X028/301

NATIONAL QUALIFICATIONS 2009

FRIDAY, 12 JUNE 1.00 PM – 4.00 PM

MECHATRONICS HIGHER

100 marks are allocated to this paper.

Attempt **all** questions in Section A (50 marks).

Attempt any **two** questions from Section B (50 marks).

Use labelled diagrams and sketches to illustrate your answers where appropriate.

All calculations must be supported by working.

A PLC datasheet is included for questions 6 and 11.

A Flowchart symbol sheet is included for questions 7, 11, 12 and 13.

Worksheets are provided for questions 3, 4, 5, 8, 10, 11 and 13.

SECTION A

Attempt ALL questions in this Section (50 marks).

Marks

1. (*a*) The following is a list of typical controllers found in mechatronic systems.

ASIC (Application Specific Integrated Circuit)

PC (Personal Computer)

PLC (Programmable Logic Controller)

State how the controlling action could be altered for **each** type of controller. **3**

(*b*) Sketch a block diagram of a closed loop control system. Identify each element on your sketch. **2**

(5)

2. (*a*) State **one** type of temperature sensor that could be used in a mechatronic system. **1**

(*b*) With the aid of a simple sketch, briefly describe the basic operation of the sensor chosen in Q2(*a*). **2**

(*c*) State an appropriate application for the sensor chosen in Q2(*a*) and give **one** reason for your choice. **2**

(5)

3. (*a*) Figure Q3 shows a labelled diagram of a cylindrical robot. *Marks*

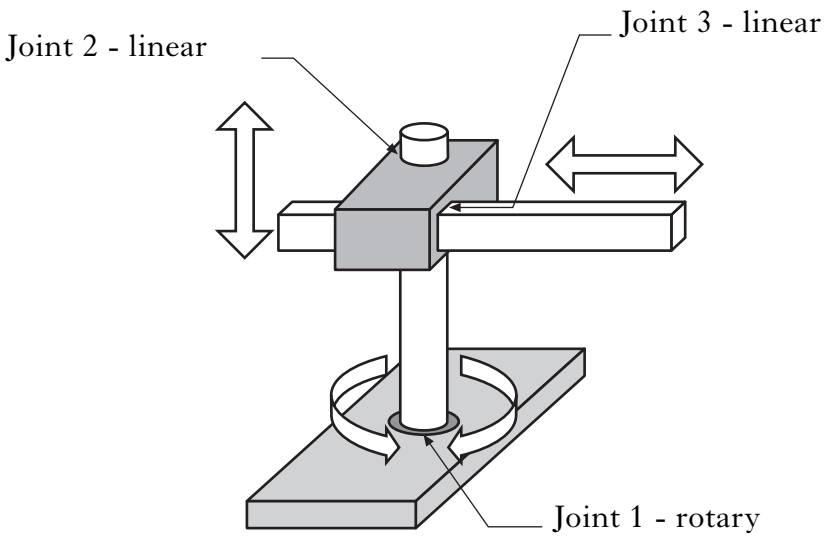

Figure Q3

Table Q3(*a*) identifies the movement of each joint of a robotic system as either Rotary or Linear. On **Worksheet Q3(*a*)**, complete Table Q3(*a*) by filling in the appropriate joint movement for the Cartesian and SCARA robots.

Robot	**Joint 1**	**Joint 2**	**Joint 3**
Cylindrical	Rotary	Linear	Linear
Cartesian	Linear		
SCARA	Rotary		

2

Table Q3(*a*)

(*b*) In your **answer book**, briefly explain the term "end effector" with reference to robots. **1**

(*c*) State **two** reasons why electrical actuators may be used in preference to hydraulic actuators on small industrial robots. **2**

(5)

[Turn over

Marks

4. (*a*) Figure Q4(*a*) illustrates the basic architecture of a microcontroller. Some elements have been identified with the letters A to D. On **Worksheet Q4**, complete Table Q4(*a*) by entering the names of the elements labelled A to D. **2**

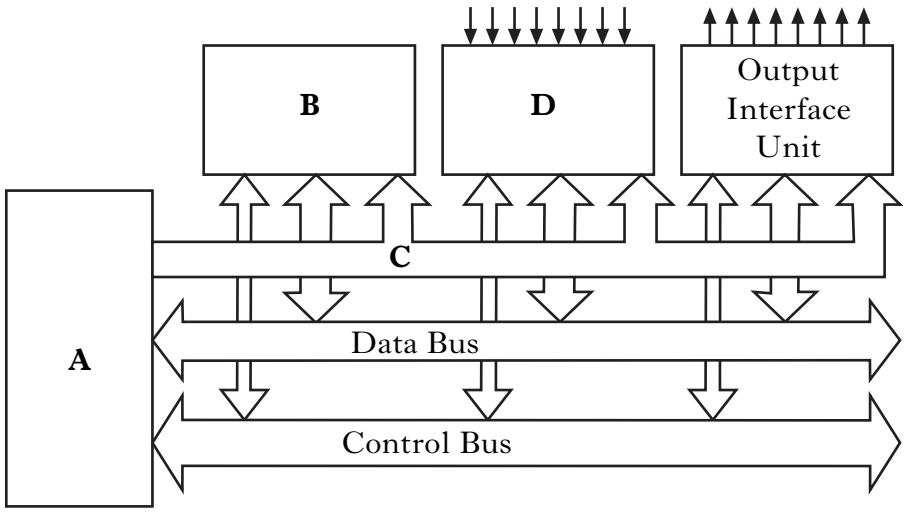

Figure Q4(*a*)

(*b*) In your **answer book**, briefly describe the term "bidirectional" with reference to data flow. **1**

(*c*) The Output Interface Unit has 8 data bits. State how many combinations can be represented with 8 bits of data. **1**

(*d*) State **one** advantage that a PLC (Programmable Logic Controller) based mechatronic control system has over a hard wired system. Assume that the application is within an industrial environment. **1**

(5)

Marks

5. (*a*) Figure Q5(*a*) illustrates a partially completed coded disc for use in an optical rotary absolute encoder. On **Worksheet Q5**, identify the number of bits represented **and** complete the shading of the disc. **3**

