ROBOTICS
PAPER 1
(THEORY)

Maximum Marks: 70
Time Allotted: Three Hours
Reading Time: Additional Fifteen Minutes

Instructions to Candidates

1. You are allowed **additional fifteen minutes** for **only** reading the question paper.
2. You must **NOT** start writing during the reading time.
3. This question paper has **8 printed pages**.
4. It is divided into **two sections** and has **9 questions** in all.
5. **Part I** is compulsory and has **two** questions.
6. **Part II** is divided into **seven questions**. Answer **any five** questions.
7. While attempting **Multiple Choice Questions** in Part I, you are required to **write only ONE option as the answer**.
8. **Each question in Part II** has **three sub parts. Any five** questions have to be attempted.
9. The intended marks for questions are given in brackets [ ].

Instruction to Supervising Examiner

1. Kindly read **aloud** the Instructions given above to all the candidates present in the examination hall.

Note: The Specimen Question Paper in the subject provides a realistic format of the Board Examination Question Paper and should be used as a practice tool. The questions for the Board Examination can be set from any part of the syllabus, though the format of the Board Examination Question Paper will remain the same as that of the Specimen Question Paper. The weightage allocated to various topics, as given in the syllabus, will be strictly adhered to.

PART I (20 MARKS)

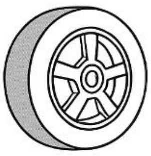
*Answer **all** questions.*

While answering questions in this Part, indicate briefly your working and reasoning, wherever required.

Question 1

(i) Which type of wheel allows for easy rotation and change of direction but is typically used in conjunction with other fixed wheels for stability? **(Recall)** **[1]**

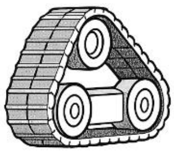
(a) Standard Wheel



(b) Castor Wheel

(c) Mecanum Wheel

(d) Crawler Wheel



(ii) Given below are two statements marked Assertion and Reason. Read the statements carefully and choose the correct option. **[1]**

Assertion: Modern robots often operate autonomously or semi-autonomously using sensors and AI.

Reason: AI and machine learning enhance a robot's ability to perceive, process information, and make decisions without constant human intervention.

(Analysis)

(a) Both Assertion and Reason are true and Reason is the correct explanation for the Assertion.

(b) Both Assertion and Reason are true but Reason is not the correct explanation for the Assertion.

(c) Assertion is true and Reason is false.

(d) Both Assertion and Reason are false.

(iii) Which component's power requirement would generally be the *highest* in a mobile robot system? **(Evaluate)** **[1]**

(a) A single IR sensor

(b) A microcontroller (SBC)

(c) Motors driving the wheels

(d) A touch sensor

(iv) Which Boolean operator would be **most** suitable to ensure a robot's safety system activates **only** when *both* an obstacle is detected *AND* the robot is in motion? **(Evaluate)** **[1]**

(a) OR

(b) NOT

(c) XOR

(d) AND

(v) Given below are two statements marked Assertion and Reason. Read the statements carefully and choose the correct option. **[1]**

Assertion: Lithium-ion batteries are widely favoured in mobile robotics.

Reason: They offer high energy density and a relatively long-life cycle compared to many other battery types, making them suitable for portable applications. **(Analysis)**

(a) Both Assertion and Reason are true and Reason is the correct explanation for the Assertion.

(b) Both Assertion and Reason are true but Reason is not the correct explanation for the Assertion.

(c) Assertion is true and Reason is false.

(d) Both Assertion and Reason are false.

(vi) Given below are two statements marked Assertion and Reason. Read the statements carefully and choose the correct option. **[1]**

Assertion: Planar mechanisms are characterized by their motion being restricted to a single two-dimensional plane.

Reason : An industrial robotic arm is an example of a planar mechanism because its movements are often complex and span three dimensions.

(Analysis)

(a) Both Assertion and Reason are true and Reason is the correct explanation for the Assertion.

