[C028/SQP107]

Higher Mechatronics

Time: 3 hours

NATIONAL QUALIFICATIONS

Specimen Question Paper

100 marks are allocated to this paper.

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

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

Use diagrams and sketches to illustrate your answer where appropriate.

SCOTTISH QUALIFICATIONS AUTHORITY

SECTION A

Attempt ALL questions in this Section (50 marks). *Marks*

1. Figure Q1 illustrates the basic architecture of a microcontroller typical of that found in a mechatronic system.

Briefly describe the basic function of the following.

(*a*) Central Processing Unit **2**

(*b*) Memory Unit **2**

(*c*) Input/Output Interface Units **1**

(5)

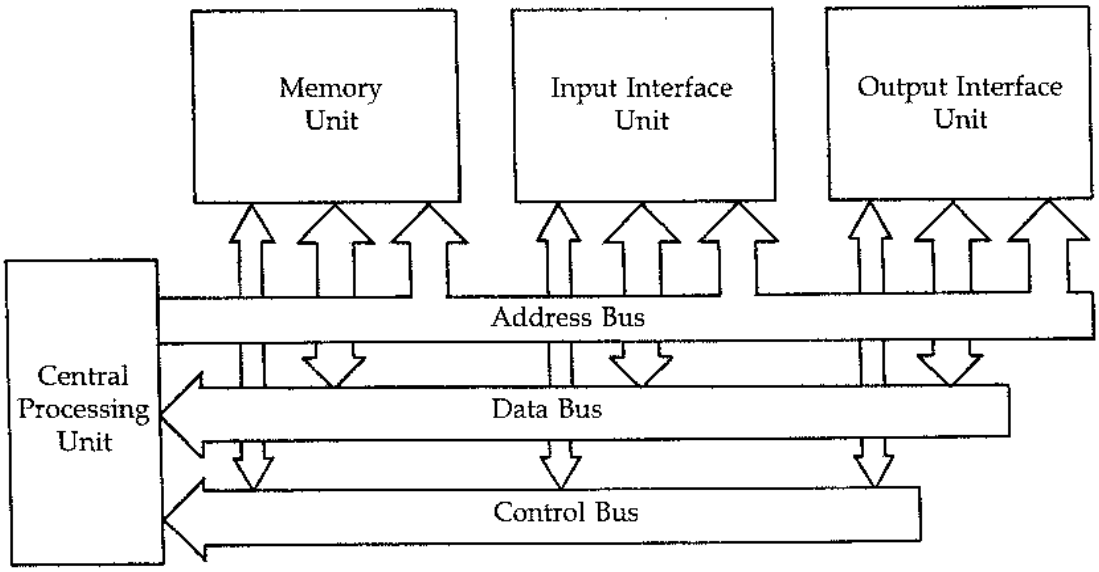


Figure Q1

2. (*a*) Outline **three** relative merits for **both** High Level programming **and** Low Level programming, as applied to a mechatronic system. **3**

(*b*) State the circumstances where High and Low Level programming may be used. **2**

(5)

3. The following is a list of typical control subsystems found in a mechatronic system.

A. Hard wired logic

B. Microcontroller based

C. ASIC based

D. PLC based

E. PC based

(*a*) Identify from the list **three** subsystems which are programmable. **3**

(*b*) State the reasons why no programming would be required for the remaining subsystems. **2**

(5)

4. (*a*) State **one** type of proximity sensor which could be used in a mechatronic system. **1**

(*b*) Give a typical application where this sensor could be effectively used. **1**

(*c*) With the aid of a simple sketch, describe the basic operation of a thermocouple. **3**

(5)

5. (*a*) State **three** advantages which a PLC (Programmable Logic Controller) based mechatronic system would have over a PC (Personal Computer) based system. Assume that the application is within a typical factory environment. **3**

(*b*) A typical software development environment may include the following elements:

(i) an Editor;

(ii) an Emulator;

(iii) a Simulator.

Describe the function of any **two** of these elements. **2**

(5)

Marks

6. Figure Q6A illustrates a tank of water which is under program control using a PLC. When the water falls below the float switch level, the tank will be topped up automatically by the top-up valve.

   If the water level remains below the float switch level for more than 2 minutes, then an audible alarm will sound.

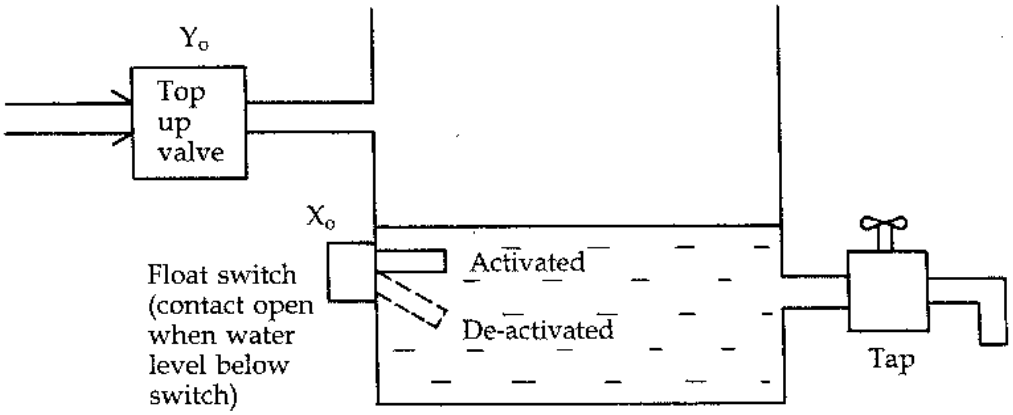


Figure Q6A

Figure Q6B shows the ladder diagram program details.

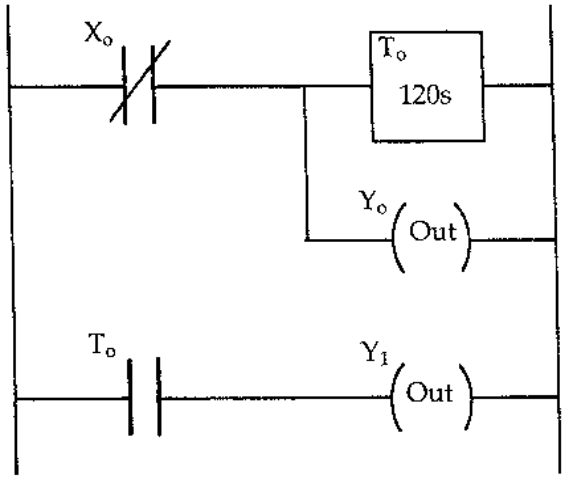


Figure Q6B

Describe the operation of the program in relation to the system, assuming that the tank is initially full of water. The description should explain the "top-up" and the alarm conditions. **(5)**

Note: The instruction set for a PLC is provided in the attached Data Sheet for Q6 and Q13.

