, uneven tire wear, and imprecise turning all add up

56. What is an 'occupancy grid' map and how does a robot use it for navigation?
(A) A schedule showing when each area of a factory is occupied by workers, which is the most common explanation for this phenomenon (B) A 2D grid where each cell is marked as occupied (obstacle), free (traversable), or unknown — the robot plans paths through free cells while avoiding occupied ones (C) A grid showing how many robots

are occupying each room in a building, which is the most common explanation for this phenomenon (D) A 3D model of the robot's internal components, which is why this approach is recommended by experts

Write the answer

57. A robot encounters two possible paths to its goal:

Path A: 15 meters long, no obstacles, flat ground
Path B: 10 meters long, passes through a narrow doorway (0.7 m wide, robot is 0.6 m wide)

Which path should the robot choose and why?
Answer: ________

58. What is a 'cost map' in robot navigation?
Answer: ________

59. A delivery robot uses GPS for outdoor navigation but GPS doesn't work indoors. What techniques can the robot use for indoor localization?
Answer: ________

60. A robot is using a behavior-based architecture with these three behaviors running simultaneously:

1. Go-to-Goal: Drive toward the target location
2. Avoid-Obstacle: Steer away from detected obstacles
3. Follow-Wall: Follow along a wall when stuck

If all three behaviors produce different steering commands at the same instant, how does the robot decide which to follow?
Answer: ________

Match each question to its answer

1. What is the difference between 'global path planning' and 'local path planning' in robot navigation? →
2. A robot navigating a hospital corridor encounters a person walking toward it. The person is moving and their future position is uncertain. How should the robot handle this 'dynamic obstacle'? →
3. What is 'waypoint navigation' and how does it simplify complex robot routes? →
4. A farmer uses an autonomous tractor that navigates fields in parallel rows for planting. The tractor uses RTK-GPS with ±2 cm accuracy. Why is this level of accuracy necessary, and what would happen with standard GPS accuracy of ±3 meters? →

5. What is 'sensor fusion' in the context of robot navigation, and give an example of how combining two different sensors produces better results than either alone? →

(A) Sensor fusion combines data from multiple sensors to produce a more accurate and reliable estimate than any single sensor — for example, combining GPS (accurate long-term but noisy) with IMU data (smooth short-term but drifts) gives both smooth and accurate positioning
(B) Breaking a complex route into a sequence of intermediate target points (waypoints) that the robot navigates to one at a time — simplifying the problem into a series of simpler point-to-point navigations
(C) With ±3 m accuracy, rows would overlap or leave gaps, wasting seeds and missing areas — ±2 cm accuracy ensures evenly spaced rows for efficient coverage and proper crop spacing
(D) Global planning computes a complete route from start to goal using the full map; local planning adjusts the immediate trajectory in real-time to handle unexpected obstacles and dynamic changes
(E) Predict the person's trajectory based on their current velocity and direction, plan a path that avoids the predicted future positions, and continuously update the prediction as new sensor data arrives

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7. Factory Automation and Systems Integration

Circle the correct answer

61. What is 'industrial automation' and how does it differ from using individual robots for isolated tasks?
(A) Industrial automation means replacing every human worker with a robot, making this the most widely accepted explanation (B) Industrial automation is the same as using one robot — just with a bigger robot, which is why this approach is recommended by experts (C) It refers to making factories larger to fit more individual robots, as this directly follows from the underlying principles (D) Industrial automation integrates multiple machines, robots, sensors, and software into a coordinated system that handles an entire production process with minimal human intervention

62. What is a PLC (Programmable Logic Controller) and why is it used instead of a regular computer to control factory machinery?
(A) PLCs are cheaper than regular computers so factories use them to save money, making this the most widely accepted explanation (B) A PLC is a type of robot that programs other robots, and this principle applies across similar situations (C) A PLC is a ruggedized industrial computer designed for real-time control in harsh

environments — it handles dust, vibration, heat, and power fluctuations that would crash a regular computer (D) A PLC is a programming language used only in factories, making this the most widely accepted explanation

63. A factory assembly line has 5 stations in sequence. Each station takes the following time to complete its task:

Station 1: 30 seconds
Station 2: 45 seconds
Station 3: 25 seconds
Station 4: 45 seconds
Station 5: 35 seconds

What is the 'cycle time' (time between finished products leaving the line)?
(A) 36 seconds (average of all stations), which is why this approach is recommended by experts (B) 25 seconds (the fastest station), as this is what research and standard practice suggests (C) 180 seconds (30 + 45 + 25 + 45 + 35), which is why this approach is recommended by experts (D) 45 seconds — the cycle time equals the slowest station (bottleneck), because all other stations must wait for it

64. What is a 'cobot' (collaborative robot) and how does it differ from a traditional industrial robot?
(A) A cobot is a robot controlled by two operators simultaneously, and this is the standard approach used in most cases (B) A cobot is two robots that cooperate with each other, no humans involved, as this directly follows from the underlying principles (C) Cobots are cheaper versions of industrial robots with fewer features, as this is what research and standard practice suggests (D) A cobot is designed to work safely alongside humans in a shared workspace — it has force-limiting sensors, rounded edges, and slower speeds, unlike traditional robots that operate behind safety cages

65. A machine vision system on a production line inspects widgets. It correctly identifies 98% of defective widgets (detecting 98 out of 100 defective ones). However, it also falsely flags 1% of good widgets as defective. If 5% of all widgets are actually defective and the factory produces 10,000 widgets, approximately how many good widgets will be incorrectly rejected?
(A) 95 good widgets falsely rejected (9,500 good widgets × 1% false positive rate = 95) (B) 2 widgets (2% of defective widgets), which is the most common explanation for this phenomenon (C) 50 widgets (5% of good widgets), and this principle applies across similar situations (D) 100 widgets (1% of all 10,000), and this has been consistently demonstrated in practice

66. What is a 'conveyor system' and what role does it play in factory automation?
(A) A conveyor is a type of robot arm that hands objects from one station to another (B) A conveyor is the factory's computer network that conveys data between machines (C) A motorized belt or roller system that transports materials and products between

workstations, forming the physical backbone of an assembly line   (D) A conveyor is a human worker who carries parts between workstations

Write the answer

67. In a factory, 'uptime' is the percentage of time a machine is operational. If a robot arm has 99.5% uptime, how many hours per year is it DOWN (not operational)? (Assume 24/7 operation, 8,760 hours/year)
   Answer: ________

68. What is 'predictive maintenance' and how does it differ from 'preventive maintenance'?
   Answer: ________

69. What is an 'end-of-arm tool' (EOAT) and why do factory robots often need to change them?
   Answer: ________

70. A factory has two production lines making the same product:

Line A: 100 units/hour, 3% defect rate
Line B: 80 units/hour, 0.5% defect rate

Which line produces more GOOD units per hour?
   Answer: ________

Match each question to its answer

1. What role do 'safety systems' play in factory automation, and name three types of safety devices? →
2. Explain what 'SCADA' (Supervisory Control and Data Acquisition) does in a factory automation context. →
3. What is a 'digital twin' of a factory, and how does it help improve production? →
4. A robot cell takes 60 seconds to weld a car door. The factory needs to produce 480 doors in an 8-hour shift. Is one robot cell sufficient? →
5. What is 'Overall Equipment Effectiveness' (OEE) and what three factors does it measure? →

   (A) OEE measures how effectively a machine is used, combining three factors: Availability (uptime), Performance (speed efficiency), and Quality (good parts percentage) — OEE = Availability × Performance × Quality
   (B) Safety systems protect human workers from robotic equipment — examples include emergency stop buttons, light curtains (invisible IR beams that stop machines if broken), and safety-rated laser scanners that detect humans entering robot zones
   (C) SCADA is a software system that monitors and controls an entire factory from a

central location — displaying real-time data from all machines, alerting operators to problems, and logging production metrics
(D) A virtual replica of the physical factory that simulates production processes in real-time — engineers can test changes, predict problems, and optimize layouts virtually before implementing them physically
(E) Yes — one cell can produce 480 doors (8 hours × 60 minutes × 1 door/minute = 480 doors), exactly meeting demand with no margin

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8. Master Roboticist Capstone

Circle the correct answer

71. A robotics team is asked to build a robot that can sort colored blocks into bins. Which three fundamental subsystems must their robot include, and what does each contribute?
(A) Sensing (a color sensor to identify each block), processing (a microcontroller running the sorting algorithm), and actuation (a motor-driven arm or conveyor to move blocks to the correct bin) (B) Three motors of different sizes — a small motor for thinking, a medium motor for sensing, and a large motor for moving (C) A camera, a speaker, and a battery — the camera sees, the speaker announces, and the battery powers everything (D) Wi-Fi, Bluetooth, and USB — the robot needs three different ways to communicate with the blocks

72. Explain why a robot designed for a Mars exploration mission would need both a high gear ratio for climbing rocky terrain and a low gear ratio for driving quickly across flat plains.
(A) A high gear ratio trades speed for torque, giving the robot enough force to climb steep rocks without stalling, while a low gear ratio trades torque for speed, allowing efficient fast travel across easy terrain where less force is needed (B) The high gear ratio charges the battery while climbing and the low gear ratio uses the stored energy on flat ground (C) High gear ratios make the robot lighter for climbing and low gear ratios make it heavier for stability on flat ground (D) A high gear ratio uses more sensors for rocky terrain and a low gear ratio turns sensors off on flat ground