(b) Both Assertion and Reason are true but Reason is not the correct explanation for the Assertion.

(c) Assertion is true and Reason is false.

(d) Both Assertion and Reason are false.

(vii) Which type of motor is known for providing precise angular movement and is commonly used in applications requiring exact positioning, like robotic arms? **[1]**

(Recall)

(a) DC Motor

(b) Stepper Motor

(c) Servo Motor

(d) Brushless DC Motor

(viii) A robotics engineer is using a software application to design and simulate the physical structure of a robot's arm before manufacturing it. This process is known as: **(Recall)** **[1]**

(a) System Visualization

(b) Algorithmic Programming

(c) Sensor Integration

(d) Computer-Aided Design (CAD) modeling

(ix) What is masking in Robotic Controllers? **(Recall)** **[1]**

(x) What is the term used for the overall planning, execution, and monitoring of a robotics project to ensure it meets its goals and is completed on time? **(Recall)** **[1]**

Question 2

(i) How does a moving frame differ from a fixed frame? **(Understanding)** **[2]**

(ii) What is the main advantage of using ‘timers’ in microcontroller programming for a robot, specifically for tasks that require precise delays or periodic actions? **[2]**

(Understanding)

(iii) The following function checkSensor() simulates a basic safety check. Assume currentSpeed is an integer and obstacleDetected is a boolean. **[3]**

```
public boolean checkSensor(int currentSpeed, boolean obstacleDetected) {
   if (currentSpeed > 5 && obstacleDetected == true) {
      return false; // Safety trigger
   } else if (currentSpeed <= 5 && obstacleDetected == true) {
      return true; // Slow and safe
   } else {
      return true; // Path clear
   }
}
```

What will the function checkSensor() return if currentSpeed = 7 and obstacleDetected = true? Perform a dry run. **(Application)**

(iv) A drone's primary mission is to collect data for aerial mapping. Identify *one* specific "sensor payload" that is essential for this task and briefly state its function in this context. **(Understanding)** **[2]**

(v) The following line of code is found in a microcontroller program for a robot: **[1]**

digitalWrite(LED_PIN, HIGH);

What action does this single line of code typically perform on a connected component in a robot? **(Recall)**

PART II (50 MARKS)

*Answer **any five** questions.*

While answering questions in this Part, indicate briefly your working and reasoning, wherever required.

Question 3

(i) A startup is designing a new autonomous delivery robot for urban environments. Discuss two critical challenges they might face regarding "New Age Robotics Systems," specifically concerning sensor integration and AI decision-making for safe navigation in unpredictable human environments. Provide a potential innovative solution for each challenge. **(Evaluate)** **[4]**

(ii) Differentiate between 'Planar Mechanisms' and 'Spatial Mechanisms' using real-life robotic examples. **(Understanding)** **[3]**

(iii) How many 'Degrees of Freedom' does a single rigid body have when operating in 3D space? Briefly state what each degree of freedom represents. **(Understanding)** **[3]**

Question 4

(i) A robot is designed to activate an alarm system. The alarm should trigger if either an intruder is detected by a motion sensor (Input M) OR when a panic button is pressed (Input P), AND simultaneously the system is armed (Input A). Draw a flowchart representing this logical decision for the robot's alarm system. **(Create)** **[4]**

(ii) Explain the significance of "Matrix Operations" in the context of programming a robotic arm to accurately perform a pick-and-place task, involving changes in its orientation and position. **(Understanding)** **[3]**

(iii) A student is trying to design a simple mobile robot that can move in any direction without physically turning its body. Which specific type of wheel would be most appropriate for designing this capability? Explain. **(Application)** **[3]**

Question 5

(i) You are given a simple robotic arm that consists of two links (L_1, L_2) and two rotating joints (J_1, J_2) operating in a 2D plane. J_1 is fixed at the origin. Draw a conceptual diagram of this 2R planar open chain mechanism. If the joint angles are theta_1 and theta_2 (relative to the previous link), explain the concept of "Forward Kinematics" for this arm. *(Note: Students are expected to draw a simple diagram of a 2R arm.)* **(Create)** **[4]**