7. (*a*) Describe the arm geometry of a revolute robot. The description should comprise:

   (i) a simple sketch with each joint labelled for reference; **2**

   (ii) an illustration on the sketch of the type of movement at each joint; **1**

   (iii) the anatomical name for each labelled joint. **1**

   (*b*) Give a basic application for a revolute robot. **1**

   (5)

8. Figure Q8 illustrates an optical rotary incremental encoder with 1000 evenly spaced transparent slots around the periphery of the disk.

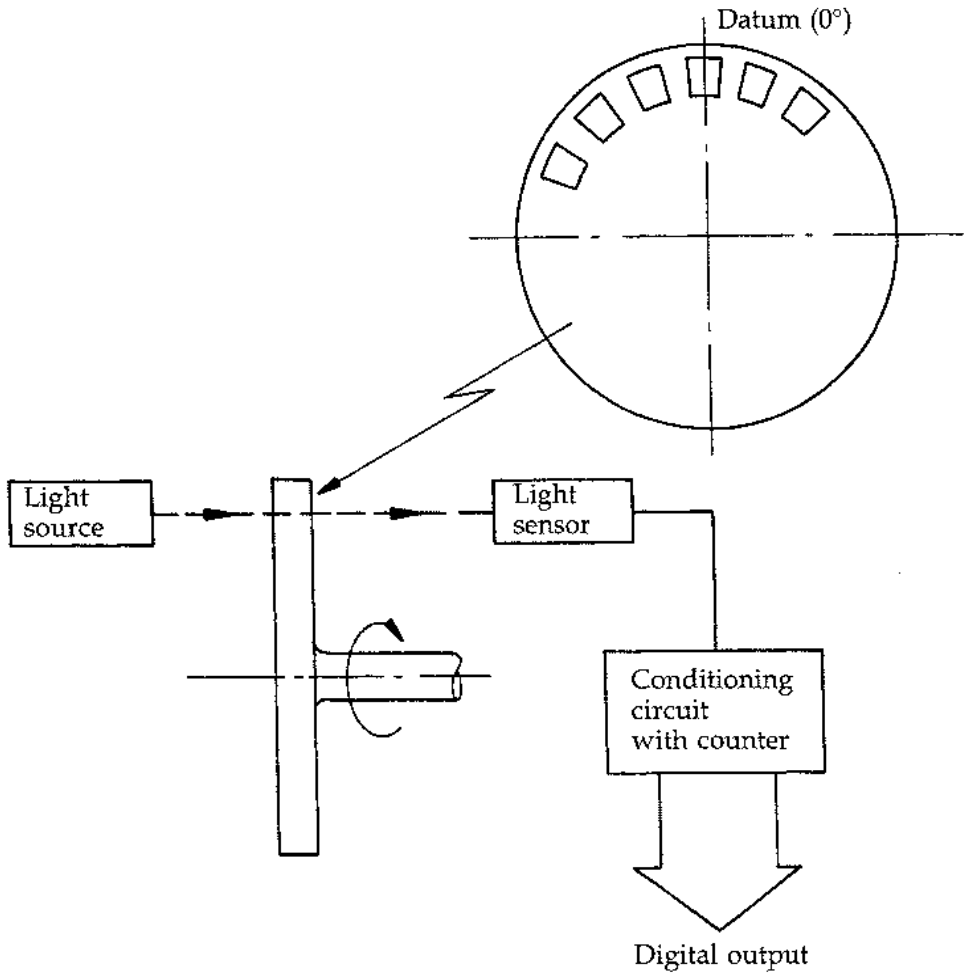


Figure Q8

(*a*) Explain the basic operation of the incremental encoder and associated signal conditioning circuitry. **2**

(*b*) Calculate the number of degrees of revolution, relative to the datum (0°), when the counter accumulates a count of 650. **1**

(*c*) Describe any additional requirements that would be needed in the above system in order to detect the direction of rotation. **2**

(5)

9. (*a*) Sketch a basic block diagram for the following control systems:

(i) an open loop system;

(ii) a closed loop system. **2**

(*b*) Describe the basic problem of a closed loop control system which incorporates only *proportional* action. **2**

(*c*) State an advantage gained by incorporating *integral* action into the control strategy. **1**

(5)

Marks

0. Figure Q10 illustrates a conveyor transfer system using two pneumatic cylinders A and B for lowering bales of hay.

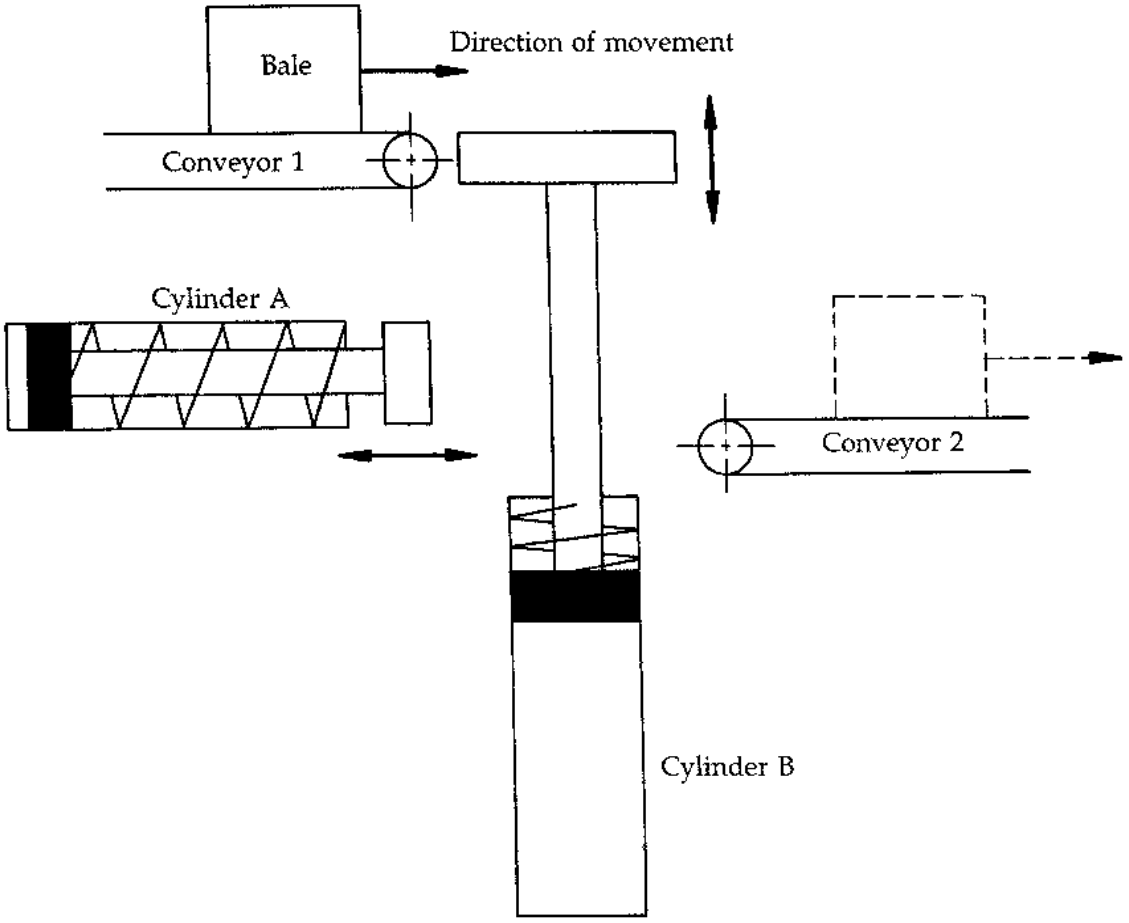


Figure Q10

Conveyor 1 supplies bales of hay which need to be lowered to Conveyor 2 to be transported away for storage.

