Exemplar examination

Paper 1: Theory

Time: 3 hours **Marks: 100**

INSTRUCTIONS AND INFORMATION

1. This question paper consists of TWO sections:
   - SECTION A: Questions 1–2 short questions (10)
   - SECTION B: Questions 1–6 medium and long questions (90)
2. Answer all the questions.
3. Read all the questions carefully.
4. Number the answers according to the numbering system used in this question paper.
5. Questions may be answered in any order, but subsections of questions must be kept together.
6. Start each question on a new page.
7. Only use a black or a blue pen.
8. Write neatly and legibly.

SECTION A: Short questions

QUESTION 1: Multiple choice

Only write the question number and the corresponding letter: e.g. 1.1.6 E

1.1 Which of the following terms is used to describe the study of motion and forces acting on a robotic system?

A. Controls
B. Kinematics and Dynamics
C. Mechatronics and Embedded Systems
D. Sensing and Signal Processing (1)

1.2 What type of component typically provides signal output in robotics projects?

A. Actuator
B. Motor controller
C. Sensor
D. Display component (1)

1.3 Which of the following is NOT part of the 3D printing software pipeline?

A. Input modelling
B. Supports
C. Cutting
D. Machine instructions (1)

1.4 In electronics, what are the TWO types of current?

A. Direct and alternating
B. Single-phase and three-phase
C. Neutral and ground
D. Parallel and series (1)

1.5 What does the acronym WSN stand for?

A. Wide Spectrum Network
B. Wireless Software Network
C. Wireless Sensor Network
D. Web Service Node (1)

QUESTION 2: TRUE or FALSE

Decide whether the following statements are true, only write the question number and TRUE or FALSE.

2.1 Microcontrollers have operating systems installed on them. (1)

2.2. Embedded systems are specialised computer systems that are designed to perform specific tasks within larger systems. (1)

2.3 In a 3D mesh, edges can be shared by multiple polygons in the mesh. (1)

2.4 A compiler is the software that converts human readable code into machine code that the processing core can understand. (1)

2.5 Voltage typically refers to the positive or negative terminals of an electronic component and is used to denote the direction that the electrical current will flow through a circuit. (1)

[10]

SECTION B

QUESTION 1: Robots and our lives

Read the except below about how Barcelona implements IoT technologies and answer the questions that follow.

> *"Starting all the way back in 2012, Barcelona began implementing IoT technologies to help improve life for citizens. That includes things like sensors to manage parking, street lighting, and even trash disposal services. In total, there are over 19,500 of these sensors.*
>
> *One area that has seen much improvement thanks to the smart sensors is transportation, including streamlined bus routes, information about when and where buses will arrive, and information about available parking spaces.*
>
> *The smart street light sensors not only incorporated new LED technology to reduce consumption, but they also detect when there are no pedestrians around to dim. This has led to 30% energy savings, a savings of over $37 million each year. These sensors can also collect air quality data to helps governments and administrations better deal with the issue.*
>
> *Not only can residents enjoy a higher-quality living experience, but the city has also reduced costs significantly and streamlined operations."*
>
> *Reference: https://blog.bismart.com/en/why-barcelona-is-a-smart-city 2019*

1.1 Expand the acronym IoT. (1)

1.2 Name TWO different sensors that might be used in Barcelona to implement their smart city and explain what each sensor would be used for. (4)

1.3 Sensors are one part of the IoT ecosystem. Name TWO other components that are part of the IoT chain and explain their purpose. (4)

1.4 Describe TWO potential concerns or negative impacts of IoT. (2)

1.5 Describe TWO other applications for IoT. (2)

[13]

QUESTION 2: 3D printing

2.1 List the FOUR main types of 3D printing. (4)

2.2 Explain how solid-based fused deposition modelling (FDM) 3D printers operate. (6)

2.3 List the THREE main types of modifications one might make to a 3D model. (3)

[13]

QUESTION 3: Electronics for robotics

3.1 A circuit contains an 18-volt battery, a 4-ohm resistor, and a 2-ohm resister connected in series.

3.1.1 What is the total resistance of the circuit? (2)

3.1.2 What is the power being dissipated by each resistor? (8)

3.2 Explain the purpose of a charge controller. (2)

3.3 Name FOUR types of power sources that can be used in robotics projects. (4)

3.4 Explain the concept of *electromotive force*. (2)

[18]