(ii) Explain briefly, why "Fixed Frame" are fundamental for defining the overall workspace and movement constraints of a complex industrial robotic arm. **(Understanding)** **[3]**

(iii) Briefly describe the primary goal of "Project Management" in a complex robotics development initiative. **(Recall)** **[3]**

Question 6

(i) A robotic arm needs to achieve extremely high precision in semiconductor manufacturing. Compare and contrast ‘Accuracy’ and ‘Repeatability’ as robot specifications. Explain how ‘Integrated Vision Systems’ and ‘Adaptive Control Systems’ contribute to improving these two specifications respectively. **(Application and Analysis)** **[4]**

(ii) Explain why an "algorithm" is considered the foundational step before writing any "pseudo code" or actual program for a microcontroller in a robotics project. **(Understanding)** **[3]**

(iii) Consider the following C-like pseudo code for a simple robotic task: **[3]**

```
int counter = 0; void setup() { // Initialize pins for LED and button // Set LED pin
as output, button pin as input }
void loop() {
 if (digitalRead(buttonPin) == HIGH) {
  delay(50); // Debounce
  if (digitalRead(buttonPin) == HIGH) {
   counter = counter + 1;
   delay(200); // Prevent multiple counts per press
  }
 }
 if (counter % 2 == 0) {
  digitalWrite(ledPin, HIGH); // Turn LED ON
 } else {
  digitalWrite(ledPin, LOW); // Turn LED OFF
 }
}
```

What will be the state of the `ledPin` (HIGH/LOW) after the button has been pressed and released exactly three times? Justify your answer. **(Application)**

Question 7

(i) A robotics engineer is debugging a new embedded C program for a mobile robot. The robot occasionally stops responding to commands. Describe a systematic approach to "debugging" this issue, including at least two specific techniques that might be employed. **(Application and Analysis)** **[4]**

(ii) Explain the importance of a well-designed "Control System" in ensuring both the "accurate" and "safe" performance of a surgical robot. **(Understanding)** **[3]**

(iii) A robotic arm is programmed to move its end-effector to a specific coordinate (X,Y,Z). If the robot's control system relies on knowing the current position for path planning, which "Boolean operator" is most likely used to confirm that the robot has reached *all three* specified coordinates simultaneously within a tolerance? **(Application)** **[3]**

Question 8

(i) Compare and contrast 'IR sensors' and 'Ultrasonic sensors' in terms of their working principles, advantages, and disadvantages when used for obstacle detection in a low-cost mobile robot. **(Analysis)** **[4]**

(ii) Describe the basic architecture of a "Microcontroller (SBC)" by explaining the roles of its three main functional blocks. **(Understanding)** **[3]**

(iii) A small drone requires a compact and lightweight power source that can deliver sustained power for flight. Which type of battery (Lithium-ion or Lead-acid) would be more suitable for this application? Justify your choice based on battery characteristics. **(Evaluate)** **[3]**

Question 9

(i) Explain how 'Manipulators' are fundamentally different from 'Mobile Robots' in terms of their primary function and typical operational environment. Provide one distinct real-world application for each type of robot. **(Understanding)** **[4]**

(ii) You are developing a farming drone for precision agriculture. Besides a camera, identify two other essential 'sensor payloads' that would significantly enhance its capability for monitoring crop health and identifying disease outbreaks. Briefly explain the function of each. **(Analysis)** **[3]**

(iii) A robotics team is integrating various sensors (e.g., gyroscope, accelerometer) with a central microcontroller on a small mobile platform. **[3]**

Which 'communication protocol' (UART, I2C, SPI, CAN) would typically be preferred for connecting multiple such sensors to a single microcontroller, allowing for simpler wiring and addressing? Justify your answer.