The sequencing of the pneumatic spring return cylinders is critical in order to complete the transfer of each bale successfully.

Note that both cylinders must never extend together.

(*a*) Sketch a flowchart which will outline the conditions of each of the cylinders for the successful transfer of each bale from Conveyor 1 to Conveyor 2. Begin with the upper level being served with a bale and the cylinders in the position shown. Simply state whether the appropriate cylinder is extended or retracted and assume that the operation of each cylinder is instantaneous. **3**

(*b*) Describe a possible hazard if Conveyor 1 runs constantly with a plentiful supply of bales. **1**

(*c*) Describe **one** method of avoiding the hazard described in (*b*). **1**

(5)

SECTION B STARTS ON PAGE EIGHT

SECTION B

Attempt any TWO questions in this section (50 marks). Each question is worth 25 marks. *Marks*

11. Figure Q11 illustrates a revolute robot working within a robotic workcell which performs the task of filling empty boxes with trays of chocolates to be forwarded for final wrapping.

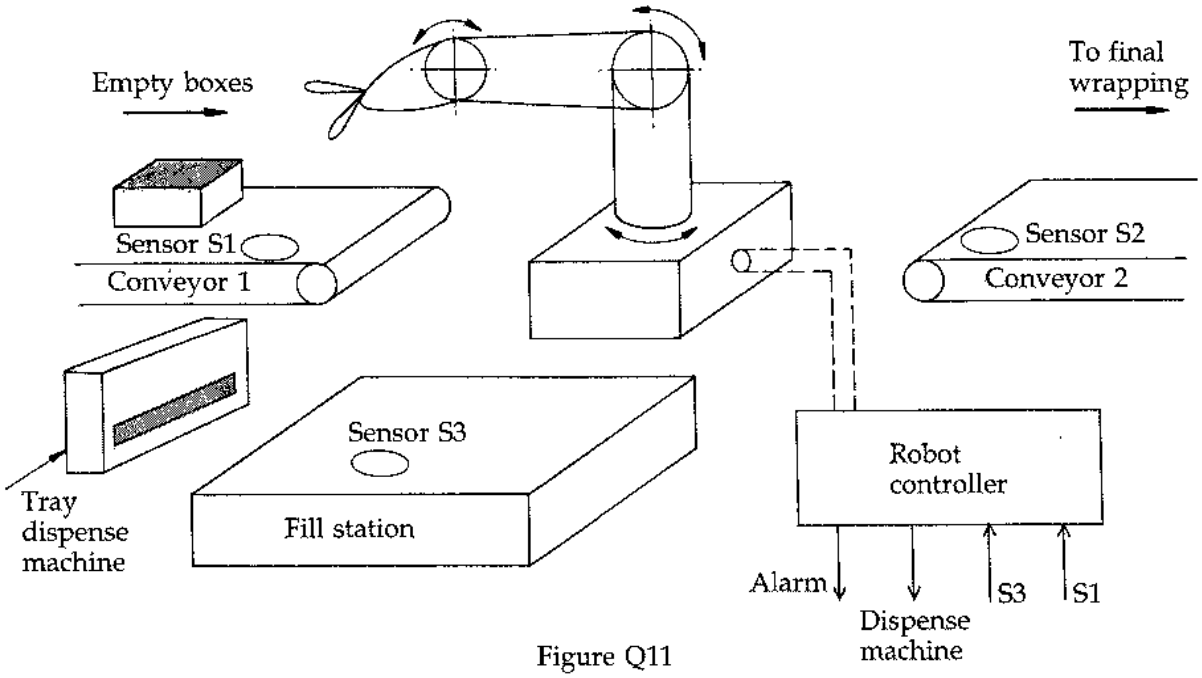


Figure Q11

The *Conveyor 1* supplies empty boxes for filling. When the sensor S1 senses the presence of an empty box, the robot is signalled and the *Conveyor 1* stopped.

On receiving a signal from S1, the robot picks up the box and transfers it to the *Fill station*.

At the *Fill station*, once the box is in position, the robot operates the *Tray dispense machine* which lowers a tray of chocolates into the box. The robot needs to wait for five seconds for this to happen.

When the tray has been dispensed, the full box is then transferred to the *Conveyor 2* which starts on receiving a signal from sensor S2 to carry the box to the final wrapping stage.

When *Conveyor 2* starts, *Conveyor 1* will be restarted also to bring in the next empty box.

A sensor S3 will confirm the dispensing of a tray to the empty box. If, after five seconds, a tray is not dispensed, the robot will then return to its home position as shown in Figure Q11 and signal an "Out of Chocolates" alarm and then stop. An operator will then fill the tray dispenser and restart the system.

The conveyors are controlled by a separate conveyor controller operating from the sensors as required.

11. (continued)

(*a*) Sketch a flowchart which describes the sequence of events required of the robot to perform the above tasks on a repetitive basis starting from the home position. **12**

(*b*) (i) Indicate the type of sensor which would be most appropriate for sensors S1, S2 and S3. **2**

(ii) Give a reason for the choice made in part (i). **4**

(*c*) The rotational position of the base of the robot is sensed using a rotary optical encoder which incorporates a Gray Code.

(i) Describe the principle of a Gray Code. **2**

(ii) Explain the main advantage of a Gray Code over a pure binary code. **1**

(iii) Calculate the resolution of the rotation in degrees, if the Gray Code is based on 12 bits. **2**

(*d*) The conveyors and the fill station of Figure Q11 are basically arranged in a circular manner. The robot used is a revolute geometry. State two alternative robot geometries that would also suit this layout. **2**

(25)

2. Figure Q12A illustrates a bottling plant in a lemonade factory. Note that the cap positioning cylinder is shown retracted and the carriage positioning cylinder is shown extended.