QUESTION 4: Components of a robot

4.1 Explain the difference between a closed and an open loop actuator. (4)

4.2 Describe FOUR criteria to consider when choosing an actuator for a robot. (4)

4.3 Identify the type of robot mobility best suited to a range of surfaces such as sand, gravel, or stairs. What operations is this type of mobility most suited for? (2)

4.4 Explain the operation of an H-bridge motor controller. (4)

4.5 Multiple sensors are used to monitor the vital signs of a patient (heart rate, temperature and blood pressure, for example) in a hospital. Identify a sensor that could be used in a hospital and explain its purpose. (2)

4.6 Explain what the wireless technology Zigbee is and what it is commonly used for. (2)

4.7 Explain how a star topology behaves. Include a labelled diagram to aid your explanation. (4)

[22]

QUESTION 5: Programming

5.1 What is the logical operator that will return a "false" value only if both inputs A and B are false? (1)

5.2 How do you define an integer variable in Arduino programming? (1)

5.3 Describe the purpose of the following functions in Arduino.

5.3.1 setup() (2)

5.3.2 loop() (3)

5.3.3 pinMode() (3)

5.4 What is the difference between analogue and digital outputs on an Arduino? (2)

5.5 How can you read data from a sensor connected to an Arduino board? (2)

[14]

QUESTION 6: Practical robotics

Problem: Design a robotic arm that can lift a one-kilogram weight and move it in three dimensions.

6.1 Analyse the given problem and list the various components required for the design. (3)

6.2 Explain how THREE of your components will be used in the design. (3)

6.3 Write out the steps for the required design. (4)

[10]

TOTAL: 100

Exemplar examination

Paper 2: Design-related

Time: 4 hours **Marks: 80**

INSTRUCTIONS AND INFORMATION

1. You will be given 10 minutes reading time before the examination starts.
2. The following software is required for this practical examination. Ensure that you have all the software installed before you start the paper.
   - Fritzing for circuits
   - Draw.io for electrical schematic diagrams
   - Arduino IDE
3. All drawings must be clear and neat with labels.
4. Answer all the questions.
5. Read all the questions carefully.
6. Number the answers according to the numbering system used in this question paper.
7. Questions may be answered in any order, but subsections of questions must be kept together.

The following scenario is the basis of this examination.

Scenario

You are a programmer for an automation company. You have been tasked with building a robot required to perform two functions.

- Function 1: Sense the level of daylight and turn on a light when it is dark outside.
- Function 2: Read the ambient temperature and humidity. Output a signal to move a servo motor that will open or close a window depending on the temperature.

QUESTION 1: Robots and our lives

1.1 Identify areas where a system like this could be used in the real world. (1)

1.2 Name TWO advantages of using a system like this in order to automate simple tasks. (2)

[3]

QUESTION 2: 3D printing

2.1 How could 3D printing be incorporated into this device? (1)

2.2 What material parameters should you consider for printing a device that will be used in an outdoor setting? (1)

2.3 Once you have chosen to 3D print a part of your device, you will need to scale and slice the design. A typical instruction is to:

"Scale to 50% and slice using default settings."

Explain the terms *scale* and *slice* in this context. (2)

[4]

QUESTION 3: Electronics for robotics

3.1 The lights you are given are rated for 60 W power and run off a 24 V power supply. Calculate the current draw for this type of light. (2)

3.2 Could we drive the light output directly from an output of the Arduino? Give a reason for your answer. (2)

3.3 What alternative method could be used to power the light from an Arduino output? (1)

3.4 Draw an appropriate circuit in Draw.io that will allow the Arduino to power and control the lights. (5)

3.5 Explain how to connect an LDR to the Arduino in order to measure light input. Use Draw.io to draw a simple circuit to show how this would work. (8)

[18]

QUESTION 4: Components of a robot

4.1 List SEVEN key components that would be needed to make up your device, and provide a short description of each component. (7)

4.2 Consider just the window opening part of the system. Break down the system into the FOUR main categories that make up a robot.