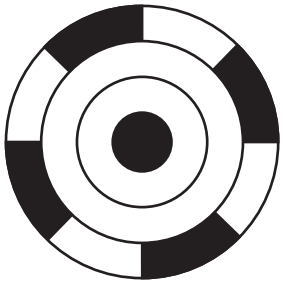

Figure Q5(*a*)

(*b*) Table Q5(*b*) shows two codes used in mechatronic systems. On **Worksheet Q5**, complete Table Q5(*b*) by inserting each of the **four** missing code values. **2**

(5)

Decimal	Pure Binary	BCD
0	0000	0000 0000
1	0001	0000 0001
2	0010	0000 0010
3		0000 0011
4	0100	0000 0100
5	0101	
6	0110	0000 0110
7	0111	0000 0111
8	1000	0000 1000
9	1001	0000 1001
10	1010	0001 0000
11	1011	0001 0001
12		0001 0010
13	1101	0001 0011
14	1110	0001 0100
15	1111	

Table Q5(*b*)

[Turn over

Marks

6. A mechatronic control system uses a PLC (Programmable Logic Controller).

(*a*) Briefly explain the operation of a Normally Open (NO) contact in a PLC ladder diagram. **1**

(*b*) A mechatronic system has a Normally Open (NO) start contact (X0) and a Normally Closed (NC) stop contact (X1). The output Y0 is enabled and latched when the start button is pressed. Output Y0 can only be switched off when the stop button is pressed. Draw a Ladder Diagram to show how this could be implemented using a PLC. **3**

(*c*) A timer within a PLC system has a "K" value of 250. Determine how long the timer will take to time out. **1**

Note: the inserted PLC data sheet Q6, Q11 gives the PLC instruction set. **(5)**

7. Figure Q7 illustrates an automatic inspection/sorting system.

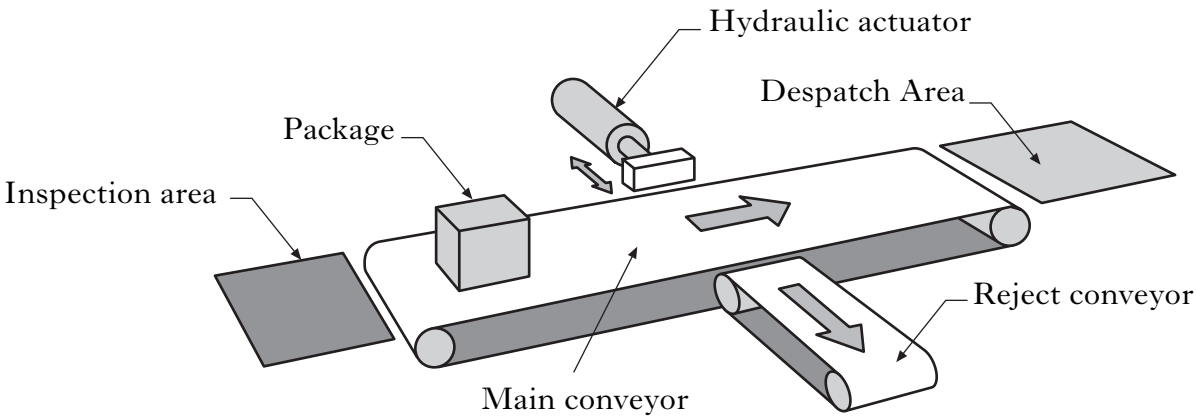

Figure Q7

The system operates as follows.

- Both conveyors run continuously.
- A package is checked in the inspection area and a "pass" or "fail" signal is generated.
- The package is then placed on the main conveyor.
- A timer will operate the actuator for re-direction to the reject conveyor if a "fail" signal has been generated.
- All other packages move to the despatch area for packing.

(*a*) Sketch a flowchart which shows the operation of the system. Start with a package at the inspection area. **3**

Note: The inserted Flowchart symbol sheet for Q7, Q11, Q12 and Q13 gives a suitable selection of Flowchart symbols.

(*b*) The above system is a "time based" sequential system. Briefly explain how the system could be converted to an "event based" system. **2**

(5)

Marks

8. A mechatronic system uses a Proportional control strategy. Figure Q8(*a*) illustrates a system response to a step change.

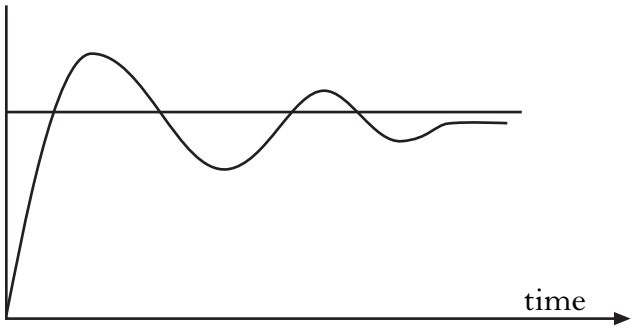

Figure Q8(*a*)

(*a*) On **Worksheet Q8**, complete Figure Q8(*a*) by entering, in the spaces provided, the appropriate label from the list below:

Overshoot;
Desired value;
Offset. **3**

(*b*) Control signals may be classified as "analogue" or "digital". In your **answer book**, briefly describe how these signals differ. You may wish to include a sketch to illustrate your answer. **2**

(5)