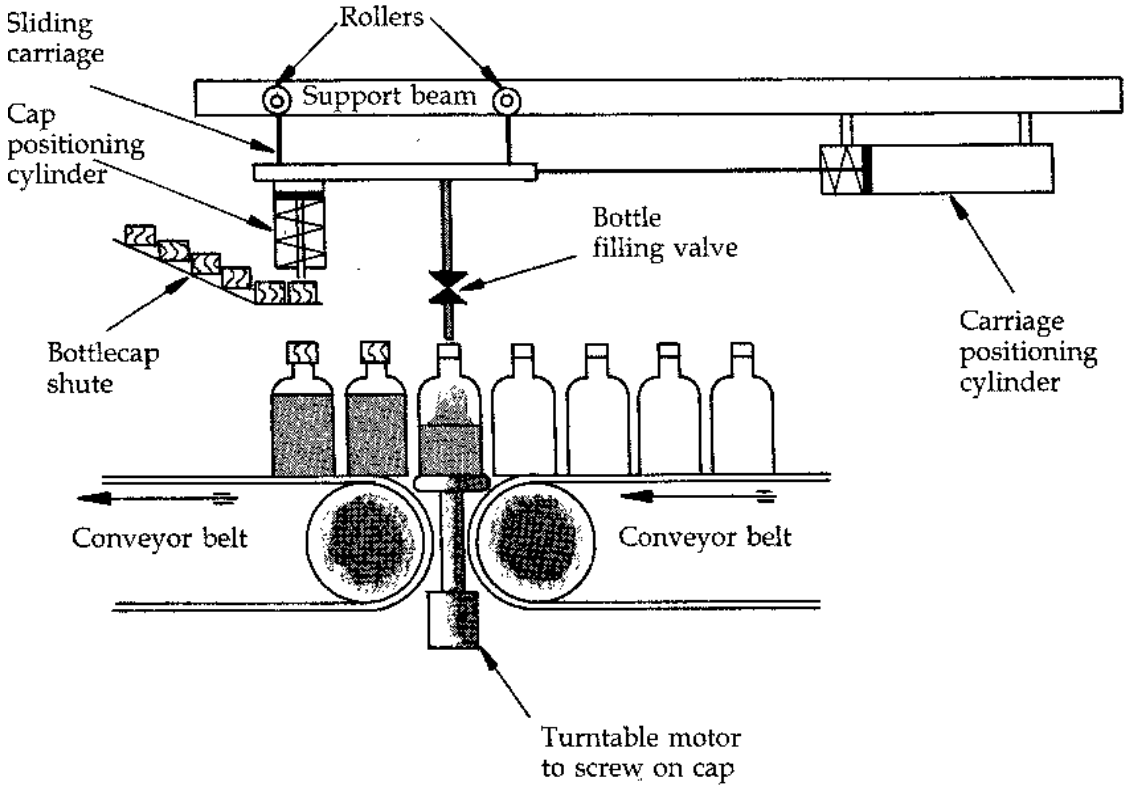


Figure Q12A

A sequence of events is required in order to fill each empty bottle delivered by the conveyor belt.

Assume that a sensor exists which will detect the presence of a bottle on the turntable. The time taken to fill a bottle is 2 seconds and it can be assumed that a bottle cap is fitted instantaneously.

A microprocessor based controller is available with I/O ports. The signals are detailed in Figure Q12B.

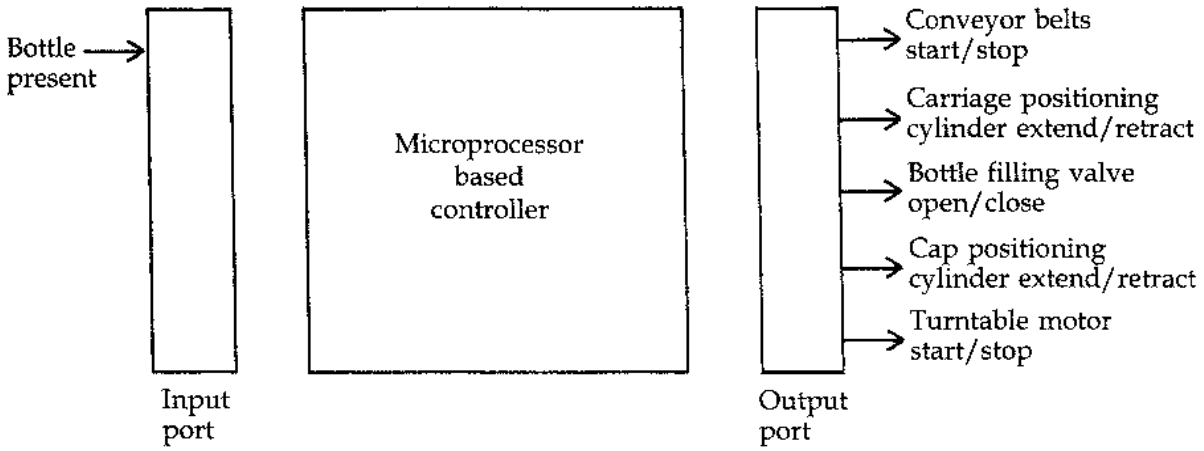


Figure Q12B

12. (continued)

(*a*) Sketch a flowchart which will outline a basic sequence of operations on the detection of each empty bottle. Begin with an "initialisation" box which is identified with:

- stopping conveyors
- extracting carriage positioning cylinder
- closing bottle filling valve
- retracting cap positioning cylinder
- stopping turntable motor. **15**

(*b*) State **two** programmable controllers that could be used for the sequencing of the operations required. **2**

(*c*) Comment on the use of:

(i) a hard wired logic sequencer; **2**

(ii) an ASIC based system; **2**

for the sequencing of the operations required.

(*d*) A high level language could be used to program the bottling sequence. There are two types - Compiled and Interpreted.

With respect to a high level language, give a short comparison of Compiled and Interpreted versions in terms of:

(i) method of the translation of the language statements; **2**

(ii) use of memory. **2**

(25)

Marks

3. The roller door of a factory entrance as shown in Figure Q13A needs to be controlled using a PLC with the sensors and actuators specified in Table Q13.

   Strategic locations have been identified for the installation of all the sensors and actuators by the letters A to E in Figure Q13A.

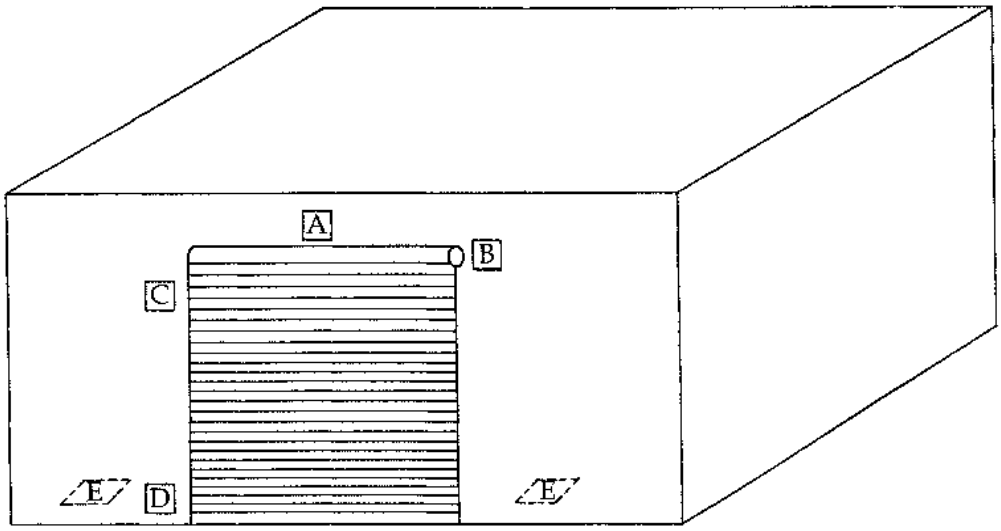


Figure Q13A

Device	*Quantity*	*Detail*
Microswitch	2	Normally open contact. Will close on operation (logic 1).
Infra-red transmitter/receiver	1	Operate together. When infra-red beam is broken will provide a logic 1.
Ultrasonic detector	1	Floods area with ultra-sonic beam. Will detect movement and provide a logic 1.
DC Reversible motor	1	Requires two connections F and R for forward and reverse. Assume F = 1 and R = 0 will raise door. i.e. F R 1 0 forward 0 1 reverse 0 0 stop

Table Q13

13. (continued)

The basic operation required is as follows.