Category	Component
Sensor	
Logic controller	
Actuator	
End effector	

(4)

4.3 Consider power sources for the system. Motivate a choice for a power source that would be suitable for such a system. (2)

[13]

QUESTION 5: Programming

5.1 List the libraries that are needed in order to make the components work. (2)

5.2 Explain how the Arduino reads a value from the LDR sensor. Write a line of code to do this. (2)

5.3 Provide a line of code that would configure an IO pin to output to the light circuit. (2)

5.4 Open the Arduino IDE and write a simple Arduino program that will turn on a light when the sensor value rises above a pre-defined threshold.

Make sure to:

- Define the threshold with an initial value of 500.
- Define all pins required.
- Include a one second delay in between each read.
- Save the program as “light_sensor.ino” and make sure it compiles. (8)

[14]

QUESTION 6: Practical robotics

Open the file *question6.ino* provided to you. You should see the following code in the Arduino IDE.

```
// Define the IO Pins for the sensors
#define DHT_PIN 2

// Define the IO Pins for the outputs
#define SERVO_PIN 3

#define CLOSE_TEMPERATURE 0 // Window fully closed temperature
#define OPEN_TEMPERATURE 30 // Window fully open temperature
#define SERVO_CLOSED_ANGLE 0 // Fully closed servo Angle
#define SERVO_OPEN_ANGLE 90 // Fully open Servo Angle

DHT dht(DHT_PIN, DHT11);
Servo servo;

void setup() {
  // Initialize the DHT sensor
  dht.begin()

  // Attach the servo motor to the corresponding pin
  servo.attach(SERVO_PIN);
}

void loop() {
  // Read temperature and humidity values from the DHT sensor
  float temperature = dht.readTemperature();

  int angle = map(temperature, CLOSE_TEMPERATURE, OPEN_TEMPERATURE,
    SERVO_CLOSED_ANGLE, SERVO_OPEN_ANGLE);

  // Move the servo to the specified angle
   servo.write(output_angle);

  // Add some delay before the next iteration
  delay(1000); // Adjust this delay according to your needs
}
```

6.1 Use the compile tool to find and fix THREE errors in this program. List the error and correction for each error. (3)

6.2 What is the purpose of this line of code?

```
  int angle = map(temperature, CLOSE_TEMPERATURE, OPEN_
TEMPERATURE, SERVO_CLOSED_ANGLE, SERVO_OPEN_ANGLE);
```

(3)

6.3 Create a physical circuit for the code provided in question 6.1 in Fritzing. Use an Arduino, servo motor and a DHT11 sensor. (5)

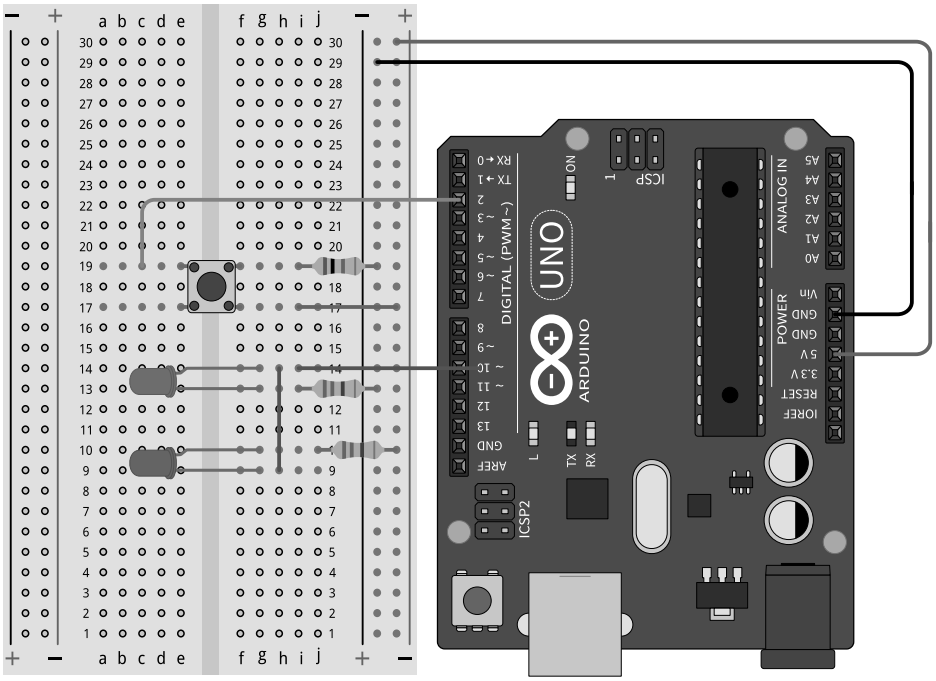
6.4 Modify the code to reverse the direction of the servo motor. (2)