[Turn over

Marks

9. Figure Q9 shows a rack system which uses a fixed rack and a carriage which moves along the rack.

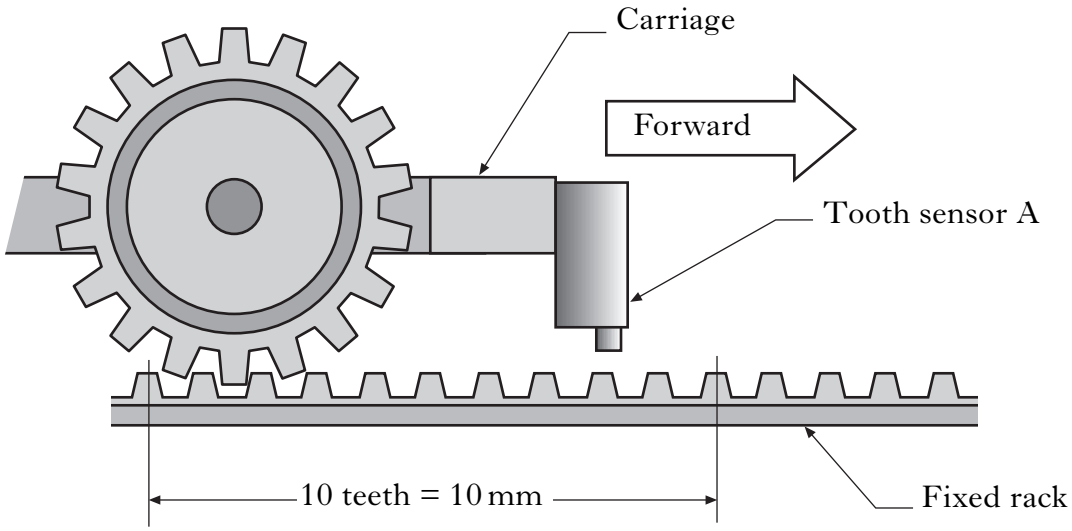

Figure Q9

(*a*) Sketch the logic level output waveform from Tooth sensor A when the carriage is moving in the forward direction. **1**

(*b*) State how the linear velocity of the carriage may be interpreted from the output of Tooth sensor A. **1**

(*c*) Calculate the linear velocity in m/s if the output waveform has a frequency of 10 Hz. **2**

(*d*) State how the system could be adapted to allow the direction of travel of the carriage to be obtained. **1**

(5)

10. This question consists of a series of multiple choice questions and answers for a number of mechatronic related themes. On **Worksheet Q10**, answer the multiple choice question by putting a tick ☑ in the correct box.

(*a*) A thermocouple is a device used to measure

a temperature ☐
b pressure ☐
c flow ☐
d force ☐
e level. ☐

(*b*) A pneumatic actuator is used to

a measure level ☐
b provide heat ☐
c provide motion ☐
d increase oil pressure ☐
e count pulses. ☐

(*c*) A hydraulic based Mechatronic System is

a maintenance free ☐
b low cost ☐
c high power ☐
d linear only ☐
e rotary only. ☐

(*d*) A rotary optical encoder system directly measures

a pressure ☐
b flow ☐
c force ☐
d movement ☐
e level. ☐

(*e*) An example of a tactile sensor is

a an electric motor ☐
b a microswitch ☐
c a thermocouple ☐
e a Light Emitting Diode ☐
e a thermistor. ☐

(5)

[*END OF SECTION A*]

[Turn over for SECTION B on *Page ten*

SECTION B

Attempt any TWO questions in this Section (50 marks).

Each question is worth 25 marks.

11. An automated chemical cleaning system uses a handler as shown in Figure Q11 and is controlled by a PLC.

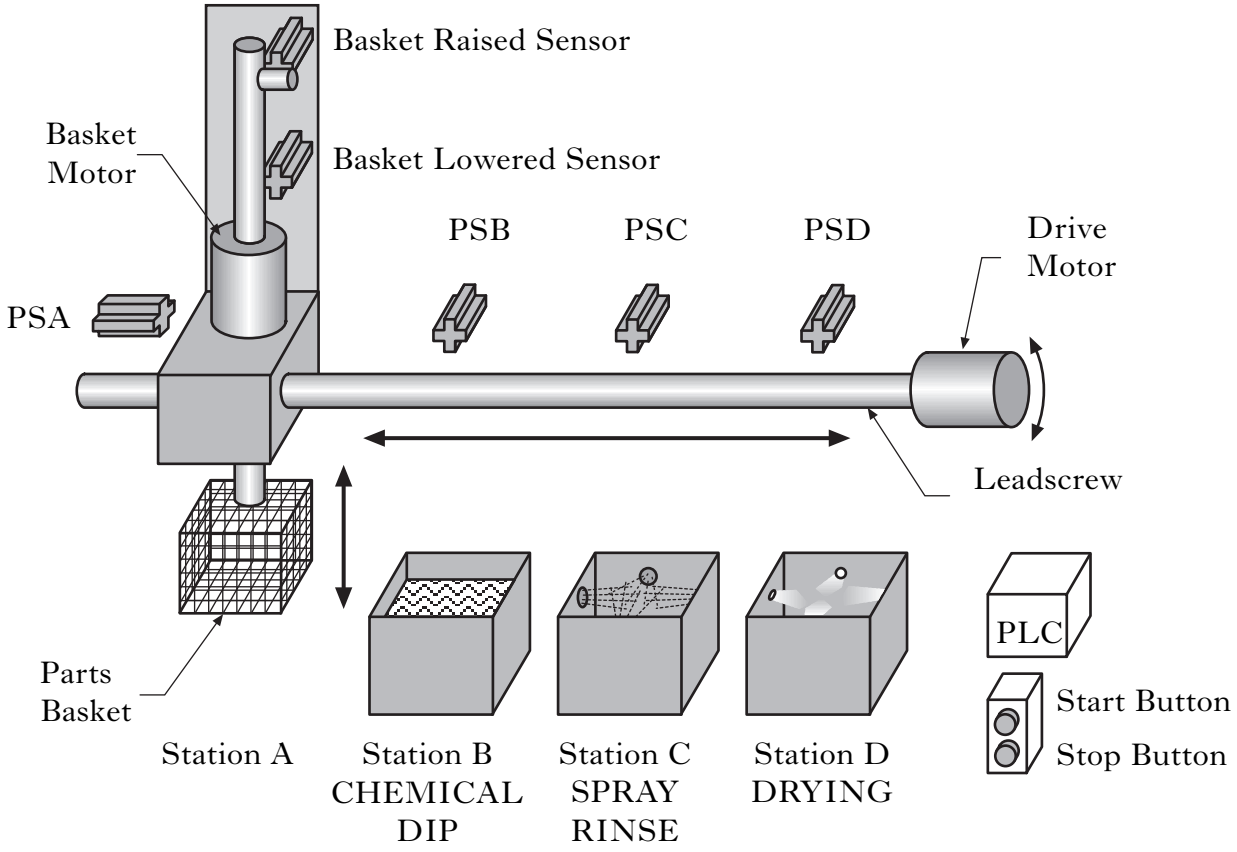

Figure Q11

The system operates in the following way.