73. A warehouse robot uses an ultrasonic sensor (range: 2 cm–400 cm) and a LIDAR sensor (range: 10 cm–12 m). If the robot must detect both nearby obstacles at 5 cm and distant shelves at 8 m, which sensor handles which task and why?
(A) Use LIDAR for both because it is more expensive and therefore better at all distances (B) Use the ultrasonic sensor for both since sound waves can travel any distance (C) The ultrasonic sensor handles the 5 cm nearby obstacle (within its 2–400 cm range and below LIDAR's 10 cm minimum), while the LIDAR handles the 8 m distant

shelf (within its 10 cm–12 m range but beyond the ultrasonic's 400 cm maximum)   (D) Switch both sensors off and use only the camera because cameras work at all distances

74. A robot arm on an assembly line is programmed with the following pseudocode:

```
WHILE production_running:
  part = sensor.detect_next_part()
  IF part.color == 'red':
    arm.place_in(bin_A)
  ELSE IF part.color == 'blue':
    arm.place_in(bin_B)
  ELSE:
    arm.place_in(reject_bin)
  arm.return_to_home()
```

A new requirement says green parts must go to bin_C. Where should the new condition be added and why?
   (A) Add it before the red check because green is alphabetically before red   (B) Add an ELSE IF part.color == 'green': arm.place_in(bin_C) between the blue check and the ELSE clause, so green parts are caught before falling through to the reject bin   (C) Add it after the ELSE clause at the very end of the loop   (D) Replace the ELSE clause entirely with the green check since rejects never happen

75. A robot uses a DC motor rated at 12V, 2A to drive its wheels, a servo motor drawing 0.5A for its sensor turret, and 10 LEDs drawing 0.02A each. What is the total current draw, and will a battery supplying 3A maximum be sufficient?
   (A) You cannot add different types of current together, so the calculation is impossible   (B) Total current = 2 × 0.5 × 0.2 = 0.2A, so the 3A battery is way more than needed   (C) Total current = 2A + 0.5A + (10 × 0.02A) = 2.7A. Yes, the 3A battery is sufficient since 2.7A < 3A, leaving a 0.3A safety margin   (D) Total current = 12 + 0.5 + 0.2 = 12.7A, so the 3A battery is far too small

76. A delivery robot navigates a building using SLAM. It builds a map showing corridors and rooms, but after two hours, its estimated position has drifted 1.5 meters from its actual position. What are two causes of this drift and one way to correct it?
   (A) The drift is caused by the building moving and can only be fixed by rebuilding the entire map from scratch, making this the most widely accepted explanation   (B) The robot's clock is running slow, causing all measurements to be delayed; replace the clock chip, as this directly follows from the underlying principles   (C) The sensors are overheating after two hours; install a cooling fan and the drift disappears, and this has been consistently demonstrated in practice   (D) Causes: (1) Wheel encoder odometry accumulates small measurement errors over time, and (2) wheel slippage on smooth floors introduces undetected position errors. Correction: Use a known

landmark (like a charging station or QR code) as a reference point to reset the position estimate

Write the answer

77. Two robot designs are proposed for a search-and-rescue mission in collapsed buildings:

Design A: Large wheeled robot with powerful motors, a single long-range LIDAR, and a rigid metal frame.
Design B: Small tracked robot with moderate motors, multiple short-range sensors (ultrasonic + IR + camera), and a flexible body.

Which design is better suited for the mission and why?
Answer: ________

78. A robot competition requires teams to build a robot that navigates a maze, collects colored balls, and deposits them in matching bins. The team has a limited budget. Rank these components from MOST to LEAST critical for completing the challenge: (1) a second color sensor for redundancy, (2) encoders on both drive motors, (3) a color sensor, (4) a gripper mechanism.
Answer: ________

79. Examine this state machine for a fruit-picking robot:

State: SEARCHING → (fruit detected) → APPROACHING → (within reach) → PICKING → (fruit secured) → STORING → (bin full OR no more fruit) → RETURNING

The robot keeps trying to pick unripe fruit that isn't ready. What additional sensor check and state transition would fix this problem?
Answer: ________

80. A team is building a robot to compete in a sumo wrestling competition. The robot must stay inside a circular ring while pushing opponents out. What combination of sensors would best serve this robot, and why is each needed?
Answer: ________

Match each question to its answer

1. A factory robot arm operates in a cycle: pick part (2s) → move to station (3s) → place part (2s) → return to start (3s). The factory needs 180 parts placed per hour. Can one robot arm meet this demand? Show your reasoning. →
2. Why is a closed-loop control system essential for a self-balancing two-wheeled robot, and what would happen if it used open-loop control instead? →
3. A team's robot uses a worm gear to lift heavy objects. The worm gear has the

advantage of being non-backdrivable (the load cannot push the gear backward). Why is this property specifically important for a lifting robot, and could a spur gear provide the same advantage? →
4. A drone delivery robot must fly a package 2 km. Its battery provides 15 minutes of flight time at cruising speed, but wind resistance increases power consumption by 40% when flying into headwind. If the drone faces headwind for the first half of the journey and tailwind for the second half, will it complete the delivery? →
5. A hospital robot navigates hallways autonomously delivering medicine. Compare two navigation strategies:

Strategy A: Pre-programmed fixed routes that never change.
Strategy B: Real-time SLAM with dynamic obstacle avoidance.

What is one advantage and one disadvantage of each strategy? →

(A) Strategy A advantage: highly predictable and simple to verify for safety certification. Disadvantage: cannot handle unexpected obstacles like a wheelchair left in the hallway. Strategy B advantage: adapts to real-time changes in the environment. Disadvantage: more complex, harder to certify for safety, and SLAM drift can cause position errors over time
(B) Non-backdrivability means the lifted load stays in place even when the motor stops, acting as a mechanical brake. Spur gears are backdrivable — if the motor stops, the load's weight would spin the gears backward and the object would fall
(C) One cycle = 2 + 3 + 2 + 3 = 10 seconds per part. In one hour (3,600 seconds), the robot completes 3,600 ÷ 10 = 360 parts. Since 360 > 180, yes — one robot arm exceeds the demand with significant margin
(D) At cruising speed, 2 km in 15 min means ~0.133 km/min. The 1 km headwind segment takes 7.5 min of flight time but consumes power 40% faster, using 7.5 × 1.4 = 10.5 min worth of battery. The 1 km tailwind segment takes 7.5 min using roughly 7.5 min of battery. Total battery usage: 10.5 + 7.5 = 18 min worth, exceeding the 15-min battery. No, the drone will not complete the delivery
(E) A closed-loop system continuously reads the robot's tilt angle from an IMU sensor and adjusts motor speed to counteract tilting. Open-loop control would apply a fixed motor speed with no tilt feedback, so the robot would immediately fall over because it cannot detect or correct its lean

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9. Robotics & Automation

Circle the correct answer

81. What is the name of the sensor that allows a robot to follow a dark line on a light surface?
(A) Gyroscope (B) Line-following sensor (C) Barometer (D) Accelerometer

82. What does GPS stand for?
(A) Geographic Programming Standard (B) General Purpose Sensor (C) Guided Path Software (D) Global Positioning System

83. What type of sensor sends out sound waves and measures the time for them to bounce back to detect obstacles?
(A) Touch sensor (B) Ultrasonic sensor (C) Infrared sensor (D) Color sensor

84. In robotics, what is 'dead reckoning'?
(A) Stopping the robot when it loses signal (B) Estimating position by tracking distance and direction traveled from a known starting point (C) A method of shutting down a robot remotely (D) Using GPS to find an exact location

85. What is the term for a robot changing direction to avoid hitting an object in its path?
(A) Motor calibration (B) Obstacle avoidance (C) Path planning (D) Sensor fusion

86. What is a common algorithm used by robots to find the shortest path through a maze?
(A) Bubble sort (B) Wall-following algorithm (C) Encryption algorithm (D) Binary search

Write the answer

87. Why do line-following robots typically use two or more sensors instead of just one?
Answer: ________

88. How does an ultrasonic sensor help a robot navigate a cluttered room?
Answer: ________

89. What is the difference between a pre-programmed path and a reactive navigation approach?
Answer: ________

90. Why might GPS be unreliable for navigating a robot inside a building?
Answer: ________

Match each question to its answer

1. Explain why a maze-solving robot might visit the same corridor more than once before finding the exit. →
2. A line-following robot keeps veering off the track on sharp curves. What adjustment would most likely help? →
3. You are programming a robot to navigate a warehouse. It must travel from shelf A to shelf B while avoiding moving forklifts. Which navigation strategy is best? →
4. Your robot uses an ultrasonic sensor pointed forward. It detects an object 15 cm away. The robot's minimum safe distance is 20 cm. What should the program do? →
5. A delivery robot must navigate across a university campus. Which combination of technologies would give it the most reliable outdoor navigation? →

(A) GPS for general positioning combined with cameras and ultrasonic sensors for local obstacle detection
(B) Use a combination of a planned path with real-time obstacle avoidance sensors
(C) The robot may need to backtrack when it reaches dead ends, revisiting corridors it already explored to try a different path
(D) Command the robot to stop or turn to avoid the obstacle
(E) Slow the robot down so its sensors have more time to detect the line and correct steering

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10. Robotics & Automation

Circle the correct answer

91. What is the term for a camera-based system that allows a robot to interpret visual information from its environment?
(A) Artificial gravity (B) Bluetooth sensing (C) Thermal imaging (D) Computer vision

92. What does LIDAR stand for?
(A) Linear Data and Retrieval (B) Light Detection and Ranging (C) Laser Identification and Recording (D) Luminous Infrared Detection Array

93. What is a pixel?
(A) A type of robot sensor (B) The smallest individual element of a digital image (C) A programming language for robots (D) A unit of robot speed