6.5 Define the process of calibration. (3)

[16]

QUESTION 7: Breadboards and circuits

7.1 Consider the following circuit diagram. Build the circuit on a breadboard in Fritzing. (6)



7.2 Write an Arduino program that will turn on the red LED when the button is pressed, and turn on the blue LED when the button is not pressed. (6)

[12]

TOTAL: 80

Exemplar examination memorandum

Papers 1 and 2

Paper 1: Theory

Time: 3 hours Marks: 120

SECTION A: Short questions

QUESTION 1: Multiple choice

1.1 B. Kinematics and Dynamics (1)
1.2 D. Display component (1)
1.3 C. Cutting (1)
1.4 A. Direct and alternating (1)
1.5 C. Wireless Sensor Network (1)

QUESTION 2: TRUE or FALSE

2.1 False (1)
2.2 True (1)
2.3 True (1)
2.4 True (1)
2.5 False (1)
[10]

SECTION B

Question 1: Robots and our lives

1.1 Internet of Things ✓ (1)

1.2 for sensor ✓ and for explanation ✓. Any TWO of:
- Camera – could be used to observe available parking
- Infrared – check for pedestrians at street lights
- Humidity, gas or air quality sensors – to monitor air quality
- Any other sensor and explanation related to the article excerpt above. (4)

1.3 for component ✓ and for explanation ✓. Any TWO of:
- Actuator ✓ to move parts such as for trash disposal services ✓
- Edge node ✓ collect and process data and control actuators and lights ✓
- Gateway/network interface ✓ connect nodes and endpoints to the internet ✓ (4)

1.4 Any TWO of:
- Security – the sensors or computer systems could be hacked (lights turned off, bus routes changed etc.) ✓
- Privacy – data might be used for targeted advertising without permission ✓
- It is highly dependent on access to the internet. If the internet goes down, then services may be interrupted. ✓ (2)

1.5 Any TWO of:

- Agriculture – optimise crop management, monitor soil conditions, and automate irrigation systems
- Smart wearable devices – smartwatches, fitness trackers, and health monitoring devices collect real-time health data and transmit it to healthcare providers for remote monitoring and analysis
- Smart homes – connecting lights, devices, climate control and security systems to the residents
- Automotive industries – provide real-time data on traffic conditions, vehicle performance, and driver behaviour (2)

[13]

QUESTION 2: 3D printing

2.1 Granular ✓, extrusion ✓, light polymerised ✓ and laminated ✓ (4)

2.2 Fused deposition modelling printers use long lengths of wire-like thermoplastic material known as filament ✓. The filament is unrolled (fed) from a spool by the extruder assembly ✓, melted by a hot end ✓ and extruded through a heated nozzle onto a build platform layer-by-layer to create the 3D object ✓. The nozzle moves in the *x*-*y* plane, while either the build platform or the printer head moves in the *z*-axis (up and down) to build the layers ✓. Cooling is provided by fans, usually cooling both the material as it leaves the nozzle as well as the hot end itself to help keep the temperature consistent ✓. (6)

2.3 Repair ✓, resize ✓ and redesign. ✓ (3

[13]

QUESTION 3: Electronics for robotics

3.1 **3.1.1** Total resistance = R1 + R2 ✓
= 4 + 2
= 6 ohms ✓ (2)

3.1.2 Total current = V/R ✓
= 18/6
= 3 A ✓
R1 voltage = R × I ✓
= 4 × 3
= 12 V ✓
R1 Power = V × I ✓
= 12 × 3
= 36 W ✓
R2 voltage = R × I
= 2 × 3
= 6 V ✓
R2 Power = V × I
= 6 × 3
= 18 W ✓ (8)

3.2 A charge controller regulates the voltage and current ✓ flowing into a battery while it is being charged. ✓ (2)

3.3 Any FOUR of: batteries, solar power, wind power, fuel cells, wired power, hybrid power ✓✓✓✓ (4)

3.4 EMF refers to the voltage or electrical potential difference that exists between two points in a circuit or between two conductors that are not in contact. ✓ It is the force that drives the flow of electrons in a circuit and is measured in units of volts (V). ✓ (2)

[18]

QUESTION 4: Components of a robot

4.1 Open: the controlling device will only have a rough idea of the behaviour of the actuator when it sends a control signal to the device. There is no feedback ✓ of the position or speed, so the controller will not know the exact position of the actuator after it has performed a movement ✓.