Stage	Location	Process
1	Station A	Parts to be cleaned are manually loaded into "Parts Basket".
2		Start button is pressed.
3	Station B	Parts in basket dipped in chemical cleaner for 5 seconds.
4	Station C	Parts in basket spray rinsed for 8 seconds.
5	Station D	Parts in basket dried for 60 seconds.
6		Parts basket is returned to station A.
7	Station A	Parts are manually unloaded from "Parts Basket".

11. (continued)

The chemical dip and spray rinse take place at room temperature. The Parts Basket is initially in the raised position. The Stop Button can stop the system at any point.

The position of the handler is detected by the appropriate Position Sensors (PSA, PSB, PSC or PSD).

The drive motor is reversible allowing bi-directional travel along the horizontal leadscrew. The timing of each Stage does not start until the appropriate position sensor is activated. The details of the raise/lower drive mechanism have been omitted for clarity on the diagram, but the "Basket Raised Sensor" and "Basket Lowered Sensor" are shown.

(*a*) (i) State **one** example of a sensor which may be used for the Position Sensors (PS) on the handler. **1**

(ii) Sketch and describe the operation of your chosen sensor. **3**

(*b*) Using **Worksheet Q11(*b*)** complete the flowchart of the cleaning sequence commencing with "Stage 2" and only continuing as far as the completion of "Stage 3". Ensure all the appropriate input and output signals are clearly shown on your flowchart. Assume the Parts Basket is at Station A and in the raised position when the Start Button is pressed. **7**

Note: The inserted Flowchart symbol sheet for Q7, Q11, Q12 and Q13 gives a suitable selection of Flowchart symbols.

(*c*) The PLC ladder diagram implementing part of the flowchart in Question 11(*b*) is shown in **Worksheet Q11(*c*), Ladder Diagram Q11**. The ladder diagram covers from when the Start Button is pressed to the point where the Parts Basket is fully lowered into the Station B Chemical Dip.

(i) Using **Worksheet Q11(*c*)**, complete the labelling of **Ladder Diagram Q11** using the I/O allocations supplied in **Table Q11**. **6**

(ii) On **Worksheet Q11(*c*)**, complete the description of the operation of your completed ladder diagram (**Ladder Diagram Q11**). **3**

Note: The inserted PLC data sheet Q6, Q11 gives the PLC instruction set.

(*d*) The system requires two modifications. The level in the chemical dip tank is to be monitored. The chemical dip is to be heated to 60°C and be maintained at that temperature. It has been decided to use the PLC to monitor the level and control the temperature of the chemical dip.

(i) State what additional hardware you would need to add to the system. **3**

(ii) State what additional I/O allocation will be required on the PLC. **2**

(25)

[Turn over

12. Figure Q12 illustrates a simplified lift system used to move boxes between the "Storage level" and the "Customer level" in a catalogue retail outlet. The system is presently controlled by a microcontroller.

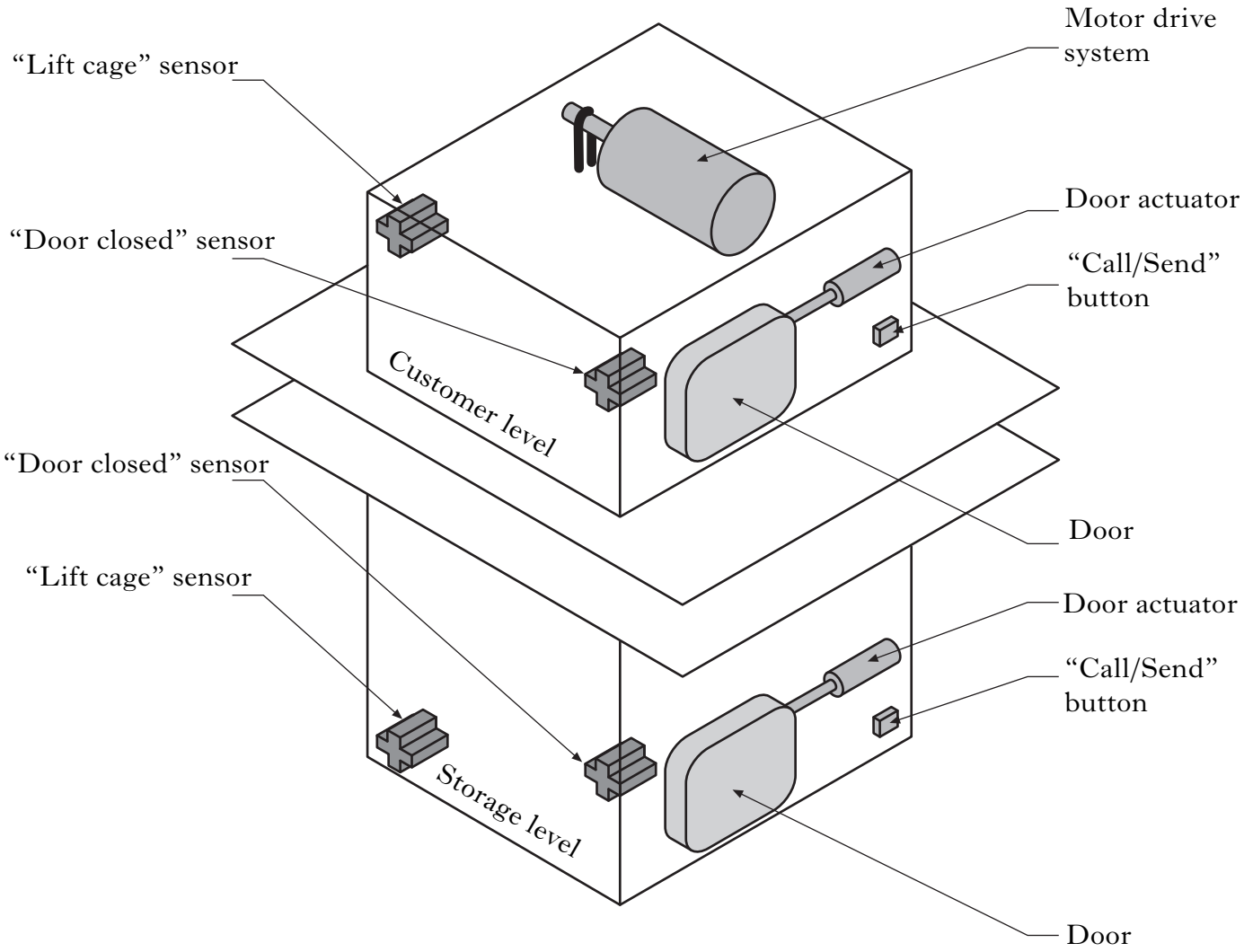

Figure Q12

The system uses an electric motor connected to a cable system to move the cage between the two levels. On **each** level there is:

– a "Call/Send" button to signal to the microcontroller that you wish to call the lift from the other floor **or** send the lift to the other floor;
– a "Lift cage" sensor that detects the presence of the lift cage;
– a "Door closed" sensor.