(Evaluate)

ROBOTICS
PAPER 1
(THEORY)
ANSWER KEY

PART I (20 MARKS)

Question 1

(i)	(b) or Castor Wheel	**[1]**
(ii)	(a) or Both Assertion and Reason are true and Reason is the correct explanation for the Assertion.	**[1]**
(iii)	(c) or Motors driving the wheels	**[1]**
(iv)	(d) or AND	**[1]**
(v)	(a) or Both Assertion and Reason are true, and Reason is the correct explanation for the Assertion.	**[1]**
(vi)	(c) or Assertion is true and Reason is false.	**[1]**
(vii)	(b) or Stepper Motor	**[1]**
(viii)	(d) or Computer-Aided Design (CAD) modelling	**[1]**
(ix)	**Masking:** Temporarily disabling hardware or software interrupts during critical operations. It is used to prevent interference while the robot performs time-sensitive tasks.	**[1]**
(x)	Project Management	**[1]**

Question 2

(i) **Fixed Frame (also called World Frame or Inertial Frame)** **[2]**

A coordinate system that does **not move**. It is fixed in space and used as a reference.

Moving Frame (also called Body Frame or Local Frame)

A coordinate system that **moves along with an object**, such as a robot's hand or a drone.

(ii) The main advantage of using **timers** is that they allow for precise, time-based actions without halting or "blocking" the main program execution. Unlike a simple delay() function which stops all other code from running, a timer works in the background. **[2]**

(iii) (a) currentSpeed = 7 **[3]**

obstacleDetected = true

The if statement (currentSpeed > 5 && obstacleDetected == true) is checked.

(7 > 5 && true == true) evaluates to (true && true), which is true.

The code block inside this if statement is executed.

The function will return false.

Answer: The function checkSensor() will return **false**.

(iv) Sensor Payload: A crucial sensor payload for aerial mapping is a high-resolution camera (often a multispectral or hyperspectral camera). **[2]**

Function: A standard high-resolution camera captures visible light images, which can be stitched together to create a detailed map of the area.

(v) This line of code, digitalWrite(LED_PIN, HIGH);, will typically **turn ON the LED** (or any other component) connected to the specified pin (LED_PIN). The HIGH state corresponds to a high voltage level (e.g., 5V or 3.3V), which provides the power to activate the component. **[1]**

PART II (50 MARKS)

Question 3

(i) **Challenge 1: Sensor fusion and unreliable data in dynamic environments.** **[4]**

Explanation: A delivery robot in a city must navigate crowds, varying weather conditions (rain, sun glare), and unpredictable objects (potholes, a child's toy). No single sensor (e.g., a camera, LiDAR) is perfectly reliable in all these conditions. Rain can obscure camera images, and sun glare can blind sensors. The robot needs to process data from multiple sensors simultaneously (sensor fusion) to build a robust environmental model, but conflicting or noisy data can lead to dangerous misinterpretations.

Innovative Solution: Implement an AI model based on a **Kalman Filter** or a **Particle Filter** for sensor fusion. This probabilistic approach can weigh the reliability of each sensor's data in real-time, effectively "trusting" the more reliable sensor data while accounting for the uncertainty of the others. The system could learn to prioritize LiDAR data in low-light conditions and visual data in clear weather, dynamically adapting to the environment.

Challenge 2: Ethical and instantaneous decision-making in unforeseen situations.

Explanation: The robot's AI might encounter an ethical dilemma, such as whether to swerve to avoid a collision with a pedestrian, potentially hitting another object or person. Traditional programming can't account for every possible scenario. The AI needs to make a decision in a fraction of a second, but without the "common sense" or ethical framework of a human. A wrong decision could lead to injury or property damage.

Innovative Solution: Develop a **predictive risk assessment module** within the AI. This module would not just detect obstacles but would also predict the likely trajectories of pedestrians, vehicles, and other dynamic objects. The AI would then calculate the risk of collision for a range of possible actions (e.g., braking, swerving, continuing) and choose the action with the lowest overall risk, prioritizing human safety above all. This system would be trained on vast datasets of real-world urban scenarios, allowing it to "learn" a safe and responsible decision-making strategy.