Closed: uses a rotational or linear position sensor ✓ in order to verify the location of the actuator both after and during the movement ✓. (This allows for extremely precise control over the position or speed of the actuator and can also be used to compensate or correct any errors that might occur during operation, as well as detect and adjust back if the actuator is moved by an external force.) (4)

4.2 Any FOUR of:

- Integration and compatibility
- Feedback type
- Torque and speed requirements
- Power and efficiency
- Size and weight
- Cost
- Reliability and durability
- Direction of motion
- Safety (4)

4.3 Tracks ✓, making them suitable for applications like exploration or military operations. ✓ (2)

4.4 An H-bridge is a motor control circuit that can drive a DC motor ✓ both forwards ✓ and in reverse ✓. It uses two pairs of transistors to switch the flow direction of current through the motor ✓. (4)

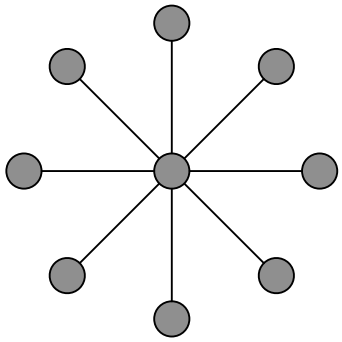
4.5 for the sensor ✓ and for the purpose ✓. Any ONE of:

- Temperature Sensor: This sensor is used to measure a patient's body temperature, which can indicate whether they are running a fever or not.
- Pressure sensor: used to measure the blood pressure of a patient
- Light sensor: used to measure heart rate by shining a light through the skin (2)

4.6 Zigbee is a low-power, low-data-rate wireless technology ✓ designed for applications that require long battery life and low-cost connectivity. It is commonly used in home automation, smart lighting, and certain industrial applications. ✓ (2)

4.7 In a star topology, all nodes are connected directly to a central node ✓, known as a gateway ✓. All communication between nodes occurs through the central hub, which handles all the wireless data transmission ✓. (It offers centralised control and easy scalability but relies heavily on the gateway, which can become a single point of failure. It also limits range as every device must be in range of the gateway.)

Diagram with labels (nodes around the gateway) ✓ (4)



[22]

QUESTION 5: Programming

5.1 OR ✓ (1)

5.2 Variables are declared by specifying the data type followed by the name of the variable, such as int myVar; ✓ (1)

5.3 **5.3.1** The setup() function in Arduino is used to initialise variables, pin modes, and other settings ✓ that need to be configured before the main loop of the program starts running ✓. (2)

5.3.2 The loop() function in Arduino is the main program loop ✓ that runs continuously ✓ after setup() has been called. It is where you place code that needs to be repeated over and over, such as commands to interact with sensors, actuators, or other devices. ✓ It is also where you can check for events or changes in state and respond accordingly. (3)

5.3.3 The pinMode() function in Arduino is an initialisation command ✓, used to configure a specific GPIO pin ✓ on the Arduino as an output ✓. (3)

5.4 Analog outputs are used to control devices that require varying levels of power ✓, while digital outputs are used to control devices that only require two states (on/off). ✓ (2)

5.5 Data from a sensor connected to an Arduino board can be read using the analogRead() ✓ or digitalRead() ✓ functions depending on whether it is an analogue or digital sensor respectively. (2)

[14]

QUESTION 6: Practical robotics

6.1 0 marks – no components listed

1 mark – 1–3 components listed

2 marks – 4–5 components listed

3 marks – 6–7 components listed

The components required for this design include motors, sensors, actuators, control boards, jumper wires, power sources, and a frame or body to hold all the components together. (3)

6.2 Only THREE marks for three components explained.

The motors will provide power and torque necessary to lift the one-kilogram weight. ✓ Sensors will provide feedback on position and movement. ✓ Actuators will allow for precise movement of the robotic arm. ✓ Control boards will provide instructions for operation of all components. Jumper wires will connect all components together. ✓ A power source will provide energy for operation of all components. ✓ A frame or body will hold all these components together securely. ✓ (3)

6.3 0 marks – four or more steps missing

1 mark – missing three important steps

2 marks – missing two important steps

3 marks – missing one important step

4 marks – steps fully outlined

Example answer:

Step 1: Design a frame or body that can securely hold all the necessary components.