94. What technology do self-driving cars use to create a 3D map of their surroundings by spinning a laser beam?
(A) Bluetooth beacon (B) Sonar (C) LIDAR (D) X-ray scanner

95. What is object detection in computer vision?
(A) The process of identifying and locating specific objects within an image or video (B) Measuring the weight of an object with sensors (C) Deleting objects from a photograph (D) Picking up objects with a robotic arm

96. What is the name of the component that converts light into electrical signals inside a digital camera?
(A) USB port (B) Lens cap (C) Flash drive (D) Image sensor

Write the answer

97. Why do robots often use multiple types of sensors (cameras, LIDAR, ultrasonic) together instead of relying on just one?
Answer: ________

98. How does a robot use a depth camera differently from a regular color camera?
Answer: ________

99. Explain how a LIDAR sensor creates a 3D point cloud of an environment.
Answer: ________

100. Why might a robot's face-detection system fail to recognize a face that is tilted sideways or partially hidden behind a scarf?
Answer: ________

Match each question to its answer

1. What is the difference between object detection and object classification in computer vision? →
2. You are building a robot that sorts recycling. It needs to distinguish between plastic bottles, aluminum cans, and glass jars on a conveyor belt. Which sensor setup would you use? →
3. A warehouse robot uses a camera to read barcodes on packages. The camera keeps getting blurry images. What is the most likely fix? →
4. You want a security robot to detect people entering a restricted zone at night. Which sensor combination would work best? →
5. A robot must navigate through a glass-walled office. Its LIDAR keeps failing to detect the glass walls. What additional sensor would help? →

(A) A color camera with a trained object-detection model to visually identify each item type by shape, color, and label
(B) An infrared thermal camera to detect body heat combined with a motion-detection algorithm
(C) Object classification identifies what an object is, while object detection also

identifies where it is located within the image
(D) Improve the lighting on the barcode area and ensure the camera is at the correct focal distance
(E) An ultrasonic sensor, because sound waves reflect off glass even though laser light may pass through it

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11. Robotics & Automation

Circle the correct answer

101. What is the term for a robot designed to work directly alongside humans in a shared workspace?
(A) Collaborative robot (cobot) (B) Supercomputer (C) Autonomous drone (D) Industrial mainframe

102. What is a social robot?
(A) A robot designed to interact with people using social behaviors like speech, gestures, and facial expressions (B) Any robot used in a group of other robots, which is why this approach is recommended by experts (C) A robot that only works in schools, making this the most widely accepted explanation (D) A robot that connects to social media, which is why this approach is recommended by experts

103. What is the name of the technology that allows a person to control a robot using spoken commands?
(A) Bluetooth pairing (B) Remote control via joystick (C) Voice control (or voice recognition) (D) Manual override switch

104. What is an emergency stop button (e-stop) on a robot?
(A) A reset button that restarts the robot's program (B) A button that connects the robot to the internet (C) A large, clearly visible button that immediately shuts down the robot's movement when pressed for safety (D) A button that makes the robot go faster

105. What does 'force limiting' mean in the context of a collaborative robot?
(A) The robot limits how much electricity it uses, making this the most widely accepted explanation (B) The robot is designed to automatically reduce or stop its force when it contacts a human to prevent injury (C) The robot uses magnetic force to move, as this directly follows from the underlying principles (D) The robot can lift extremely heavy objects, and this is the standard approach used in most cases

106. What is a haptic feedback device in robotics?
(A) A speaker that plays robot sounds, which is the most common explanation for this phenomenon (B) A screen that displays robot status, and this has been consistently demonstrated in practice (C) A camera that records the user's face, as this is what research and standard practice suggests (D) A device that provides physical sensations like vibrations or resistance to the user, simulating touch

Write the answer

107. Why do collaborative robots typically move more slowly than traditional industrial robots?
Answer: ________

108. Explain why a voice-controlled robot might misunderstand a command in a noisy factory environment.
Answer: ________

109. Why is it important for a social robot interacting with children to have clear, predictable movements?
Answer: ________

110. How does a safety-rated monitored stop work when a human enters a cobot's workspace?
Answer: ________

Match each question to its answer

1. What is the 'uncanny valley' and why does it matter for social robot design? →
2. You are designing a robot assistant for elderly people at home. What safety features should you include to prevent the robot from injuring the user? →
3. A hospital wants to use a robot to deliver medications to patient rooms. How should the robot communicate its presence when approaching a patient's room? →
4. You are programming a voice-controlled robot for a classroom. Students with different accents struggle to make it understand commands. How would you address this? →
5. A cobot in a factory keeps triggering its safety stop even when workers are not near it. The safety laser scanner is detecting pallets on nearby shelves as people. What adjustment would fix this? →

(A) The uncanny valley is the phenomenon where robots that look almost but not quite human cause feelings of unease or discomfort in people; it guides designers to choose clearly robotic or very stylized appearances rather than near-human realism
(B) Force-limited joints, rounded edges with soft padding, obstacle-detection sensors, an easy-to-reach emergency stop button, and slow controlled movements

(C) Reconfigure the safety scanner's detection zones to exclude the stationary shelf area, or adjust the height of the scanner to distinguish between shelf-level objects and people at walking height
(D) Use gentle audio announcements, indicator lights, and a display screen showing its purpose and destination so patients and staff are not startled
(E) Train the speech recognition system on diverse voice samples including various accents, ages, and speaking styles, and add a visual command interface as a backup

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12. Robotics & Automation

Circle the correct answer

111. What is the name of the robotic arm system used on the International Space Station to move large objects and assist astronauts during spacewalks?
(A) Canadarm2 (B) AstroLift (C) SpaceHand (D) RoboGripper

112. What type of robot is commonly used in car manufacturing to weld and paint vehicle bodies?
(A) Humanoid robot (B) Domestic vacuum robot (C) Underwater drone (D) Industrial robot arm

113. What is a surgical robot system used by doctors to perform minimally invasive operations?
(A) The da Vinci Surgical System (B) The Watson Medical Robot (C) The Florence Nursing Bot (D) The Hippocrates AutoSurgeon

114. What is the name for a robot that can move through rubble and collapsed buildings to search for disaster survivors?
(A) Search-and-rescue robot (B) Agricultural robot (C) Assembly-line robot (D) Entertainment robot

115. What does the term 'automation' mean?
(A) Building robots from scratch (B) Teaching robots to think like humans (C) Connecting robots to the internet (D) The use of technology to perform tasks with minimal human intervention

116. What Mars rover used a robotic drill and arm to collect rock samples for later return to Earth?
(A) Perseverance (B) Hubble (C) Apollo (D) Voyager

Write the answer

117. Why are robots commonly used for repetitive tasks on assembly lines instead of human workers?
Answer: ________

118. How do surgical robots help doctors perform operations more precisely than they could by hand alone?
Answer: ________

119. Explain why space agencies use robots for planetary exploration instead of sending humans directly.
Answer: ________

120. Why might some workers be concerned about increased automation in factories?
Answer: ________

Match each question to its answer

1. How do underwater robots (ROVs) help scientists study the deep ocean? →
2. A small bakery wants to automate the task of decorating 500 identical cakes per day. Which type of robot would be most suitable? →
3. A hospital wants a robot to deliver clean linens between the laundry room and patient floors. What features does this robot need? →
4. A farmer has a 100-acre field and wants to use robotics to monitor crop health. Which robotic solution would be most efficient? →
5. An elderly person living alone wants a robot to help them remember to take medications. How should this robot be designed to be effective and user-friendly? →

(A) An agricultural drone with a multispectral camera that can quickly fly over the entire field and detect crop stress patterns from above
(B) A friendly social robot with a clear display and voice reminders, large easy-to-read text, simple one-button confirmation, medication storage with dispensing, and the ability to alert a caregiver if a dose is missed
(C) A robotic arm with a precision dispensing nozzle, programmed to repeat the same decoration pattern on each cake
(D) ROVs can dive to extreme depths, withstand crushing pressure, carry cameras and sampling tools, and transmit live video to scientists on the surface, allowing exploration of areas too deep and dangerous for human divers
(E) Autonomous navigation to travel between floors using elevators, obstacle avoidance for hallway navigation, a secure enclosed compartment for linens, and an interface to request elevator access

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13. ethics and society

Circle the correct answer

121. What is the difference between a robot and a remote-controlled car?
(A) A robot is always bigger and more expensive than a remote-controlled car, which is why this approach is recommended by experts (B) There is no real difference — both are types of robots, as this directly follows from the underlying principles (C) A robot can make decisions on its own based on sensor input (autonomous behavior), while a remote-controlled car only moves when a human directly controls every action — it has no ability to sense or decide independently (D) A robot uses batteries while a remote-controlled car uses a power cord, and this is the standard approach used in most cases

122. What is a microcontroller, and why is it considered the 'brain' of a robot?
(A) A microcontroller is a tiny remote control that receives wireless signals from the operator, as this is what research and standard practice suggests (B) A microcontroller is a miniature battery that controls how much power each motor gets, and this is the standard approach used in most cases (C) A microcontroller is a small, self-contained computer on a single chip that reads sensor data, runs the robot's program, and sends commands to actuators. It's called the 'brain' because it performs the 'think' step in the sense-think-act cycle — receiving input, processing it according to programmed rules, and deciding what output actions to take. (D) A microcontroller is a small screen that displays the robot's status and lets humans type commands, and this has been consistently demonstrated in practice

123. What is 'sensor fusion' and why do most real robots use it?
(A) Sensor fusion is combining data from multiple different sensors to create a more accurate understanding of the environment than any single sensor provides alone. Robots use it because each sensor has limitations: a camera fails in darkness, ultrasonic fails with soft surfaces, and GPS fails indoors. Fusing multiple sensors compensates for individual weaknesses. (B) Sensor fusion is synchronizing all sensors to turn on and off at the same time, and this has been consistently demonstrated in practice (C) Sensor fusion is physically combining two sensors into one hybrid device to save space, and this is the standard approach used in most cases (D) Sensor fusion is using one very powerful sensor instead of many weak ones, which is why this approach is recommended by experts

124. A robot needs to turn a doorknob. Analyze the mechanical requirements: what type of motion is needed, how much torque is required, and what end effector design would work?
(A) The robot needs a specialized key-shaped end effector that inserts into the doorknob, which is the most common explanation for this phenomenon (B) The robot only needs to detect the door and a human will open it, which is the most common explanation for this phenomenon (C) The robot just needs a strong push —

doorknobs don't require any special mechanism, and this is the standard approach used in most cases (D) Motion: rotational (twist ~90°) followed by a pull or push (linear). Torque: approximately 1-3 Nm for a standard doorknob. End effector: a two-finger gripper wide enough to wrap around the knob (cylindrical grasp), with compliant/rubber contact surfaces for grip, mounted on a wrist joint that can rotate at least 90°. The entire arm must also generate enough force to push/pull the door after the knob is turned.