When a moving vehicle such as a forklift is sensed, the roller door should be raised all the way to the top where it will be stopped.

When the vehicle is inside, the roller door should be lowered all the way to the bottom where it will be stopped.

(*a*) Assign an installation location A to E for each of the I/O devices, giving **one** reason for each of the selections. **5**

(*b*) Assign the I/O devices to appropriate X and Y I/O terminals of the PLC. **4**

(*c*) Sketch a flowchart of the desired sequence of operations assuming that the door is initially closed. **7**

(*d*) A basic ladder diagram program for use with the PLC to control the opening/closing operation is illustrated in Figure Q13B. Describe the operation of this program in relation to the application. **6**

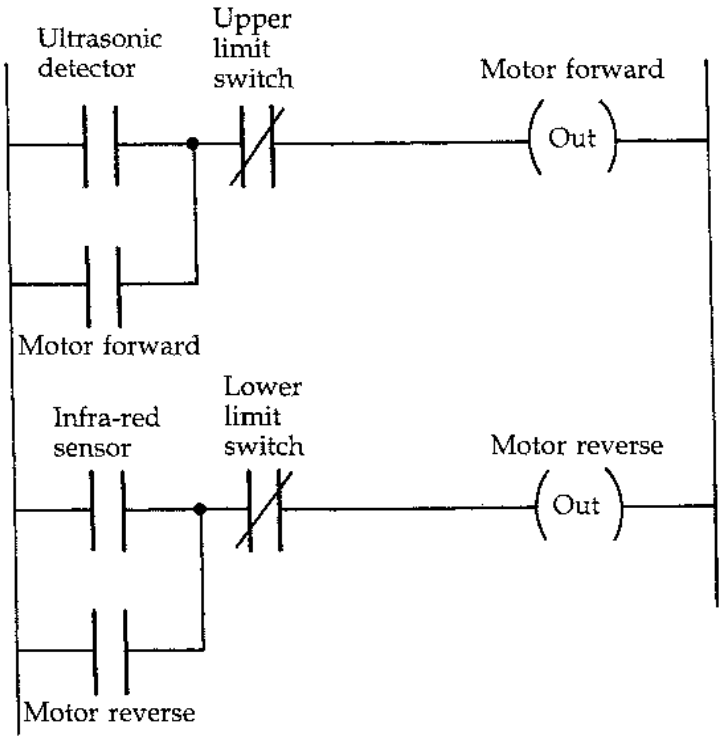


Figure Q13B

(*e*) Clearly indicate the elements of the ladder diagram program which include references to the I/O assignments made in part (*b*). Redraw and indicate the X/Y assignments. **3**

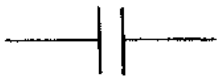
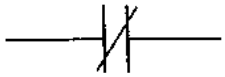
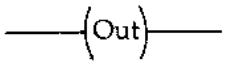
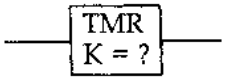
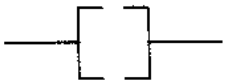
Note: The instruction set for a PLC is provided in the attached Data Sheet for Q6 and Q13.

(25

DATA SHEET FOR Q6 and Q13

PLC programming details

i) Ladder diagram programming

Function type	Function symbol	Function name	Function operand (see following table)
Input		Normally open contact	X, Y, M, T
Input		Normally closed contact	X, Y, M, T
Output		Output	M, Y
Timer		Timer	
End			

(ii) Table

Operand	Range	Type
X	0–7	I/P terminal contact
Y	0–7	O/P terminal contact
M	0–49	Marker/auxiliary contact
T	0–49	Timer
K	Any integer value multiplier of 0·1s	Constant

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Higher Mechatronics

NATIONAL QUALIFICATIONS

Specimen Marking Instructions

SCOTTISH QUALIFICATIONS AUTHORITY

Section A

1. "Underlined" keywords (or equivalent) must be present.

(*a*) The central processing unit performs a repetitive fetch and execute action to achieve all processing needs. Processes are data transfers, bit manipulations, arithmetic and logic functions. **2**

(*b*) The memory unit provides storage locations for all instructions (processes) required and data which is to be processed. **2**

(*c*) The input/output interface units provide for data input and output to and from the system. **1**

5

2. (*a*) High level programming:

Self documenting, easier to read, easier for programming, usually slow in operation, uses more memory, portable, easier to debug. Any 3 @ $\frac{1}{2}$

Low level programming:

Machine dependent, unfriendly to read, difficult to program, fast in operation, uses less memory, difficult to debug. Any 3 @ $\frac{1}{2}$ **3**

(*b*) For high level programming:

non time critical,
good user interaction (graphical). Any 1 @ 1 **1**

For low level programming:

time critical,
limited memory. Any 1 @ 1 **1**

5

3. (*a*) The three sub-systems are:

Microcontroller based,

PLC based

and PC based. 3 @ 1 **3**

An ASIC could possibly be chosen here.

(*b*) For hard wired logic

A rewiring of the system would be required.

For ASIC based

A replacement ASIC would be required. 2 @ 1 **2**

If ASIC included in part (*a*) then it would not be included in (*b*).

5

4. (*a*) Any one type from:

Electromechanical,
Optoelectric,
Inductive,
Capacitive. **1**

(*b*) Applications (any one):

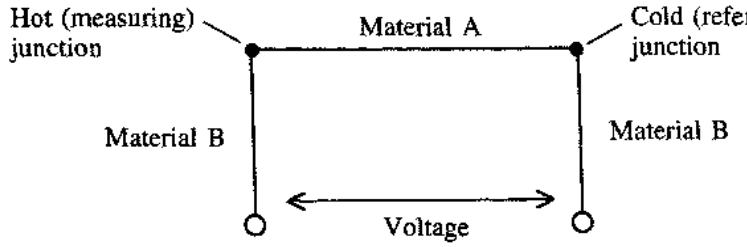
Electromechanical – force to operate switch (microswitch).

Optoelectric – any application which involves detection of change in the light path.

Inductive – any application which involves detection of change in magnetic field.