Step 2: Choose two motors that can provide enough power and torque to lift a one-kilogram weight.

Step 3: Choose/design two actuators that can allow precise movements in three dimensions.

Step 4: Choose/design two sensors that can provide feedback on position and movement.

Step 5: Design a control board that can provide instructions for operation of all other components.

Step 6: Connect all necessary components with jumper wires.

Step 7: Select an appropriate power source for operation of all other components.

Step 8: Test each component individually before assembling them into a single unit. (4)

[10]

TOTAL: 100

Paper 2: Design-related

Time: 4 hours Marks: 80

QUESTION 1: Robots and our lives

1.1 (Any one) ✓
Agricultural automation, home automation (1)

1.2 (Any two) ✓ ✓
Increased system efficiency, Less human interaction required ✓(2)

[3]

QUESTION 2: 3D printing

2.1 (Any one) ✓
You could 3D print the mechanism that is used to operate the window.
You could also 3D print brackets to hold the sensors or the light fittings. (1)

2.2 (Any one) ✓
Melting temperature; UV resistance (1)

2.3 If you need to make a specific size adjustment in the file you are planning to print, you can scale the model by a user-defined percentage. Scale to 50% means halving the size. ✓ You will change the scale parameter in the slicing software.
Slice means to generate the G-code ✓ for the design. (2)

[4]

QUESTION 3: Electronics for robotics

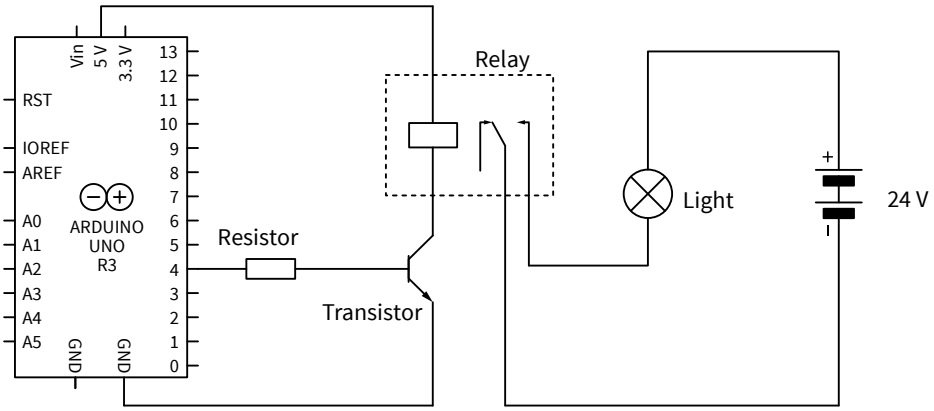
3.1 (One mark for formula, one for correct answer)

$$\text{Current} = \frac{\text{power}}{\text{voltage}} \checkmark$$
$$= \frac{60\ \text{W}}{24\ \text{V}}$$
$$= 2{,}5\ \text{A} \checkmark$$ (2)

3.2 No. ✓
The Arduino operates at only 5 V ✓ and is not able to output the required amount of electrical current. (2)

3.3 You could use a relay in order to increase the power.✓ (1)

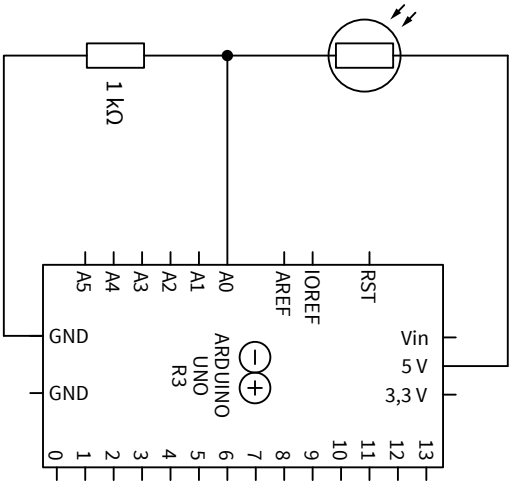
3.4 Circuit diagram:



Circuit (5 marks: correct position of relay, correct position of resisitor, transistor, light, connected correctly on the board.) (5)

3.5 The LDR would be connected in series with a resistor✓ between power and ground, ✓making a resistor divider.✓ You can then measure the voltage at the midpoint to find out the current light level.✓

Circuit (4 marks: correct position of LDR, correct position of resisitor, connected correctly on the board.) (8)



[18]

QUESTION 4: Components of a robot

4.1 DHT11 Sensor – Temperature and humidity sensor ✓

LDR - Light dependent resistor. Changes resistance based on light intensity ✓

Resistor – resists current flow ✓

Arduino/Microcontroller – the main logic controller ✓

Servo Motor – closed loop motor unit ✓

Relay – interface for the light ✓

Light – end effector ✓ (7)

4.2

Category	Component
Sensor	DHT11 ✓
Logic controller	Arduino/microcontroller ✓
Actuator	Servo motor ✓
End effector	Window ✓

(4)

4.3 The system should be powered by normal wall power ✓ as it will be used in a room and will be fixed in place✓ and won't move. (2)

[13]

QUESTION 5: Programming

5.1 Servo.h, ✓ DHT.h ✓ (2)

5.2 The Arduino will read in an analogue signal from the LDR sensor. ✓

```
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0); ✓
```

(2)

5.3

```
  // Set the relay pin as an OUTPUT
  pinMode(LIGHT_PIN ✓, OUTPUT ✓);
```

(2)

5.4 (Allocate 1 mark for all pins defined, 1 mark for correct file name)

```
// Define the IO Pin for the sensor
#define LDR_PIN A0

// Define the IO Pin for the output
#define LIGHT_PIN 4

// Define the light level that will turn on the light
#define LIGHT_THRESHOLD 500 ✓

void setup() {
  // Set the relay pin as an OUTPUT
  pinMode(LIGHT_PIN, OUTPUT);
}

void loop() {
  // Check if it is dark outside based on the light level
  bool isDark = (lightLevel < LIGHT_THRESHOLD); ✓

  // Check if the light level is below the threshold
  if (isDark) ✓ {
    // If it is dark outside, turn on the light by
    // activating the relay
    digitalWrite(LIGHT_PIN, HIGH); ✓
  } else {
    // Otherwise, turn off the light
    digitalWrite(LIGHT_PIN, LOW); ✓
  }
```

```
// Add some delay before the next iteration
  delay(1000); ✓
  // Adjust this delay according to your needs
}
```

(8)

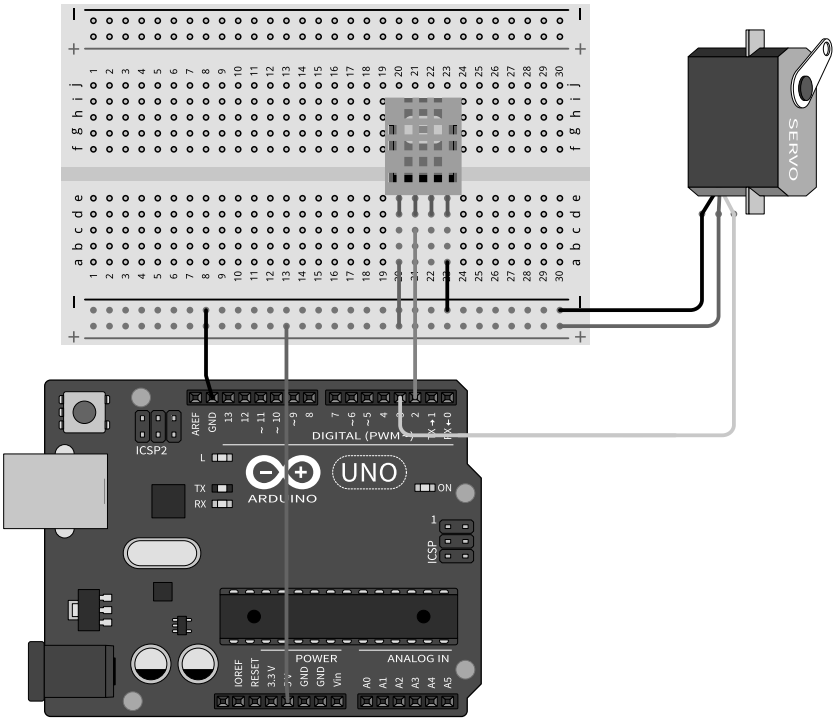
[14]