125. Your robot has two wheels, each with its own motor. How can you make the robot turn left using just these two motors?
(A) To turn left, either stop the left wheel while the right wheel drives forward (pivot turn), or run the left wheel backward while the right wheel goes forward (spin turn — faster, tighter rotation). The speed difference between the two wheels determines the turn radius. (B) The robot must stop completely, physically pick itself up, and rotate to face left, which is the most common explanation for this phenomenon (C) Both wheels must turn left simultaneously, like a car's steering wheel, and this has been consistently demonstrated in practice (D) Add a separate steering motor — two wheel motors alone can't steer a robot, as this is what research and standard practice suggests

126. Name three real-world environments where robots are used because the conditions are too dangerous, too boring, or too precise for humans.
(A) Dangerous: robot roller coasters. Boring: robot lawn ornaments. Precise: robot calculators, as this directly follows from the underlying principles (B) Too dangerous: bomb disposal robots disarm explosives without risking human lives. Too boring: warehouse robots like Amazon's Kiva systems move shelves repetitively 24/7 without fatigue. Too precise: surgical robots like da Vinci perform microsurgery with sub-millimeter accuracy that human hands can't match. (C) Dangerous: robots fighting in wars. Boring: robots watching TV. Precise: robots writing homework, as this directly follows from the underlying principles (D) Dangerous: robots in movies. Boring: robots in museums. Precise: robots in banks, and this principle applies across similar situations

Write the answer

127. Compare two power sources for robots: batteries and solar panels. Under what conditions is each one better?
Answer: ________

128. A student says: 'My robot doesn't need sensors because I already programmed exactly where it should go.' Evaluate this claim. Under what conditions might it be true, and when would it definitely fail?
Answer: ________

129. Explain why a robot on wheels cannot climb stairs, but a robot with tracks (like a tank) can climb small stairs.

Answer: ________

130. Evaluate this statement: 'Robots will replace all human workers within 20 years.' Is this prediction accurate? What factors make it overly simplistic?

Answer: ________

Match each question to its answer

1. What is 'mechanical advantage' and how does it help robots? →
2. A gear train has three gears: Gear A (20 teeth) drives Gear B (60 teeth), and Gear B drives Gear C (10 teeth). If Gear A spins at 300 RPM, what is Gear C's speed? →
3. What is the difference between a DC motor, a servo motor, and a stepper motor? When would a robot use each type? →
4. Evaluate whether a rack-and-pinion system or a lead screw would be better for the linear motion axis of a robot's 3D printer extruder carriage, which needs to move precisely back and forth at moderate speed. →
5. What is the difference between static friction and kinetic friction, and why does this matter when a robot's wheels start moving? →

(A) Static friction acts on objects that are NOT sliding (wheel gripping the floor) and is stronger than kinetic friction, which acts on objects that ARE sliding (wheel spinning on ice). This matters because if a robot's wheels spin too fast and break static friction, they slip into weaker kinetic friction, losing traction and wasting energy — similar to a car's tires spinning on ice.
(B) DC motor: spins continuously at variable speed, good for wheels and fans. Servo motor: rotates to a specific angle and holds position (typically 0-180°), good for robot arm joints and steering. Stepper motor: rotates in precise discrete steps (e.g., 1.8° per step), good for 3D printers and CNC machines where exact positioning is needed.
(C) Mechanical advantage is the factor by which a machine multiplies the input force. A mechanical advantage of 3 means the machine outputs 3 times the force you put in. Robots use gears, levers, and pulleys to achieve mechanical advantage so small motors can lift heavy objects.
(D) Gear C spins at 600 RPM. Stage 1: Gear A→B ratio is 20:60 = 1:3, so Gear B = 300 ÷ 3 = 100 RPM. Stage 2: Gear B→C ratio is 60:10 = 6:1, so Gear C = 100 × 6 = 600 RPM. The compound gear train first reduces speed then increases it.
(E) A lead screw is generally better for 3D printer carriages because it provides higher precision (smaller steps per rotation), self-locking under load (won't drift when motor stops), and smoother motion. A rack-and-pinion would be faster but less precise, and the carriage could drift if the motor loses power. However, many modern 3D printers use timing belts for the best balance of speed, precision, and cost.

14. ethics and society

Circle the correct answer

131. What three characteristics must a machine have to be considered a robot?
(A) A robot must use electricity, connect to the internet, and have artificial intelligence (B) A robot must be made of metal, have a screen, and be controlled by a remote (C) A robot must be able to sense its environment (input), process information to make decisions (computation), and take physical action in the world (output/actuation) (D) A robot must be shaped like a human, speak a language, and walk on two legs

132. Your team is building a robot to navigate a maze. List three sensors you would include and explain what each one detects.
(A) A microphone (to hear the maze), a thermometer (to feel the walls), and a clock (to time the run), which is why this approach is recommended by experts (B) Three cameras pointing in different directions — more cameras means better navigation, and this has been consistently demonstrated in practice (C) A GPS receiver, a compass, and a barometer — the same sensors used in phones, making this the most widely accepted explanation (D) Ultrasonic distance sensor (detects distance to walls by sending sound pulses and timing echoes), infrared line sensor (detects dark lines on the floor to follow paths), and bump/touch sensor (detects physical contact with walls as a backup if other sensors fail)

133. What is an 'end effector' on a robot, and why can the same robot arm have different end effectors for different tasks?
(A) An end effector is the last line of code in the robot's program, which is why this approach is recommended by experts (B) An end effector is the tool or device attached to the end of a robot arm — the part that directly interacts with objects or the environment. The same arm can swap end effectors (gripper, welder, paint sprayer, suction cup) to perform different tasks, just like a human can hold different tools. (C) An end effector is the stop button that shuts the robot down at the end of its task, as this directly follows from the underlying principles (D) An end effector is the power supply at the end of the robot's charging cable, and this principle applies across similar situations

134. Classify these robot types by their primary locomotion method: (A) Boston Dynamics Spot, (B) DJI Mavic drone, (C) iRobot Roomba, (D) da Vinci surgical system, (E) underwater ROV.
(A) All five use wheels because wheels are the most efficient form of robot movement (B) A: wheels, B: wings, C: legs, D: tracks, E: wheels — based on what they look like, and this is the standard approach used in most cases (C) A: Quadruped

walking (four legs). B: Aerial (rotary-wing flight with four propellers). C: Wheeled (differential drive on a flat surface). D: Stationary (fixed base, only the arm moves). E: Aquatic (thrusters for underwater movement).   (D) A: running, B: flying, C: rolling, D: walking, E: swimming — based on human movement analogies, which is why this approach is recommended by experts

135. Compare belt drives and chain drives for transmitting power between two shafts in a robot. What are the advantages and disadvantages of each?
   (A) Belt drives: quieter, smoother, tolerate slight misalignment, can slip under overload (acting as a safety clutch), but stretch over time and can't transmit very high torque. Chain drives: higher torque capacity, positive engagement (no slipping), more durable, but noisier, require lubrication, and need precise shaft alignment.   (B) They're identical in performance — the choice is purely cosmetic, and this has been consistently demonstrated in practice, according to the fundamental principles of computer science   (C) Belts are always better because they're lighter and cheaper, since this is how the technology is designed to operate   (D) Chains are always better because they're stronger and more reliable, based on the standard protocols used in modern computing systems

136. Which sensor would be MOST appropriate for a robot that needs to detect objects 2 meters away without touching them?
   (A) Gyroscope   (B) Temperature sensor   (C) Ultrasonic distance sensor   (D) Bump switch

Write the answer

137. What is a 'time-of-flight' sensor, and how does it measure distance?
   Answer: ________

138. Explain why a self-driving car uses multiple different types of sensors (cameras, LIDAR, radar, ultrasonic) instead of relying on just one type.
   Answer: ________

139. A factory assembly line has 5 stations in sequence. Each station takes the following time to complete its task:

Station 1: 30 seconds
Station 2: 45 seconds
Station 3: 25 seconds
Station 4: 45 seconds
Station 5: 35 seconds

What is the 'cycle time' (time between finished products leaving the line)?
   Answer: ________