Capacitive – any application which involves detection of change in electric field. **1**

(*c*)



A thermocouple is formed when two different materials are connected and experience a change in temperature. A voltage is generated which varies with the temperature. **3**

5

5. (*a*) Any three from:

Rugged, tolerate abuse.
Immunity to electrical noise.
Ease of I/O interfacing.
User friendly programming.
Space saving.
Ease of expansion.
Detachable hand controller. **3**

(*b*) "Underlined" keywords (or equivalent) must be present. Any two from:

Editor – allows programmer to <u>create and/or edit functional programs</u>.

Emulator – a piece of <u>hardware which can impersonate the characteristics of a target system</u> usually by direct connection.

Simulator – a piece of <u>software used to model an operation</u> and possibly display graphics. **2**

5

6. Marks distribution shown.

Initial condition:

When the tank is topped up (full) of water the float switch X_0 is activated.
Rung 1 of ladder diagram has no continuity hence timer T_0 and output Y_0 are off.
Rung 2 of ladder diagram has no continuity until timer T_0 times out. **2**

Top-up:

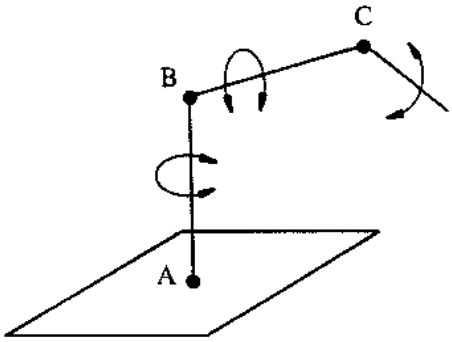
When water is drained from the tank by opening the tap, eventually the float switch X_0 will de-activate and cause continuity for rung 1.
The timer T_0 will begin timeout period of 2 minutes and the output Y_0 will switch on the top-up valve to allow refill of tank.
If the tap is turned off or fill speed is greater than drain speed, eventually the float switch X_0 will activate and open rung 1 thereby switching off the timer T_0 and the top-up valve Y_0. **2**

Alarm:

If the water level remains below the float switch such that the switch is de-activated for longer than 2 minutes then rung 2 will achieve continuity through the contact T_0 and switch on the alarm Y_1. **1**

Alternative answers may be acceptable. **5**

7. (*a*) (i) Minimum sketch requirement would be a "stick" diagram as illustrated with joints labelled. **2**



(ii) Direction of rotation indicated on diagram presented in part (i). **1**

(iii) The anatomical name:

A – waist;
B – shoulder;
C – elbow.

All three must be present and correct. **1**

(*b*) Any application which involves a basic circular motion described briefly e.g. basic 'pick and place' or simple assembly. **1** **1** **5**

8. Marks distribution shown.

(*a*) The rotating disk interrupts the light beam between the transmitter (source) and the receiver (sensor) thereby creating logic pulses at the receiver O/P. 1 @ 1

These pulses are counted by an electronic counter in the processing circuitry. Each count represents a fixed angle of rotation. The counter will accumulate a count proportional to the total angular movement. 1 @ 1 **2**

(*b*) 1000 represents 360°.

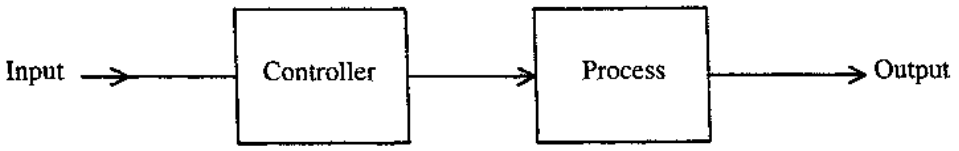
650 represents $\frac{650}{1000} \times 360° = 234°$. **1**

(*c*) In order to detect direction of rotation another set of 1000 windows would be needed around the periphery of the disk along with additional light source and sensor. 1 @ 1

These windows would be displaced by quarter of a window pitch (distance between two adjacent windows). Electronic process circuit would interpret the phase difference into rotational direction. 1 @ 1 **2**

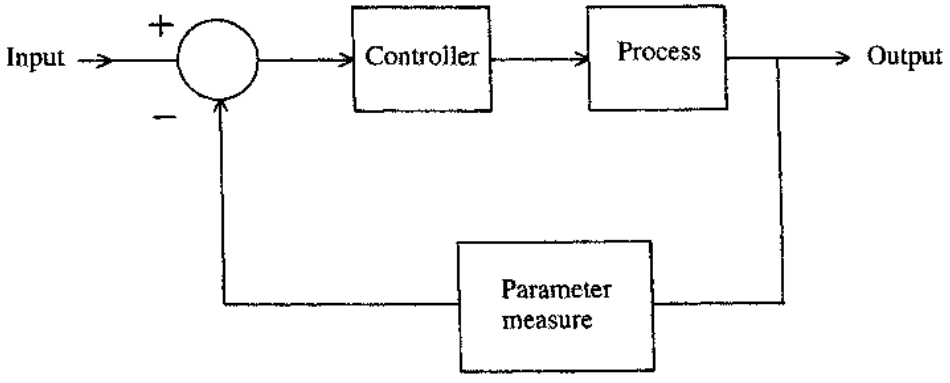
5

9. (*a*) (i)



1

(ii)



1

Labelling of blocks need not be same but should show basic idea of open loop – no feedback, closed loop – feedback (negative).

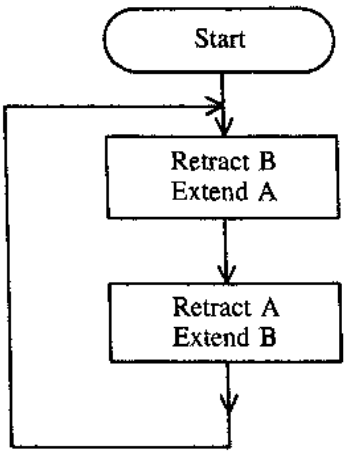
(*b*) Proportional action on its own will always result in a finite steady state error. 1 @ 1

Proportional action is varied by altering system gain. The higher the gain the less the steady state error but system could become unstable. 1 @ 1 **2**

(*c*) Advantage of integral processing is to remove the steady state error (offset). **1**

5

10. (*a*)



(*b*) If conveyor 1 runs constantly with a plentiful supply of bales, bales will arrive for delivery to the conveyor 2. When the cylinder B is not extended bales will then fall from the upper level unchecked.

(*c*) To avert the hazard install a sensor which will detect the presence of a bale for delivery and will signal to stop the conveyor 1 until bale is removed.