(ii) **Planar Mechanisms vs Spatial Mechanisms** **[3]**

Planar Mechanisms: These are robotic systems whose links and joints are constrained to move within a single, two-dimensional plane.
Example: A simple robotic arm used for drawing or a pick-and-place robot on a flat conveyor belt. The motion is defined by two translational axes (X, Y) and one rotational axis (Z).

Spatial Mechanisms: These are robotic systems that are free to move and operate in all three dimensions of space.
Example: An industrial welding robot or a surgical robot arm. The movements are complex, involving three translational axes (X, Y, Z) and three rotational axes (roll, pitch, yaw) to position the end-effector at any point in its workspace with any desired orientation.

(iii) A single rigid body in 3D space has **six Degrees of Freedom (DoF)**. **[3]**

Three Translational Degrees of Freedom: These represent the ability to move the body along the three Cartesian axes:

- **x-axis:** Movement forward and backward.
- **y-axis:** Movement left and right.
- **z-axis:** Movement up and down.

Three Rotational Degrees of Freedom: These represent the ability to rotate the body about the three Cartesian axes:

- **Roll:** Rotation about the x-axis.
- **Pitch:** Rotation about the y-axis.
- **Yaw:** Rotation about the z-axis.

Question 4

(i) **[4]**

```
graph TD
    A[Start]      --> B(Is System Armed? (A));
    B -- No       --> C[End];
    B -- Yes      --> D(Intruder Detected? (M));
    B – Yes       --> E(Panic Button Pressed? (P));
    D             --> F{M OR P};
    E             --> F;
    F – True      --> G[Trigger Alarm];
    F – False     --> C;
```

Reasoning: The alarm should trigger if (M OR P) is true, but *only if* A is also true. The flowchart first checks if the system is armed (Input A). If not, it ends. If it is armed, it then checks for either a motion sensor trigger (Input M) or a panic button press (Input P). The OR operator is represented by the two lines converging to a single decision block. If that condition is met, the alarm is triggered.

(ii) **Matrix Operations for Robotic Arm** **[3]**

Significance: Matrix operations are the mathematical language of robotics for describing and manipulating a robot's position and orientation.

Representation: The position and orientation of each joint and the end-effector are represented as transformation matrices. These matrices contain both rotational and translational information.

Forward Kinematics: By multiplying the transformation matrices of each successive joint, a robot can calculate the final position and orientation of its end-effector relative to its base (fixed frame). This is crucial for knowing where the robot is in space.

Path Planning: To move the end-effector from point A to point B, matrix operations are used to interpolate between the starting and ending transformations, generating a smooth path of intermediate poses for the arm to follow.

Inverse Kinematics: This is the inverse of the forward process. Given a desired position and orientation (a matrix), matrix operations help solve for the required joint angles that will achieve that final pose. This is essential for pick-and-place tasks where the goal is to place an object at a specific location.

(iii) The most appropriate wheel type would be the **Mecanum wheel**. **[3]**

Mecanum wheels are unique because their rollers are mounted at a 45-degree angle. By individually controlling the speed and direction of the motors for each of the four wheels, the resulting forces can be vector-summed to achieve a net force in any direction. For example, by spinning two wheels forward and two backward, the robot can move sideways. This allows for omnidirectional movement (translation in any direction) without the robot's body having to change its orientation (rotation).

Question 5

(i) **Conceptual Diagram of a 2R Planar Open Chain Mechanism:** **[4]**

Diagram:

- Draw a point at the origin (0,0) representing J_1.
- From J_1, draw a line segment L_1 of length l_1 at an angle θ_1 to the horizontal axis.
- At the end of L_1, draw a point representing J_2.
- From J_2, draw a line segment L_2 of length l_2 at an angle θ_2 relative to L_1.
- The endpoint of L_2 is the end-effector. Label its coordinates as (X, Y).