When the cage arrives at a level, the door is opened by the actuator. Before the cage departs from a level, the door is closed by the actuator.

12. (continued)

(*a*) Sketch a flowchart showing the steps required to move the lift cage from the "Customer level" to the "Storage level". Start with customer level door open and the "Call/Send button" being pressed on the storage level. **4**

Note: The inserted Flowchart symbol sheet for Q7, Q11, Q12 and Q13 gives a suitable selection of Flowchart symbols.

(*b*) (i) Identify all the signals from the lift system which require interfacing to the microcontroller inputs. **3**

(ii) Identify all the output signals from the microcontroller which require interfacing to the lift system. **2**

(*c*) Each lift door is opened and closed by an actuator.

(i) Choose a suitable actuator for door operation. **1**

(ii) Sketch and briefly describe the operation of your chosen actuator. **2**

(*d*) To ensure the maximum working load is not exceeded, it is intended to fit a sensing system that will prevent the lift operating when the load exceeds 160 kg. Choose a suitable sensor and briefly describe your chosen sensing system. You may wish to include a sketch to illustrate your answer. **4**

(*e*) Currently there is nothing to prevent the lift door trying to close even if there is an object in the way.

(i) Choose a suitable sensor that could be used to detect if there is an object which might prevent the door closing. **1**

(ii) List **three** actions that the lift control system could take on detecting an object in the way. **3**

(*f*) The lift uses an electric motor drive system. Briefly explain **two** issues involved in interfacing a large electric motor to the microcontroller. **2**

(*g*) Suggest **three** additional safety measures that could be incorporated into the system. **3**

(25)

[Turn over

13. Figure Q13 illustrates a robotic work cell which places **one** lawn mower engine in an empty container. The work cell is controlled by a separate controller system which reads the sensors as required. Initially all Robots are in their home position and both conveyors are running.

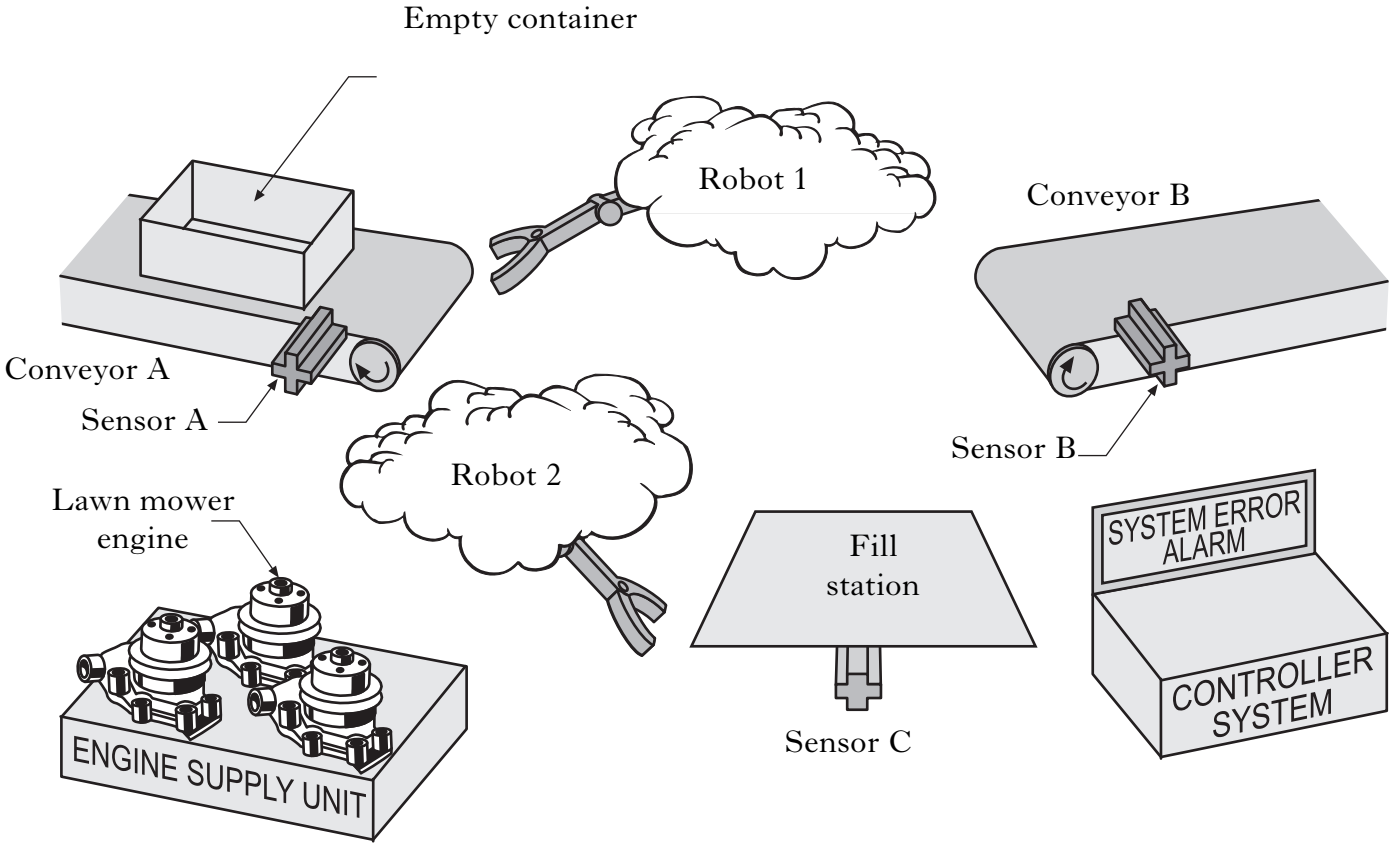

Figure Q13

Conveyor A supplies an empty container for filling. When sensor A is activated by the presence of an empty container, conveyor A is stopped and Robot 1 is signalled. On receiving the signal from sensor A, Robot 1 picks up the empty container and transfers it to the "Fill station". Robot 1 returns to its home position.