3

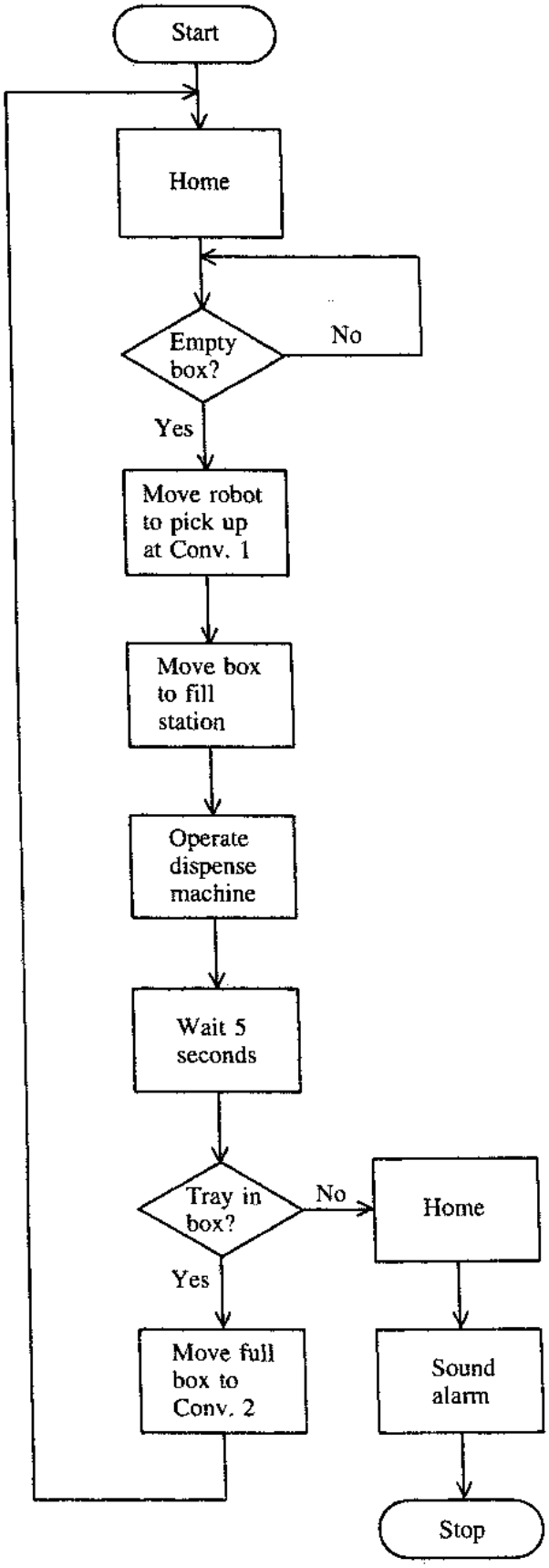
1

1

5

Section B

11. (*a*) 1 mark/flowchart part = 12 marks.



Note: minor variations of this are acceptable. Each will have to be judged on its own merit.

12

(*b*) A digital signal is required.
All three sensors S1, S2 and S3 can all be identical.

(i) The choice would be either:

Microswitch or photoelectric, because these will provide digital signal more readily. (choice) **2**

(ii) The photoelectric sensor would be the best choice from the points of view:

easy to install;

can detect objects up to reasonable distance from sensor, so allowing installation away from moving parts for safety and routing of supply wires;

these would provide logic signals for operation;

no mechanical moving parts providing higher reliability.

In contrast the microswitch although capable would:

be difficult to install requiring accurate setting up;

need objects to come into contact to operate, i.e. need very close proximity near moving parts;

have poor reliability. (reasoning) **4**

(*c*) (i) Gray Code is a binary code in which the adjacent codewords differ by only one bit change,

e.g. in pure binary of 4 bit length
0111 would then change to 1000
all bits change

in Gray Code of 4 bit length
0111 could change to any codeword which only involves 1 bit, i.e. 0101. **2**

(ii) In Gray Code where only 1 bit changes window alignment problems which can cause false readings are averted. **1**

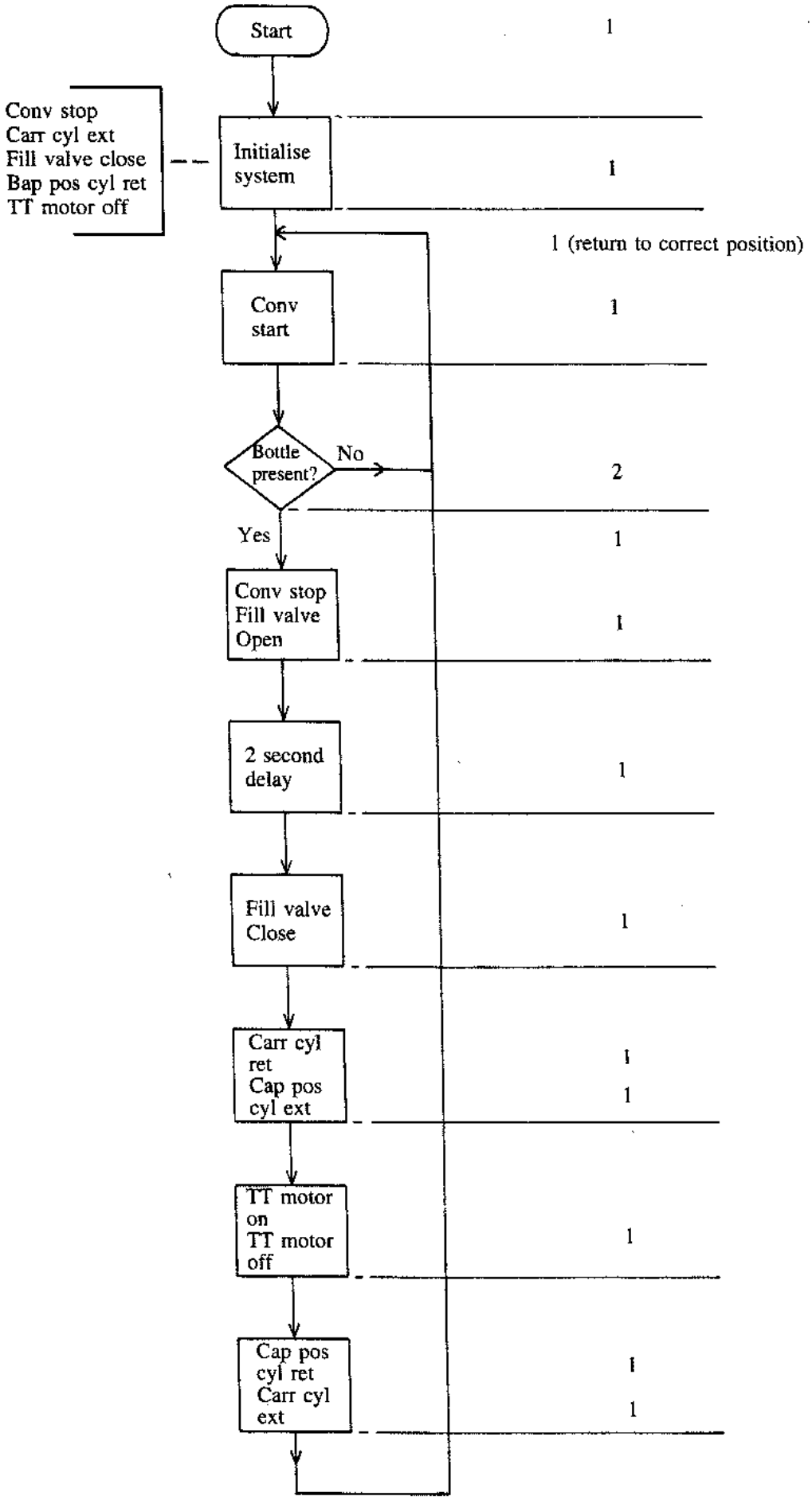
(iii) Resolution = $\frac{360}{2^n} = \frac{360}{4095} = 0.088°$. **2**

(*d*) Any geometry which involves a rotation of the waist (base). Choose two from:

cylindrical
polar
scara. 2 @ 1 **2**

25

12. (*a*) Minor variations are acceptable.