Forward Kinematics: Forward kinematics is the process of calculating the position and orientation of the robot's end-effector given the lengths of its links and the values of its joint angles. For this 2R planar arm, the position (X, Y) of the end-effector is a function of the joint angles θ_1 and θ_2 and the link lengths l_1 and l_2. The equations are:

- $X=l_1\cos(\theta_1)+l_2\cos(\theta_1+\theta_2)$
- $Y=l_1\sin(\theta_1)+l_2\sin(\theta_1+\theta_2)$

This process essentially "maps" the robot's internal joint configuration to a specific point in its workspace.

(ii) **Fixed frames** are fundamental in industrial robotics because they provide a stable, universal reference point for all motion planning, workspace definition, and safety constraints. They anchor the entire robot system, allowing consistent calculation of positions, orientations, and limits for each joint and tool. Without a fixed frame, the robot cannot accurately understand its position in the environment, coordinate with other machines, or safely operate within defined zones. **[3]**

(iii) The primary goal of **Project Management** in a robotics development initiative is to ensure that the project is completed **on time, within budget, and to the specified quality standards**. This involves: **[3]**

Planning: Defining the project scope, goals, and deliverables.

Organizing: Allocating resources (personnel, funds, equipment) and scheduling tasks.

Controlling: Monitoring progress, managing risks, and making adjustments to keep the project on track.

Communication: Facilitating clear communication among team members and stakeholders. In essence, it's about systematically guiding a complex process from concept to completion, minimizing failures and maximizing efficiency.

Question 6

(i) **Accuracy vs. Repeatability** **[4]**

Accuracy: How close the robot's end-effector is to a desired target point in space. An accurate robot will consistently hit the target, but its subsequent attempts might be slightly scattered around that target.

Repeatability: How close the robot's end-effector is to the same point over multiple attempts. A highly repeatable robot will hit the same spot every time, but that spot might not be the actual target. It is a measure of consistency.

How Integrated Vision Systems improve Accuracy: A vision system can be used to locate the exact position of the target (e.g., a semiconductor wafer) in the workspace. By providing the robot's control system with this real-time, precise target location, the robot can adjust its path to account for any slight misalignment or drift, ensuring it hits the *true* target, thus improving accuracy.

How Adaptive Control Systems improve Repeatability: Adaptive control systems constantly monitor the robot's performance, such as joint position and motor torque. They can compensate for changes in the system dynamics, like temperature fluctuations, joint wear, or varying payloads. By continuously adjusting the control parameters to counteract these factors, the system ensures the robot's movements are consistent over time, leading to high repeatability.

(ii) An **algorithm** is the foundational step because it is a high-level, language-independent plan or set of instructions for solving a problem. It describes the logical steps a robot needs to take, such as "sense obstacle," "make a decision," "turn left." Writing an algorithm forces the designer to think through the problem logically and systematically before getting bogged down in the specific syntax of a programming language. This ensures the *logic* is sound. The **pseudo code** and the final program are simply the implementations of that sound logic, translating the algorithm into a format that the microcontroller can understand. **[3]**

(iii) **Justification:** **[3]**

1. **Initial state:** counter = 0. counter % 2 == 0 is true, so the ledPin is HIGH.
2. **First Press:** The button is pressed. The if condition digitalRead(buttonPin) == HIGH is met. The counter is incremented to 1. counter % 2 == 0 (1 % 2 == 0) is now false, so the ledPin is set to LOW.
3. **Second Press:** The button is pressed again. The counter is incremented to 2. counter % 2 == 0 (2 % 2 == 0) is true, so the ledPin is set back to HIGH.
4. **Third Press:** The button is pressed for the third time. The counter is incremented to 3. counter % 2 == 0 (3 % 2 == 0) is false, so the ledPin is set to LOW.

Answer: After the button has been pressed and released exactly three times, the ledPin will be **LOW**.