Robot 2 then picks up a lawn mower engine from the engine supply unit and places it in the empty container. Sensor C provides a signal which confirms that the container has been filled with one lawn mower engine. Robot 2 returns to its home position. Conveyor B stops on the activation of sensor C.

The filled container is then transferred to conveyor B by Robot 1. Robot 1 returns to its home position. Conveyor B starts on the activation of sensor B and transports the filled container to the next work cell where it is sealed and a label applied.

When conveyor B starts, conveyor A is restarted to supply another empty container and the cycle is repeated.

13. (continued)

(*a*) (i) State **one** type of sensor which would be appropriate to use for sensor A and briefly explain why it would be suitable. **2**

(ii) State **one** type of sensor which would be appropriate to use for sensor C and briefly explain why it would be suitable. **2**

(*b*) Using **Worksheet Q13(*b*)** complete the flowchart which describes one complete cycle of operations. The flowchart starts with an empty container arriving on conveyor A. **6**

Note: The inserted Flowchart symbol sheet for Q7, Q11, Q12 and Q13 gives a suitable selection of Flowchart symbols.

(*c*) Briefly explain **three** safety features which you would add to the system in Figure Q13. **3**

(*d*) The rotary position of one axis on Robot 1 is sensed using an optical rotary encoder which uses a 10 bit Gray code.

(i) Give **one** advantage of using Gray code instead of pure binary coding. **1**

(ii) Calculate the resolution in degrees for this Gray code if the 10 bit code is distributed evenly over the full 360 degrees of the encoder disc. **3**

(iii) Accurate position control is required. State **one** suitable robotic drive system and give a reason which justifies your choice. **2**

(*e*) A mechatronics engineer has decided to redesign the system and replace conveyor A and conveyor B with one continuously moving conveyor X. Conveyor X brings in empty containers at regular intervals which are filled by the Robot while conveyor X continues to move. Briefly explain **two** issues which would need to be considered and suggest a solution to each issue. **6**

(25)

[*END OF SECTION B*]

[*END OF QUESTION PAPER*]

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FOR OFFICIAL USE

Total Marks | | |

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NATIONAL QUALIFICATIONS 2009

FRIDAY, 12 JUNE
1.00 PM – 4.00 PM

MECHATRONICS
HIGHER
Worksheets for Q3, Q4, Q5, Q8, Q10, Q11 and Q13

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Date of birth
Day Month Year

Scottish Candidate number

Number of seat

To be inserted inside the front cover of the candidate's answer book and returned with it.

Worksheet Q3(*a*)

Figure Q3 shows a labelled diagram of a cylindrical robot.

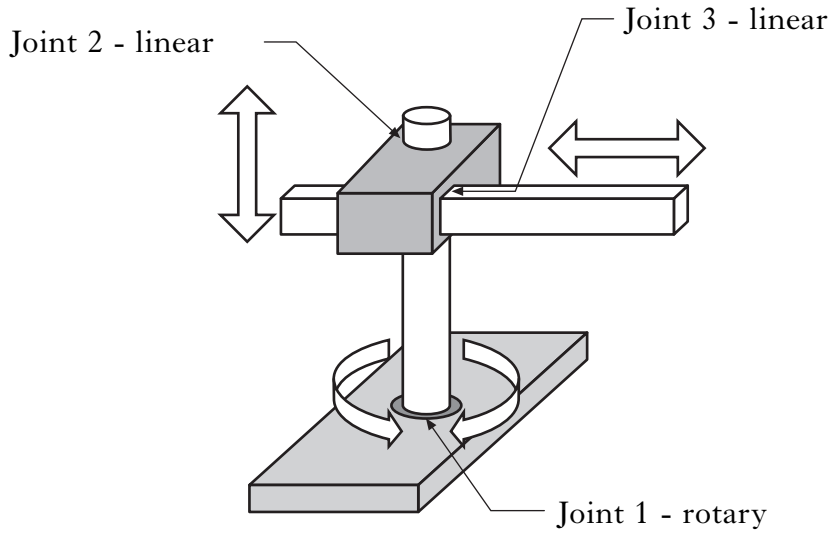


Figure Q3

Complete Table Q3(*a*) by filling in the appropriate joint movement for the Cartesian and SCARA robots.

Robot	**Joint 1**	**Joint 2**	**Joint 3**
Cylindrical	Rotary	Linear	Linear
Cartesian	Linear		
SCARA	Rotary		

Table Q3(*a*)

Worksheet Q4

Complete Table Q4(*a*) by entering the names of the elements labelled A to D.

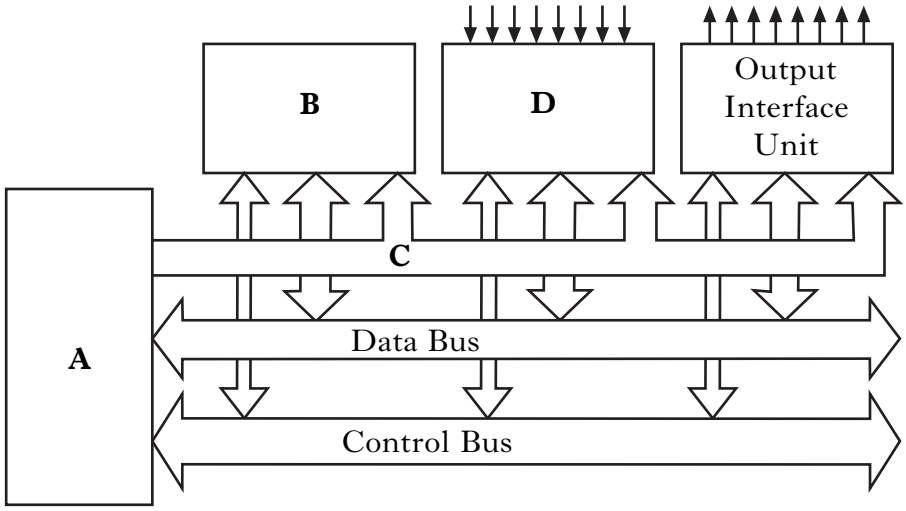


Figure Q4(*a*)

Label	Name of element
A	
B	
C	
D	

Table Q4(*a*)

[Turn over

Worksheet Q5

(*a*) Identify the number of bits represented **and** complete the shading on the disc.