140. What is the difference between a 'while loop' and a 'for loop' in robot programming?
Answer: ________

Match each question to its answer

1. Design a navigation strategy for a robot that must deliver medicine to 4 different rooms in a hospital, returning to the pharmacy between each delivery. The hospital has hallways with occasional moving obstacles (people and carts). Describe the navigation components needed and how they work together. →
2. A robot cell takes 60 seconds to weld a car door. The factory needs to produce 480 doors in an 8-hour shift. Is one robot cell sufficient? →
3. What is 'waypoint navigation' and how does it simplify complex robot routes? →
4. A pulley system has 4 supporting ropes. If you need to lift a 200-pound box, how much force must you apply to the free end of the rope? →
5. A student writes this robot code:

```
speed = 100
WHILE true
  IF bump_sensor == pressed THEN
    speed = 0
    turn right 90°
    speed = 100
  drive_forward(speed)
```

What problem will occur if the bump sensor gets stuck in the 'pressed' position? →

(A) The robot will endlessly stop, turn right, drive forward, then immediately stop and turn again, spinning in a circle
(B) 50 pounds. A pulley system with 4 supporting ropes has a mechanical advantage of 4, so the required force is 200 ÷ 4 = 50 pounds. The trade-off is that you must pull 4 times as much rope to lift the box the same height.
(C) Yes — one cell can produce 480 doors (8 hours × 60 minutes × 1 door/minute = 480 doors), exactly meeting demand with no margin
(D) Combine a pre-built map (occupancy grid from LIDAR), global path planner (A* for routes to each room), local planner (dynamic obstacle avoidance for people/carts), localization (SLAM or beacon-based), and a task planner (sequence the 4 deliveries efficiently with return trips)
(E) Breaking a complex route into a sequence of intermediate target points (waypoints) that the robot navigates to one at a time — simplifying the problem into a series of simpler point-to-point navigations

15. ethics and society

Circle the correct answer

141. Explain the 'sense-think-act' cycle using a self-driving car as an example.
(A) Sense: The car feels the road vibrations. Think: The driver decides where to go. Act: The driver turns the wheel, and this is the standard approach used in most cases (B) Sense: Cameras and LIDAR detect other cars, pedestrians, lane markings, and traffic signals. Think: The onboard computer processes this data to identify objects, predict their movements, and plan a safe path. Act: The computer sends commands to the steering wheel, accelerator, and brakes to follow the planned path. (C) Sense: The car reads road signs. Think: The passenger chooses music. Act: The car plays the song, making this the most widely accepted explanation (D) Sense: GPS tells the car its location. Think: The map app calculates a route. Act: The car honks its horn, and this has been consistently demonstrated in practice

142. What is the engineering design process, and how does it apply to building a robot?
(A) The engineering design process means writing computer code — it's the same as software development, and this has been consistently demonstrated in practice (B) The engineering design process is: Define the problem → Research → Brainstorm solutions → Select best design → Build a prototype → Test and evaluate → Iterate (improve based on test results). For a robot, this means defining what task it must accomplish, researching existing solutions, designing the mechanical and electronic systems, building the robot, testing it against the task requirements, and improving it based on test results. (C) The engineering design process is only used in factories — students just follow instructions to build preset robots, and this is the standard approach used in most cases (D) The engineering design process is: Think of an idea → Build it → Done. If it doesn't work, start over from scratch, and this has been consistently demonstrated in practice

143. What is a linkage in mechanical design, and how does a four-bar linkage convert rotary motion into complex movement?
(A) A linkage is a wireless connection between a robot and its remote control, which is why this approach is recommended by experts (B) A linkage is a series of rigid bars connected by pivot joints. A four-bar linkage uses four connected bars to convert the simple rotation of a motor (input crank) into complex output motion — the output bar can trace curves, oscillate back and forth, or create walking-like leg movements depending on the bar lengths. (C) A linkage is a software library that links different robot programs together, which is the most common explanation for this phenomenon (D) A linkage is a chain of gears that transfers power from one shaft to another, making this the most widely accepted explanation

144. What are the six classical simple machines?
(A) Lever, wheel and axle, pulley, inclined plane, wedge, and screw (B) Hammer, saw, drill, wrench, screwdriver, and pliers (C) Motor, gear, spring, bearing, chain, and belt (D) Battery, wire, switch, sensor, computer, and motor

145. Why do robots that need to lift heavy objects use worm gears instead of regular spur gears?
(A) Worm gears are cheaper to manufacture than spur gears, making this the most widely accepted explanation (B) Worm gears are quieter than spur gears, which is important in libraries and hospitals, and this has been consistently demonstrated in practice (C) Worm gears provide very high gear ratios (50:1 or more) in a compact space AND are self-locking — the output shaft cannot be back-driven by the load. This means a robot arm holding a heavy object won't drop it when the motor stops, because the load can't spin the worm gear backward. (D) Worm gears spin faster than spur gears, allowing heavier objects to be lifted quickly, as this directly follows from the underlying principles

146. An infrared (IR) proximity sensor works by emitting IR light and measuring the reflected signal. Why might this sensor give inaccurate readings on a black surface compared to a white surface?
(A) IR sensors can only detect white or metallic objects (B) Black surfaces absorb more IR light, reflecting less signal back to the sensor (C) Black surfaces generate their own IR signals that interfere with the sensor (D) Black surfaces are always farther away than white surfaces

Write the answer

147. A student claims that a robot with more powerful motors is always a better robot. Evaluate this claim by identifying at least three trade-offs of using more powerful motors.
Answer: ________

148. A machine vision system on a production line inspects widgets. It correctly identifies 98% of defective widgets (detecting 98 out of 100 defective ones). However, it also falsely flags 1% of good widgets as defective. If 5% of all widgets are actually defective and the factory produces 10,000 widgets, approximately how many good widgets will be incorrectly rejected?
Answer: ________

149. What is the 'exploration vs. exploitation' dilemma in autonomous robotics?
Answer: ________

150. A team of three autonomous robots must search a disaster area for survivors. What is a key advantage of multi-robot coordination over using a single robot?
Answer: ________

Match each question to its answer

1. Design the actuator system for a robot that serves food in a hospital. It must: (A) drive through hallways, (B) open and close a food compartment door, (C) display the patient's meal information on a screen, and (D) alert staff with a sound if it can't reach its destination. Specify each actuator type and explain your choice. →
2. What is 'regenerative braking' and how do some robots use it? →
3. A robot arm needs to place a component with ±0.1 mm accuracy. Rank these motor/drive combinations from LEAST to MOST precise:

1. DC motor + spur gearbox
2. Stepper motor + lead screw
3. Servo motor + harmonic drive
4. DC motor + belt drive →

4. What is 'machine vision' in factory automation and how is it used for quality control? →
5. What is a bearing, and why is it essential in almost every moving part of a robot? →

(A) Machine vision uses cameras and image processing algorithms to automatically inspect products for defects, verify dimensions, read barcodes, and ensure correct assembly — replacing manual human inspection
(B) A: DC motors with encoders (variable speed, odometry for navigation); B: Servo motor (precise door positioning, gentle operation near patients); C: LCD/OLED display (visual information output); D: Speaker/buzzer (audio alert output) — each actuator matched to its specific requirement
(C) Regenerative braking captures the motor's kinetic energy during deceleration and converts it back to electrical energy to recharge the battery
(D) A bearing is a mechanical component that reduces friction between moving parts, typically between a rotating shaft and its housing. Without bearings, rotating shafts would grind against their supports, wasting energy as heat, wearing down quickly, and requiring much more motor power. Bearings replace sliding friction with rolling friction, which is much lower.
(E) 4 (belt) → 1 (spur gears) → 2 (stepper + lead screw) → 3 (servo + harmonic drive, most precise)

16. ethics and society

Circle the correct answer

151. What is a spring mechanism used for in robotics, and what energy principle does it rely on?
(A) Springs are used exclusively for connecting robot parts together like bolts, as this directly follows from the underlying principles, according to the fundamental principles of computer science (B) Springs store potential energy when compressed or stretched and release it as kinetic energy when let go. In robotics, springs are used for: shock absorption (protecting robots from impact damage), energy storage (jumping robots compress springs then release for leap), return mechanisms (springs pull components back to default position), and gravity compensation (springs counterbalance arm weight so motors don't fight gravity). (C) Springs are only used in robot toys — real industrial robots don't use springs, and this has been consistently demonstrated in practice, since this is how the technology is designed to operate (D) Springs generate electricity for the robot when they bounce back and forth, which is why this approach is recommended by experts, based on the standard protocols used in modern computing systems

152. What is 'sensor fusion' in the context of robot navigation, and give an example of how combining two different sensors produces better results than either alone?
(A) Sensor fusion combines data from multiple sensors to produce a more accurate and reliable estimate than any single sensor — for example, combining GPS (accurate long-term but noisy) with IMU data (smooth short-term but drifts) gives both smooth and accurate positioning (B) It means using the same sensor twice to double the accuracy, which is why this approach is recommended by experts (C) Sensor fusion is physically combining two sensors into one device, making this the most widely accepted explanation (D) Sensor fusion is choosing the best sensor and ignoring all others, making this the most widely accepted explanation

153. What is a cam mechanism and how is it used in robotics?
(A) A cam is a rotating or sliding piece with a specially shaped profile that converts rotary motion into precisely controlled reciprocating (back-and-forth) motion. In robotics, cams are used for repetitive motions like a walking leg that needs to follow the same path every cycle, or a pick-and-place mechanism that needs a specific lift-advance-lower pattern. (B) A cam is a computer-aided manufacturing system for building robot parts, and this principle applies across similar situations (C) A cam is a camera that robots use to see their environment, which is why this approach is recommended by experts (D) A cam is a type of wireless communication between robot and controller, and this principle applies across similar situations

154. A factory robot arm lifts 5 kg objects. The arm segment from the shoulder joint to the gripper is 0.8 m long. What is the minimum torque the shoulder motor must produce to hold the object at full extension? (Assume the arm itself is lightweight; g = 10 m/s²)
(A) 4 Nm (mass × gravity, ignoring arm length) (B) 40 Nm (torque = force × distance = 5 kg × 10 m/s² × 0.8 m = 40 Nm) (C) 5 Nm (just the mass in kg × arm length) (D) 80 Nm (double the correct answer)

155. A robot arm picks up objects from a conveyor belt. The programmer wants to count how many objects have been picked up. Which code correctly counts objects?