Question 7

(i) **Systematic Debugging Approach:** **[4]**

1. **Define the problem:** Clearly identify the behavior: "The robot occasionally stops responding to commands." This suggests a potential race condition, memory leak, or a state machine failure.
2. **Isolate the issue:** Try to reproduce the problem consistently. Does it happen after a specific sequence of commands? In a particular environment? For a certain duration? This helps narrow down the cause.
3. **Hypothesize potential causes:** Based on the behavior, formulate hypotheses. For example, "Maybe a memory buffer is overflowing," or "The communication protocol is getting desynchronized."

Specific Techniques:

Technique 1: Logging and Serial Communication. Print messages to the serial monitor (or a log file) at key points in the code. For example, print the values of variables, the state of the robot's state machine, or a "heartbeat" message to confirm the program is still running. When the robot stops responding, the last message in the log can provide a clue as to which part of the code was executing or what the state of the robot was at that moment.

Technique 2: Using a Debugger and Breakpoints. If the microcontroller supports it (e.g., via JTAG or SWD), use a hardware debugger. Set breakpoints at suspicious lines of code (e.g., inside a loop that handles commands or a communication function). When the code hits a breakpoint, the program execution pauses, and the engineer can inspect the values of all variables, step through the code line by line, and watch for unexpected behavior. This is much more powerful than simple logging for complex issues.

(ii) A well-designed **Control System** is paramount for a surgical robot's performance. **[3]**

Accurate Performance: The control system uses feedback from sensors (e.g., encoders on the joints, force sensors) to precisely track the robot's movements. A **closed-loop control system** continuously compares the desired position of the surgical tool with its actual position and makes rapid adjustments to eliminate any error. This ensures the robot performs the commanded movements with sub-millimeter precision, which is critical for delicate surgical tasks.

Safe Performance: The control system implements crucial safety protocols. It can have redundant safety checks, such as monitoring for excessive force (preventing tissue damage), and setting virtual boundaries to prevent the robot from moving outside of the sterile field. In a master-slave system, the control system acts as a filter, dampening a surgeon's tremors to ensure smooth, precise movements. Furthermore, a failsafe mechanism in the control system can immediately stop all motion if an error is detected or power is lost.

(iii) The most likely Boolean operator is **AND**. **[3]**

Justification: The robot's control system needs to confirm that it has reached the target position in the x-direction **AND** the y-direction **AND** the z-direction. For example, the pseudocode might look like this:

```
if (x_current== x_target && y_current == y_target && z_current == z_target)
```

The && (AND) operator ensures that all conditions are simultaneously true before the system confirms the robot has successfully reached its destination.

Question 8

(i) **[4]**

Feature	IR Sensor	Ultrasonic Sensor
Working Principle	Emits an infrared light beam and measures the amount of reflected light. The distance is calculated based on the intensity of the reflected light (analog) or the time of flight (digital).	Emits a high-frequency sound wave and measures the time it takes for the echo to return. The distance is calculated using the speed of sound.
Advantages	- **Fast response time:** Can detect obstacles very quickly. - **Unaffected by ambient light:** Works well in both light and dark conditions (though bright sunlight can interfere with some). - **Low power consumption.**	- **Unaffected by object color:** Measures distance to both dark and reflective objects equally well. - **Wider beam angle:** Can detect a wider range of obstacles with a single sensor. - **Reliable over a moderate range.**
Disadvantages	- **Affected by object color/material:** Dark or non-reflective surfaces absorb IR light, making them difficult to detect. - **Prone to interference from ambient light:** Direct sunlight can flood the sensor. - **Limited range:** Typically shorter range and less precise at longer distances.	- **Slower response time:** Needs to wait for the sound wave to travel and return. - **Narrow beam (cone):** Can miss small, thin objects that pass between the sound waves. - **Affected by soft surfaces:** Materials like cloth or foam can absorb sound, making them difficult to detect.