Number of bits represented .....

Now complete the shading of the disc.

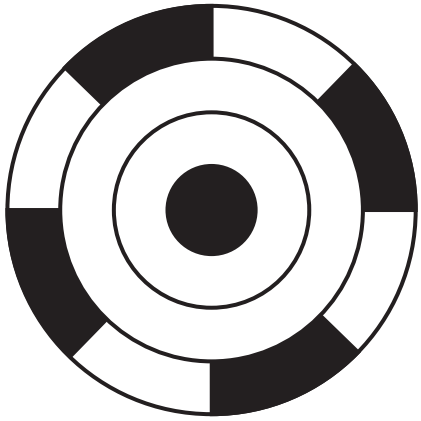


Figure Q5(*a*)

(*b*) Complete Table Q5(*b*) by inserting each of the **four** missing code values.

Decimal	Pure Binary	BCD
0	0000	0000 0000
1	0001	0000 0001
2	0010	0000 0010
3		0000 0011
4	0100	0000 0100
5	0101	
6	0110	0000 0110
7	0111	0000 0111
8	1000	0000 1000
9	1001	0000 1001
10	1010	0001 0000
11	1011	0001 0001
12		0001 0010
13	1101	0001 0011
14	1110	0001 0100
15	1111	

Table Q5(*b*)

Worksheet Q8

(*a*) Complete Figure Q8(*a*) by entering, in the spaces provided, the appropriate label from the list below:

Overshoot;
Desired value;
Offset.

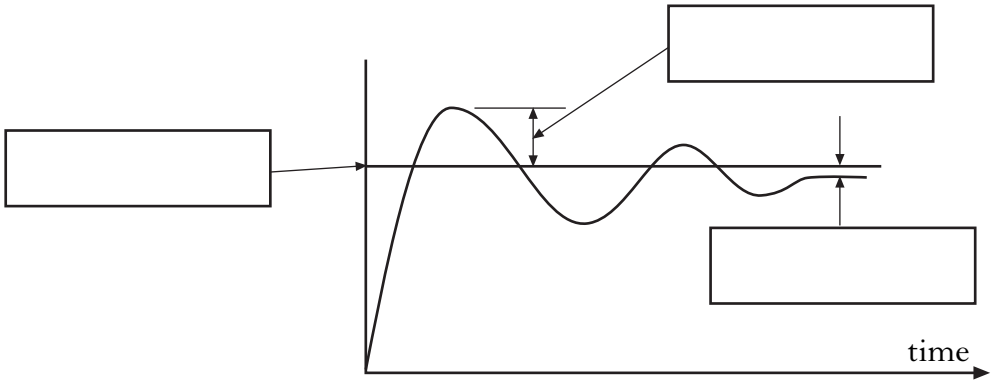


Figure Q8(*a*)

[Turn over

Worksheet Q10

10. This question consists of a series of multiple choice questions and answers for a number of mechatronic related themes. Answer the multiple choice question by putting a tick ☑ in the correct box.

(*a*) A thermocouple is a device used to measure

a temperature ☐
b pressure ☐
c flow ☐
d force ☐
e level. ☐

(*b*) A pneumatic actuator is used to

a measure level ☐
b provide heat ☐
c provide motion ☐
d increase oil pressure ☐
e count pulses. ☐

(*c*) A hydraulic based Mechatronic System is

a maintenance free ☐
b low cost ☐
c high power ☐
d linear only ☐
e rotary only. ☐

(*d*) A rotary optical encoder system directly measures

a pressure ☐
b flow ☐
c force ☐
d movement ☐
e level. ☐

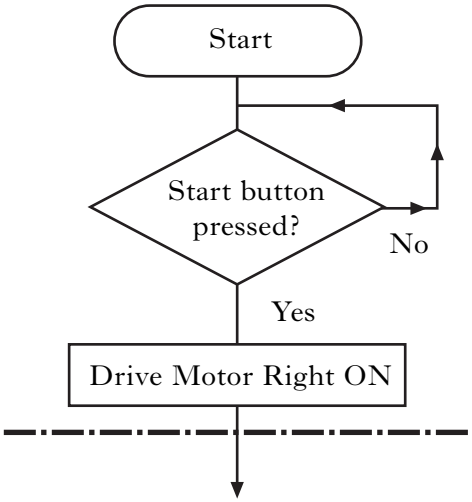
(*e*) An example of a tactile sensor is

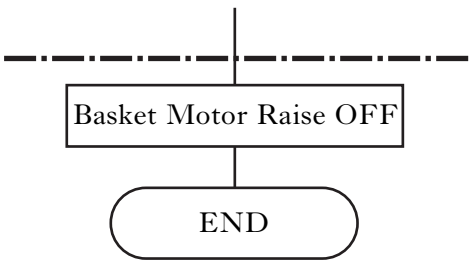
a an electric motor ☐
b a microswitch ☐
c a thermocouple ☐
e a Light Emitting Diode ☐
e a thermistor. ☐

Worksheet Q11(*b*)

Complete the flowchart of the cleaning sequence commencing with "Stage 2" and only continuing as far as the completion of "Stage 3". Ensure all the appropriate input and output signals are clearly shown on your flowchart. Assume the Parts Basket is at Station A and in the raised position when the Start Button is pressed.