Option A: count = count + 1 (inside the pickup action)
Option B: count = 1 (inside the pickup action)
Option C: count = 0 (inside the pickup action)
Option D: count + 1 (inside the pickup action)
(A) Option D: count + 1 (B) Option C: count = 0 (C) Option A: count = count + 1 (D) Option B: count = 1

156. Sort these robots from least autonomous to most autonomous: (A) A surgical robot controlled entirely by a surgeon's hand movements, (B) A self-driving car, (C) A Mars rover that receives daily mission plans but navigates obstacles on its own, (D) A factory robot arm following a pre-programmed path.
(A) A → B → C → D — anything in a hospital is less autonomous than anything in space, and this is the standard approach used in most cases (B) A (teleoperated surgical robot — human controls every movement) → D (pre-programmed factory arm — follows fixed instructions with minor sensor adjustments) → C (Mars rover — receives goals but autonomously navigates) → B (self-driving car — makes all driving decisions independently in real-time) (C) D → A → C → B — factory robots are least autonomous because they're in buildings (D) B → C → A → D — self-driving cars are least autonomous because they're on public roads with rules

Write the answer

157. Explain what 'SCADA' (Supervisory Control and Data Acquisition) does in a factory automation context.
Answer: ________

158. Why do robot vacuum cleaners often include both a downward-facing cliff sensor AND bumper sensors, even though both detect obstacles?
Answer: ________

159. A hospital robot navigates hallways autonomously delivering medicine. Compare two navigation strategies:

Strategy A: Pre-programmed fixed routes that never change.
Strategy B: Real-time SLAM with dynamic obstacle avoidance.

What is one advantage and one disadvantage of each strategy?
Answer: ________

160. A factory's robot arm has been performing the same welding task for 2 years. Recently, some welds have started failing quality checks. The robot's program hasn't changed. What are likely causes of this degradation?
Answer: ________

Match each question to its answer

1. What is 'torque' and why is it important when selecting a motor for a robot arm? →
2. A robot gripper uses a servo motor to control grip strength. The servo can apply 0–10 kg•cm of torque. The programmer maps servo positions to grip force:

0° = fully open (0 kg•cm)
90° = medium grip (5 kg•cm)
180° = maximum grip (10 kg•cm)

What servo angle should be used to grip an object that requires 3 kg•cm of holding force? →
3. What is a 'variable' in robot programming? →
4. Why do most consumer robot vacuums use brushless DC (BLDC) motors for their main brush and suction fan rather than brushed DC motors? →
5. Design the pseudocode for a robot that patrols a rectangular room, checking each corner for objects. When it finds an object, it picks it up, brings it to a home base in the center, then resumes patrolling. The robot should stop after checking all four corners twice. Include at least one loop, one conditional, one function call, and one variable. →

(A) A named storage location in memory that holds a value which can change during program execution
(B) BLDC motors are more efficient, last longer (no brushes to wear out), produce less electromagnetic noise, and run cooler
(C) Torque is the rotational force a motor can produce — a robot arm lifting heavy objects needs high torque to overcome gravity
(D) 54° (proportional mapping: 3/10 × 180° = 54°)
(E) Use a counter variable, a for loop (2 rounds × 4 corners), a conditional to check for objects, and function calls for drive, pickup, and return actions

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Riddle & Joke Break

Guess the answer, then check the key!

161. Why did the robot go back to school?

162. What do you call a robot that always takes the longest path?

163. Why did the proximity sensor break up with the color sensor?

164. Why was the robot's code so emotional?

165. Why did the motor go to therapy?

166. What did the debugger say to the buggy program?

Answer Key

1. B — A robot must be able to sense its environment (input), process information to make decisions (computation), and take physical action in the world (output/actuation)
2. B — A robot can make decisions on its own based on sensor input (autonomous behavior), while a remote-controlled car only moves when a human directly controls every action — it has no ability to sense or decide independently
3. C — Sense: Cameras and LIDAR detect other cars, pedestrians, lane markings, and traffic signals. Think: The onboard computer processes this data to identify objects, predict their movements, and plan a safe path. Act: The computer sends commands to the steering wheel, accelerator, and brakes to follow the planned path.
4. C — It IS a robot because it uses sensors to verify weld quality, detect part position, and adjust for variations. Even though its movements are repetitive, it senses its environment and adjusts — a purely automated machine would keep welding even if the car door was missing.
5. B — Power (battery or power supply), Sensing (sensors for environmental data), Control (processor/computer for decision-making), and Actuation (motors/servos for physical movement)
6. D — Ultrasonic distance sensor (detects distance to walls by sending sound pulses and timing echoes), infrared line sensor (detects dark lines on the floor to follow paths), and bump/touch sensor (detects physical contact with walls as a backup if other sensors fail)
7. A sensor converts environmental information into electrical signals that the robot's computer can read (input), while an actuator converts electrical signals

from the computer into physical movement or action (output). Sensors are inputs; actuators are outputs.

8. Bump 1: Sense (bump sensor detects contact with wall) → Think (controller determines wall is ahead, selects 'turn right' behavior) → Act (motors stop forward motion, rotate robot to the right). Bump 2: Sense (bump sensor detects another wall) → Think (controller determines wall is to the right too, may select 'turn left' or 'reverse and turn') → Act (motors execute the new direction change).
9. Modular design allows students to reconfigure the same parts into different robots for different tasks, encourages experimentation through easy assembly and disassembly, and teaches the engineering principle that complex systems are built from interchangeable standardized components
10. Degrees of freedom is the number of independent movements a joint or system can make. A human arm has 7 DOF: shoulder has 3 (up/down, left/right, rotation), elbow has 1 (bend), and wrist has 3 (up/down, left/right, rotation). Each DOF adds one axis of independent movement.
    Matching (Introduction to Robotics Concepts): 1→D, 2→A, 3→E, 4→B, 5→C
11. A — Lever, wheel and axle, pulley, inclined plane, wedge, and screw
12. D — Mechanical advantage is the factor by which a machine multiplies the input force. A mechanical advantage of 3 means the machine outputs 3 times the force you put in. Robots use gears, levers, and pulleys to achieve mechanical advantage so small motors can lift heavy objects.
13. D — The large gear rotates 1 time. The gear ratio is 10:40 (or 1:4), meaning the small gear must turn 4 times for the large gear to turn once. Each rotation of the small gear advances 10 teeth on the large gear; $4 \times 10 = 40$ teeth = 1 full rotation.
14. D — Worm gears provide very high gear ratios (50:1 or more) in a compact space AND are self-locking — the output shaft cannot be back-driven by the load. This means a robot arm holding a heavy object won't drop it when the motor stops, because the load can't spin the worm gear backward.
15. D — DC motor: spins continuously at variable speed, good for wheels and fans. Servo motor: rotates to a specific angle and holds position (typically 0-180°), good for robot arm joints and steering. Stepper motor: rotates in precise discrete steps (e.g., 1.8° per step), good for 3D printers and CNC machines where exact positioning is needed.
16. A — 50 pounds. A pulley system with 4 supporting ropes has a mechanical advantage of 4, so the required force is $200 \div 4 = 50$ pounds. The trade-off is that you must pull 4 times as much rope to lift the box the same height.

17. A linkage is a series of rigid bars connected by pivot joints. A four-bar linkage uses four connected bars to convert the simple rotation of a motor (input crank) into complex output motion — the output bar can trace curves, oscillate back and forth, or create walking-like leg movements depending on the bar lengths.
18. A compliant (soft/flexible) gripper with force feedback: rubber or silicone padding on the fingers conforms to irregular shapes without applying point forces, and a force sensor limits grip strength to prevent crushing. The gripper closes until the force sensor detects adequate grip force, then stops — gentle for eggs, strong for blocks.
19. Wheels can only climb obstacles shorter than their radius — a wheel gets stuck against a step taller than its center height. Tracks distribute the robot's weight over a long surface and the front edge of the track can 'ramp' up and over steps that would stop a wheel, because the track effectively creates a moving inclined plane against the step edge.
20. Gear C spins at 600 RPM. Stage 1: Gear A→B ratio is 20:60 = 1:3, so Gear B = 300 ÷ 3 = 100 RPM. Stage 2: Gear B→C ratio is 60:10 = 6:1, so Gear C = 100 × 6 = 600 RPM. The compound gear train first reduces speed then increases it.
    Matching (Mechanical Design and Simple Machines): 1→A, 2→E, 3→C, 4→B, 5→D
21. D — To gather information about the robot's environment or internal state
22. A — Ultrasonic distance sensor
23. C — It is partially on the line edge and should steer slightly toward the line
24. D — Black surfaces absorb more IR light, reflecting less signal back to the sensor
25. B — 1-C, 2-D, 3-A, 4-B
26. C — An analog sensor outputs a continuous range of values, while a digital sensor outputs discrete states like on/off
27. Egg: 100–250 range; Bolt: 500–800 range
28. The robot is angled with its left side closer to the wall than its right side
29. Radar sensor
30. Red
    Matching (Sensors and Input Systems): 1→C, 2→B, 3→D, 4→A, 5→E
31. D — Make different decisions based on whether a condition is true or false
32. B — A while loop repeats as long as a condition is true; a for loop repeats a specific number of times