15

(*b*) Two alternatives are:

PLC based system
PC based system. 2 @ 1 **2**

(*c*) Two less flexible systems are:

(i) Hard wired logic sequencer, as this would require rewiring if any change was required to the system of operations. **2**

(ii) ASIC based system, as this would require a new ASIC replacement to accommodate a system change. **2**

(*d*) Key points which need to be made are:

Compiled – translates complete program before execution.
– uses lots of memory for storage of compilation.
2 @ 1 **2**

Interpreted – translates statement by statement.
– uses only a little memory. 2 @ 1 **2**

25

13. (*a*) Location A: Ultrasonic detector.
This is a good position for centrally flooding the active area with ultrasonic beam. **1**

Location B: DC reversible motor.
To rotate roller door with minimum mechanical couplings. **1**

Location C: Normally open switch.
To detect upper position of the roller door. **1**

Location D: Normally open switch.
To detect lower position of the roller door. **1**

Location E: Infra-red transmitter and receiver pair.
To detect forklift inside factory by infra-red beam interruption. **1**

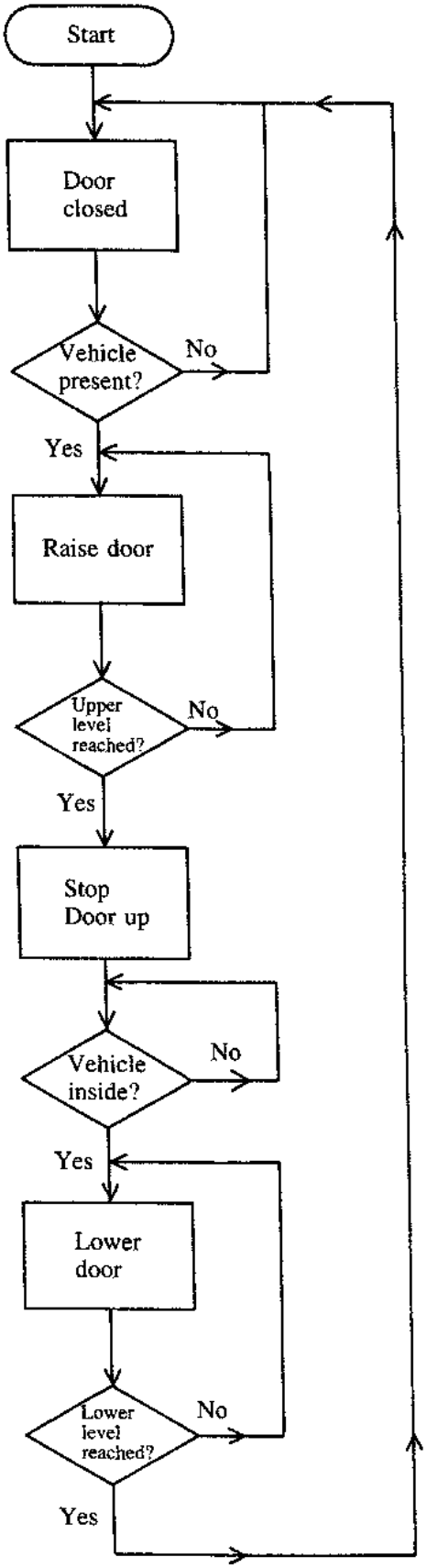
(*b*) Consider inputs:

These must be assigned to any X input of the PLC
e.g. upper switch (C) – X_0
lower switch (D) – X_1
ultrasonic det (A) – X_2
infra-red pair (E) – X_3. 2 @ 1 **2**

Consider outputs:

DC reversible motor with two connections 'F' and 'R' – these must be treated as two outputs and assigned to any two 'Y' outputs of the PLC
e.g. motor 'F' – Y_0
motor 'R' – Y_1. 2 @ 1 **2**

(*c*) 1 mark/flowchart part = 7 marks, excluding 'door closed' and 'start'.



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(*d*) When the door is closed:

The lower limit switch is operated, i.e. contact open.
The upper limit switch is de-operated, i.e. contact closed.
The ultrasonic detector is de-operated, i.e. contact open.
The infra-red sensor is de-operated, i.e. contact open.
Both rungs of ladder diagram program give no continuity so motor is off. **2**

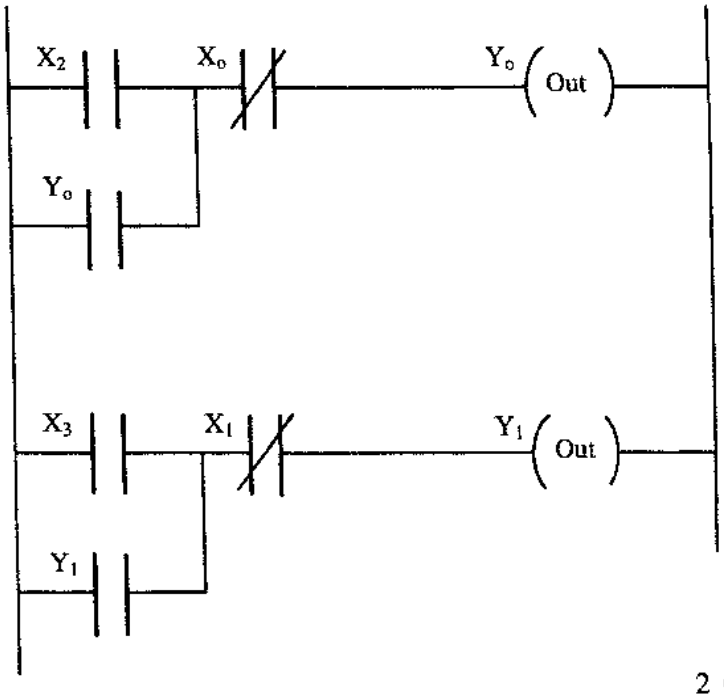
On detection of a forklift present:

The ultrasonic detector is operated, i.e. contact closed.
Rung 1 has continuity, so motor forward switches on to raise door. The lower limit de-operates to close, motor forward contact closes to latch on raising of door.
When door reaches upper limit switch, this operates, opening the contact and stopping the door raising. **2**

On detection of forklift inside:

The infra-red sensor operates closing the contact.
Rung 2 has continuity so motor reverse switches on to lower door. The upper limit de-operates to close. Motor reverse contact closes to latch on lowering of door.
When door reaches lower limit switch, this operates, opening the contact and stopping the door lowering. **2**

(*e*) Assignments must match (*b*).



2 @ $1\frac{1}{2}$ **3**

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