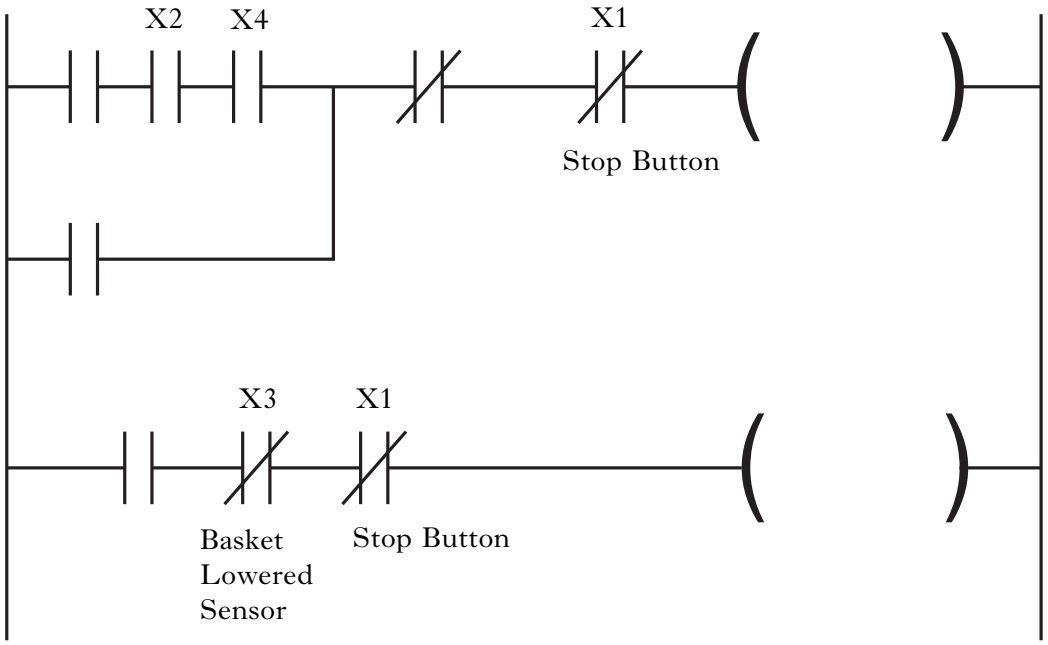
Note: The inserted Flowchart symbol sheet for Q7, Q11, Q12 and Q13 gives a suitable selection of Flowchart symbols.





Worksheet Q11(*c*)

(i) Complete the labelling of Ladder Diagram Q11 using the I/O allocations supplied in Table Q11.



Ladder Diagram Q11

Inputs	***PLC Allocation***	***Outputs***	***PLC Allocation***	***Timers***	***PLC Allocation***
Start Button	X0	Drive Motor Right	Y0	5 second dip time	T0
Stop Button	X1	Drive Motor Left	Y1	8 second rinse time	T1
Basket Raised Sensor	X2	Basket Motor Lower	Y2	60 second drying time	T2
Basket Lowered Sensor	X3	Basket Motor Raise	Y3		
PSA	X4				
PSB	X5				
PSC	X6				
PSD	X7				

Table Q11

Worksheet Q11(*c*) (continued)

(ii) Complete the description of the operation of your completed ladder diagram (Ladder Diagram Q11).

Description

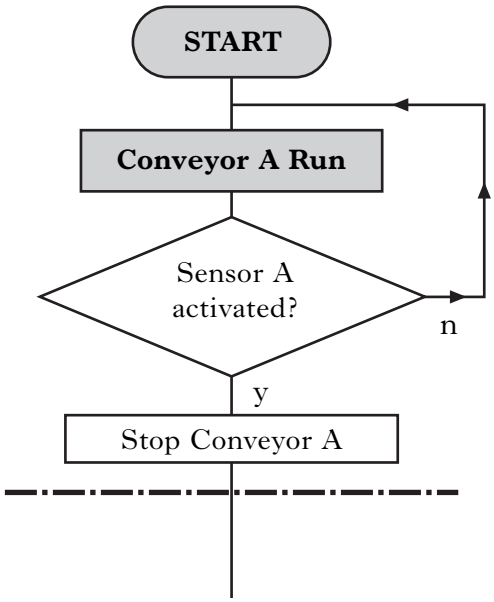
The Stop Button (X1) is present on every rung and can stop the system operation at any time. The handler is at Station A with the basket in the raised position. Position Sensor A (X4) and the Basket Raised Sensor (X2) are activated and on pressing the Start Button (X0) . . .

[Turn over

Worksheet Q13(*b*)

Complete the flowchart which describes one complete cycle of operations. The flowchart starts with an empty container arriving on conveyor A.

Note: The inserted Flowchart symbol sheet for Q7, Q11, Q12 and Q13 gives a suitable selection of Flowchart symbols.



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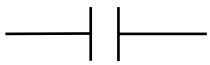
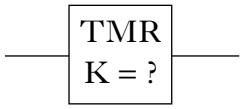
PLC Datasheet Q6, Q11

PLC Programming Details for Ladder Diagram Programming

Functions

Function type	*Function symbol*	*Function name*	*Function operand (see following table)*
Input		Normally open contact (NO)	X, Y, M, T
Input		Normally closed contact (NC)	X, Y, M, T
Output		Output	M, Y
Timer		Timer	
End			

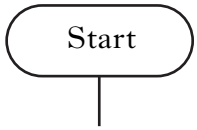
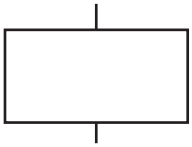
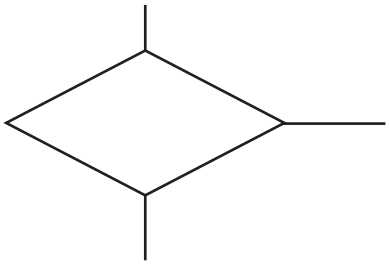
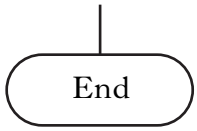
Operands

Operand	*Range*	*Type*
X	0 – 7	Input (I/P) terminal contact
Y	0 – 7	Output (O/P) terminal contact
M	0 – 49	Memory/auxiliary contact
T	0 – 49	Timer (see below)
K	Any integer value multiplier of 0·1 s	Constant

The timer functions begin a timeout for the set duration of time. When timeout occurs, the timer contact(s) are activated. If continuity of the timer rung is broken during timeout, the timeout will immediately reset.

Flowchart Symbol Sheet Q7, Q11, Q12, Q13

The following table shows a selection of Flowchart symbols suitable for use in answering the questions.

Symbol	*Use*
	Starting Point for the flowchart
	Process / Action Box
	Decision Box
	Ending Point(s) for the flowchart