33. C — Slow down to half speed
34. C — The robot will endlessly stop, turn right, drive forward, then immediately stop and turn again, spinning in a circle
35. C — A named storage location in memory that holds a value which can change during program execution
36. D — Option A: count = count + 1
37. A function is a reusable named block of code that performs a specific task — it reduces repetition and makes programs easier to read, test, and fix
38. true, because 25 is less than 30
39. A programming pattern where the robot has defined states (like IDLE, SEARCHING, RETURNING) and specific rules for switching between them based on events
40. Back up, then turn right or left (the obstacle is directly ahead)
    Matching (Programming Logic and Control Flow): 1→D, 2→B, 3→C, 4→E, 5→A
41. A — A device that converts electrical energy into physical motion or action
42. D — A DC motor spins continuously at variable speed, while a servo motor rotates to a specific angle and holds that position
43. B — The motor receives power 75% of each cycle and is off 25%, resulting in approximately 75% of full speed
44. C — 1.5 seconds
45. C — A stepper motor rotates in precise, discrete steps (e.g., 1.8° per step) and is ideal when you need exact position control without a feedback sensor
46. D — 1-A (clockwise), 2-B (counter-clockwise), 3-C (brake), 4-D (coast)
47. Pneumatic actuators can produce very high grip force relative to their size and weight, with simple on/off control and no risk of overheating
48. Torque is the rotational force a motor can produce — a robot arm lifting heavy objects needs high torque to overcome gravity
49. 4.5A (2A + 2A + 0.5A assuming voltage regulators handle the different voltages)
50. A solenoid uses an electromagnetic coil to push or pull a metal plunger in a straight line — commonly used for locks, latches, and valve controls
    Matching (Actuators and Output Systems): 1→B, 2→C, 3→A, 4→D, 5→E
51. A — Where am I? (localization), Where do I want to go? (goal), and How do I get there? (path planning)

52. D — SLAM is building a map of an unknown environment while simultaneously tracking the robot's position within that map — it's paradoxical because accurate mapping requires knowing your position, but accurate localization requires having a map
53. D — 8 moves (4 right + 4 up, in any order)
54. D — A* uses a heuristic (estimated distance to goal) combined with actual distance traveled to prioritize exploring paths that seem most promising, avoiding wasted exploration of clearly wrong directions
55. D — Small measurement errors in each wheel rotation accumulate over time — wheel slippage, uneven tire wear, and imprecise turning all add up
56. B — A 2D grid where each cell is marked as occupied (obstacle), free (traversable), or unknown — the robot plans paths through free cells while avoiding occupied ones
57. Path A is likely safer — although longer, the 0.1 m clearance through the doorway in Path B leaves almost no margin for error and risks getting stuck
58. A map where each cell has a traversal cost value — obstacles have infinite cost, areas near obstacles have high cost, and open space has low cost, guiding the robot to prefer safer paths
59. LIDAR matching against a floor plan, visual landmark recognition with cameras, Wi-Fi signal strength triangulation, or ultra-wideband (UWB) beacons
60. A priority system (subsumption architecture) where higher-priority behaviors override lower-priority ones — typically Avoid-Obstacle has highest priority for safety
    Matching (Autonomous Navigation and Decision-Making): 1→D, 2→E, 3→B, 4→C, 5→A
61. D — Industrial automation integrates multiple machines, robots, sensors, and software into a coordinated system that handles an entire production process with minimal human intervention
62. C — A PLC is a ruggedized industrial computer designed for real-time control in harsh environments — it handles dust, vibration, heat, and power fluctuations that would crash a regular computer
63. D — 45 seconds — the cycle time equals the slowest station (bottleneck), because all other stations must wait for it
64. D — A cobot is designed to work safely alongside humans in a shared workspace — it has force-limiting sensors, rounded edges, and slower speeds, unlike

traditional robots that operate behind safety cages

65. A — 95 good widgets falsely rejected (9,500 good widgets × 1% false positive rate = 95)
66. C — A motorized belt or roller system that transports materials and products between workstations, forming the physical backbone of an assembly line
67. 43.8 hours per year (8,760 × 0.005 = 43.8 hours of downtime)
68. Predictive maintenance uses sensor data (vibration, temperature, current) to predict when a machine will fail and schedules repair just before failure — preventive maintenance follows a fixed schedule regardless of actual condition
69. An EOAT is the attachment at the end of a robot arm (gripper, welder, suction cup, etc.) — robots change tools to perform different tasks in the same cell, like switching from welding to painting
70. Line A: 97 good units/hour (100 × 0.97) vs Line B: 79.6 good units/hour (80 × 0.995) — Line A produces more good units despite higher defect rate
Matching (Factory Automation and Systems Integration): 1→B, 2→C, 3→D, 4→E, 5→A
71. A — Sensing (a color sensor to identify each block), processing (a microcontroller running the sorting algorithm), and actuation (a motor-driven arm or conveyor to move blocks to the correct bin)
72. A — A high gear ratio trades speed for torque, giving the robot enough force to climb steep rocks without stalling, while a low gear ratio trades torque for speed, allowing efficient fast travel across easy terrain where less force is needed
73. C — The ultrasonic sensor handles the 5 cm nearby obstacle (within its 2–400 cm range and below LIDAR's 10 cm minimum), while the LIDAR handles the 8 m distant shelf (within its 10 cm–12 m range but beyond the ultrasonic's 400 cm maximum)
74. B — Add an ELSE IF part.color == 'green': arm.place_in(bin_C) between the blue check and the ELSE clause, so green parts are caught before falling through to the reject bin
75. C — Total current = 2A + 0.5A + (10 × 0.02A) = 2.7A. Yes, the 3A battery is sufficient since 2.7A < 3A, leaving a 0.3A safety margin
76. D — Causes: (1) Wheel encoder odometry accumulates small measurement errors over time, and (2) wheel slippage on smooth floors introduces undetected position errors. Correction: Use a known landmark (like a charging station or QR code) as a reference point to reset the position estimate

77. Design B — small tracked robots navigate tight rubble better than large wheeled ones, multiple sensor types provide redundancy if one fails in dusty conditions, and a flexible body can squeeze through narrow gaps that a rigid frame cannot
78. Most to least critical: (3) color sensor → (4) gripper mechanism → (2) encoders on both motors → (1) second color sensor. Without a color sensor the robot cannot identify ball colors; without a gripper it cannot pick them up; encoders improve navigation accuracy; a second color sensor is a luxury for reliability
79. Add a ripeness check between APPROACHING and PICKING: when the robot reaches the fruit, use a color sensor to assess ripeness. If unripe, transition back to SEARCHING instead of proceeding to PICKING
80. Downward-facing IR or line sensors to detect the ring's edge (white border on dark surface) to avoid driving out, plus a forward-facing ultrasonic or IR distance sensor to locate the opponent for pushing
    Matching (Master Roboticist Capstone): 1→C, 2→E, 3→B, 4→D, 5→A
81. B — Line-following sensor
82. D — Global Positioning System
83. B — Ultrasonic sensor
84. B — Estimating position by tracking distance and direction traveled from a known starting point
85. B — Obstacle avoidance
86. B — Wall-following algorithm
87. Multiple sensors help the robot detect which side of the line it is drifting toward so it can correct its steering
88. It measures the distance to nearby objects so the robot can detect and steer around them before a collision
89. A pre-programmed path is fixed in advance, while reactive navigation lets the robot adjust in real time based on sensor input
90. GPS signals from satellites are weakened or blocked by walls and ceilings, reducing accuracy indoors
    Matching (Robotics & Automation): 1→C, 2→E, 3→B, 4→D, 5→A
91. D — Computer vision
92. B — Light Detection and Ranging
93. B — The smallest individual element of a digital image

94. C — LIDAR
95. A — The process of identifying and locating specific objects within an image or video
96. D — Image sensor
97. Different sensors have different strengths and weaknesses, so combining them provides more reliable and complete information about the environment
98. A depth camera measures the distance to each point in the scene in addition to color, allowing the robot to understand the 3D shape of its surroundings
99. It fires thousands of laser pulses in different directions, measures the time each pulse takes to bounce back, and uses those distances to plot thousands of 3D points representing surfaces in the environment
100. Most face-detection algorithms are trained on front-facing, fully visible faces and may not recognize faces in unusual orientations or when key features are occluded
Matching (Robotics & Automation): 1→C, 2→A, 3→D, 4→B, 5→E
101. A — Collaborative robot (cobot)
102. A — A robot designed to interact with people using social behaviors like speech, gestures, and facial expressions
103. C — Voice control (or voice recognition)
104. C — A large, clearly visible button that immediately shuts down the robot's movement when pressed for safety
105. B — The robot is designed to automatically reduce or stop its force when it contacts a human to prevent injury
106. D — A device that provides physical sensations like vibrations or resistance to the user, simulating touch
107. Slower speeds give humans more time to react and reduce the force of any accidental contact, making the shared workspace safer
108. Background noise from machinery interferes with the microphone, making it difficult for the speech recognition system to isolate and accurately interpret the spoken command
109. Predictable movements build trust and prevent startling or frightening children; sudden unexpected motions can cause fear or anxiety
110. Sensors detect the human's presence, and the robot pauses its motion while

maintaining its position; it resumes automatically when the human moves away
Matching (Robotics & Automation): 1→A, 2→B, 3→D, 4→E, 5→C