QUESTION 6: Practical robotics

6.1 Servo.h include is missing
No semicolon after “dht.begin()”
“output_angle” should be “angle” (3)

6.2 This code will take the temperature value and scale it from the initial range of between CLOSE_TEMPERATURE and OPEN_TEMPERATURE to the new range between SERVO_CLODED_ANGLE and SERVO_OPEN_ANGLE (2)

6.3 1 mark for getting the servo pin correct
1 mark for getting the dht pin correct
3 marks for power connections and components
2 marks for downloading to the board (7)



6.4

```
#define SERVO_CLOSED_ANGLE 90 ✓
// Fully closed servo Angle
#define SERVO_OPEN_ANGLE 0 ✓ // Fully open Servo Angle
```

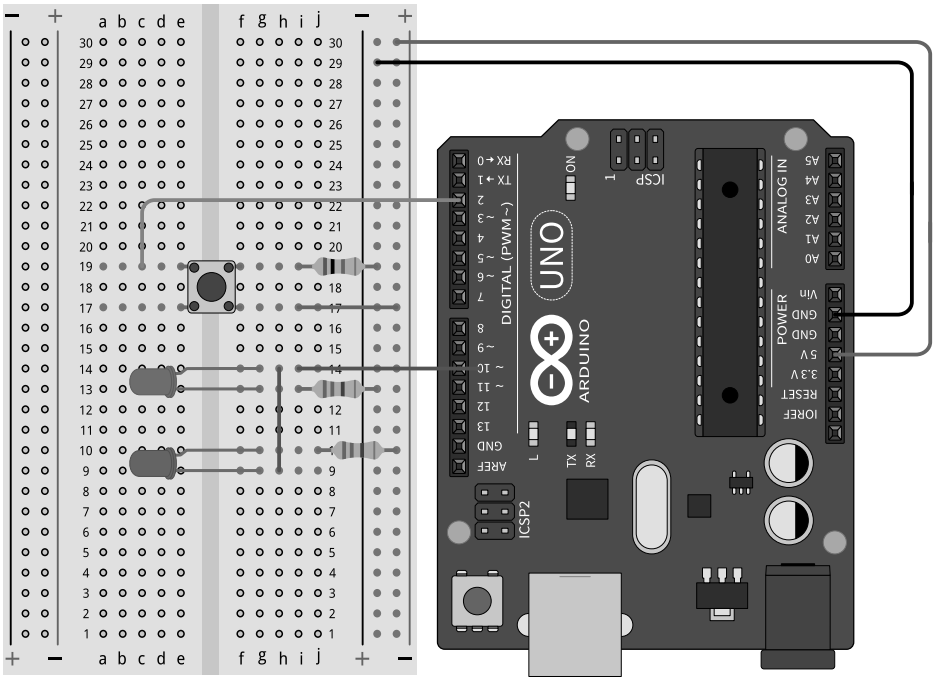
(2)

6.5 Calibration is the process of making minor adjustments in the parameters of the code in order to account for real world situations. (2)

[16]

QUESTION 7: Breadboards and circuits

7.1 Answer should resemble this:



2 marks for adding the correct components;
1 mark for connecting the button correctly to digital pin 2;
1 mark for connecting the LEDs to digital pin 10;
1 mark for wiring the LEDS in Series;
1 mark for the power wires.

(6)

7.2 **Answer code:**

```
void setup()
{
  pinMode(2, INPUT); ✓
  pinMode(10, OUTPUT); ✓
}

void loop()
{
  if (digitalRead(2) == HIGH){ ✓✓
    digitalWrite(10,LOW); ✓
  } else {
    digitalWrite(10,HIGH); ✓
  }
}
```

1 mark for setting pin 2 as an input;
1 mark for setting pin 10 as an output;
1 mark for the IF statement;
1 mark for HIGH meaning that the button is pressed;
2 marks for the digital write functions. (6)

[12]

TOTAL: 80