(ii) **Microcontroller (SBC) Architecture** The three main functional blocks of a microcontroller are: **[3]**

1. **Central Processing Unit (CPU):** This is the "brain" of the microcontroller. It's responsible for fetching, decoding, and executing instructions from the program memory. It performs all the logical and mathematical operations required for the robot to make decisions and control its components.
2. **Memory:** This block stores the program code and the data the program uses. It is typically divided into two types:
   Program Memory (ROM/Flash): This is non-volatile memory that stores the code that the CPU executes. It retains its contents even when the power is turned off.
   Data Memory (RAM): This is volatile memory that stores temporary variables and data used by the program during runtime.
3. **Input/Output (I/O) Peripherals:** These are the interfaces that allow the microcontroller to interact with the outside world. They include things like:
   Digital I/O pins: For turning things on/off (e.g., an LED) and reading switch states.
   Analog-to-Digital Converters (ADCs): To read analog sensor data (e.g., a potentiometer).
   Communication interfaces (UART, I2C, SPI): To talk to other microcontrollers, sensors, or modules.
   Timers: To perform time-based tasks.

(iii) **Lithium-ion (Li-ion) batteries** would be more suitable for a small drone. **[3]**

High Energy Density: Li-ion batteries can store a large amount of energy in a small, lightweight package. This is crucial for a drone, as every gram of weight has a significant impact on flight time and manoeuvrability. Lead-acid batteries are heavy and bulky for the amount of energy they provide.

Sustained Power Delivery: Li-ion batteries have a high power-to-weight ratio, meaning they can deliver high currents required for the drone's motors to provide thrust, without significant voltage drop. Lead-acid batteries are not as efficient in this regard.

Lower Self-Discharge: Li-ion batteries hold their charge for a longer time when not in use compared to lead-acid batteries, which is beneficial for a device that may not be used every day.

Question 9

(i) **Manipulators vs. Mobile Robots** **[4]**

Manipulators:

Primary Function: To perform specific, often repetitive, tasks at a fixed location in the workspace. Their main purpose is to manipulate objects.

Typical Operational Environment: Fixed to a base in a structured and controlled environment, such as a factory assembly line or a laboratory.

Real-world Application: An industrial robotic arm on a car manufacturing line that welds car parts.

Mobile Robots:

Primary Function: To move from one location to another. Their main purpose is locomotion.

Typical Operational Environment: Designed to navigate dynamic and often unstructured environments, such as a warehouse floor, a hospital, or an outdoor urban area.

Real-world Application: An Autonomous Guided Vehicle (AGV) in a warehouse that moves goods from one place to another.

(ii) **Essential Sensor Payloads for a Farming Drone:** **[3]**

1. **Multispectral or Hyperspectral Sensor:**

   Function: This sensor captures data from multiple light bands, including near-infrared (NIR) and red-edge. Healthy vegetation reflects high levels of NIR light, while stressed or diseased plants reflect less. By analyzing the ratios of these light bands (e.g., using the Normalized Difference Vegetation Index or NDVI), the drone can generate a map of crop health, identify nutrient deficiencies, and spot areas of disease outbreaks long before they are visible to the naked eye.

2. **Lidar (Light Detection and Ranging) Sensor:**

   Function: A Lidar sensor uses laser pulses to create a precise 3D point cloud of the environment. This can be used to generate a digital elevation model of the field. In precision agriculture, it can measure the height and density of the crops, providing data that can be used to estimate biomass, a key indicator of yield. It also provides accurate terrain mapping for obstacle avoidance and efficient flight path planning.

(iii) **I2C (Inter-Integrated Circuit)** would typically be preferred. **[3]**

Justification: I2C is a multi-master, multi-slave communication protocol that requires only two wires for communication: **SDA (Data)** and **SCL (Clock)**. Each sensor is assigned a unique address on the bus. This allows multiple sensors to be connected to the same two pins on the microcontroller. The microcontroller can then communicate with each sensor individually by addressing it by its unique address. This significantly simplifies wiring and reduces the number of pins required on the microcontroller, which is ideal for a small mobile platform with limited space and resources.