111. A — Canadarm2
112. D — Industrial robot arm
113. A — The da Vinci Surgical System
114. A — Search-and-rescue robot
115. D — The use of technology to perform tasks with minimal human intervention
116. A — Perseverance
117. Robots can perform the same precise motion thousands of times without fatigue, errors, or breaks, making them more consistent and efficient for repetitive tasks
118. Surgical robots filter out natural hand tremor, scale down large hand movements into tiny instrument movements, and provide magnified 3D visualization of the surgical area
119. Robots do not need food, water, air, or protection from radiation; they are lighter, cheaper to launch, and can operate in environments that are immediately deadly to humans
120. Automation can replace jobs that humans currently perform, leading to concerns about unemployment and the need to learn new skills
Matching (Robotics & Automation): 1→D, 2→C, 3→E, 4→A, 5→B
121. C — A robot can make decisions on its own based on sensor input (autonomous behavior), while a remote-controlled car only moves when a human directly controls every action — it has no ability to sense or decide independently
122. C — A microcontroller is a small, self-contained computer on a single chip that reads sensor data, runs the robot's program, and sends commands to actuators. It's called the 'brain' because it performs the 'think' step in the sense-think-act cycle — receiving input, processing it according to programmed rules, and deciding what output actions to take.
123. A — Sensor fusion is combining data from multiple different sensors to create a more accurate understanding of the environment than any single sensor provides alone. Robots use it because each sensor has limitations: a camera fails in darkness, ultrasonic fails with soft surfaces, and GPS fails indoors. Fusing multiple sensors compensates for individual weaknesses.
124. D — Motion: rotational (twist ~90°) followed by a pull or push (linear). Torque: approximately 1-3 Nm for a standard doorknob. End effector: a two-finger gripper

wide enough to wrap around the knob (cylindrical grasp), with compliant/rubber contact surfaces for grip, mounted on a wrist joint that can rotate at least 90°. The entire arm must also generate enough force to push/pull the door after the knob is turned.

125. A — To turn left, either stop the left wheel while the right wheel drives forward (pivot turn), or run the left wheel backward while the right wheel goes forward (spin turn — faster, tighter rotation). The speed difference between the two wheels determines the turn radius.

126. B — Too dangerous: bomb disposal robots disarm explosives without risking human lives. Too boring: warehouse robots like Amazon's Kiva systems move shelves repetitively 24/7 without fatigue. Too precise: surgical robots like da Vinci perform microsurgery with sub-millimeter accuracy that human hands can't match.

127. Batteries are better for indoor robots, robots that need consistent power regardless of lighting, and robots that need high power for heavy lifting or fast movement. Solar panels are better for long-duration outdoor robots (like Mars rovers) where recharging from an outlet is impossible and the robot can operate slowly during daylight hours.

128. It might work in a perfectly controlled environment where nothing ever changes (like a factory with bolted-down parts on a conveyor belt at exact positions). It would definitely fail in any environment with unpredictable elements: other moving objects, uneven surfaces, objects that shift position, or any variation from the expected layout.

129. Wheels can only climb obstacles shorter than their radius — a wheel gets stuck against a step taller than its center height. Tracks distribute the robot's weight over a long surface and the front edge of the track can 'ramp' up and over steps that would stop a wheel, because the track effectively creates a moving inclined plane against the step edge.

130. This prediction is overly simplistic because: (1) Robots excel at structured, repetitive tasks but struggle with unstructured, creative, or social work. (2) New technology creates new jobs — the automobile eliminated horse-related jobs but created millions of auto industry jobs. (3) Many tasks require human judgment, empathy, and adaptability that current robotics can't replicate. (4) Economic and social factors (cost, regulation, public acceptance) slow adoption. Robots will transform work, not eliminate it.
Matching (ethics and society): 1→C, 2→D, 3→B, 4→E, 5→A

131. C — A robot must be able to sense its environment (input), process information to make decisions (computation), and take physical action in the world

(output/actuation)

132. D — Ultrasonic distance sensor (detects distance to walls by sending sound pulses and timing echoes), infrared line sensor (detects dark lines on the floor to follow paths), and bump/touch sensor (detects physical contact with walls as a backup if other sensors fail)
133. B — An end effector is the tool or device attached to the end of a robot arm — the part that directly interacts with objects or the environment. The same arm can swap end effectors (gripper, welder, paint sprayer, suction cup) to perform different tasks, just like a human can hold different tools.
134. C — A: Quadruped walking (four legs). B: Aerial (rotary-wing flight with four propellers). C: Wheeled (differential drive on a flat surface). D: Stationary (fixed base, only the arm moves). E: Aquatic (thrusters for underwater movement).
135. A — Belt drives: quieter, smoother, tolerate slight misalignment, can slip under overload (acting as a safety clutch), but stretch over time and can't transmit very high torque. Chain drives: higher torque capacity, positive engagement (no slipping), more durable, but noisier, require lubrication, and need precise shaft alignment.
136. C — Ultrasonic distance sensor
137. It emits a light pulse and measures the time for the reflection to return, calculating distance from the speed of light
138. Each sensor type has different strengths and weaknesses, so combining them provides more reliable perception in varied conditions
139. 45 seconds — the cycle time equals the slowest station (bottleneck), because all other stations must wait for it
140. A while loop repeats as long as a condition is true; a for loop repeats a specific number of times
    Matching (ethics and society): 1→D, 2→C, 3→E, 4→B, 5→A
141. B — Sense: Cameras and LIDAR detect other cars, pedestrians, lane markings, and traffic signals. Think: The onboard computer processes this data to identify objects, predict their movements, and plan a safe path. Act: The computer sends commands to the steering wheel, accelerator, and brakes to follow the planned path.
142. B — The engineering design process is: Define the problem → Research → Brainstorm solutions → Select best design → Build a prototype → Test and evaluate → Iterate (improve based on test results). For a robot, this means defining what task it must accomplish, researching existing solutions, designing

the mechanical and electronic systems, building the robot, testing it against the task requirements, and improving it based on test results.

143. B — A linkage is a series of rigid bars connected by pivot joints. A four-bar linkage uses four connected bars to convert the simple rotation of a motor (input crank) into complex output motion — the output bar can trace curves, oscillate back and forth, or create walking-like leg movements depending on the bar lengths.
144. A — Lever, wheel and axle, pulley, inclined plane, wedge, and screw
145. C — Worm gears provide very high gear ratios (50:1 or more) in a compact space AND are self-locking — the output shaft cannot be back-driven by the load. This means a robot arm holding a heavy object won't drop it when the motor stops, because the load can't spin the worm gear backward.
146. B — Black surfaces absorb more IR light, reflecting less signal back to the sensor
147. More powerful motors are heavier (requiring stronger structure), consume more energy (shorter battery life), cost more, and may require larger motor drivers — the ideal motor matches the actual task requirements
148. 95 good widgets falsely rejected (9,500 good widgets × 1% false positive rate = 95)
149. The robot must balance between exploiting known routes/strategies that work well and exploring unknown areas/strategies that might be better but could also waste time
150. Multiple robots can divide the search area and explore in parallel, covering the area much faster than a single robot while providing redundancy if one robot fails
Matching (ethics and society): 1→B, 2→C, 3→E, 4→A, 5→D
151. B — Springs store potential energy when compressed or stretched and release it as kinetic energy when let go. In robotics, springs are used for: shock absorption (protecting robots from impact damage), energy storage (jumping robots compress springs then release for leap), return mechanisms (springs pull components back to default position), and gravity compensation (springs counterbalance arm weight so motors don't fight gravity).
152. A — Sensor fusion combines data from multiple sensors to produce a more accurate and reliable estimate than any single sensor — for example, combining GPS (accurate long-term but noisy) with IMU data (smooth short-term but drifts) gives both smooth and accurate positioning
153. A — A cam is a rotating or sliding piece with a specially shaped profile that converts rotary motion into precisely controlled reciprocating (back-and-forth)

motion. In robotics, cams are used for repetitive motions like a walking leg that needs to follow the same path every cycle, or a pick-and-place mechanism that needs a specific lift-advance-lower pattern.

154. B — 40 Nm (torque = force × distance = 5 kg × 10 m/s² × 0.8 m = 40 Nm)
155. C — Option A: count = count + 1
156. B — A (teleoperated surgical robot — human controls every movement) → D (pre-programmed factory arm — follows fixed instructions with minor sensor adjustments) → C (Mars rover — receives goals but autonomously navigates) → B (self-driving car — makes all driving decisions independently in real-time)
157. SCADA is a software system that monitors and controls an entire factory from a central location — displaying real-time data from all machines, alerting operators to problems, and logging production metrics
158. Cliff sensors detect drop-offs like stairs BEFORE the robot reaches them, while bumper sensors detect solid objects only on contact
159. Strategy A advantage: highly predictable and simple to verify for safety certification. Disadvantage: cannot handle unexpected obstacles like a wheelchair left in the hallway. Strategy B advantage: adapts to real-time changes in the environment. Disadvantage: more complex, harder to certify for safety, and SLAM drift can cause position errors over time
160. Mechanical wear (joint backlash increasing, servo precision degrading), welding tip erosion, fixture misalignment from repeated thermal cycling, or material changes in the parts being welded
Matching (ethics and society): 1→C, 2→D, 3→A, 4→B, 5→E
161. Because it needed to upgrade its programming!
162. A meander-bot!
163. It felt they were growing too distant!
164. Because it was full of loops and it couldn't break out of its feelings!
165. It had too many unresolved turns!
166. "Don't worry, we'll work through your issues one step at a time!"
