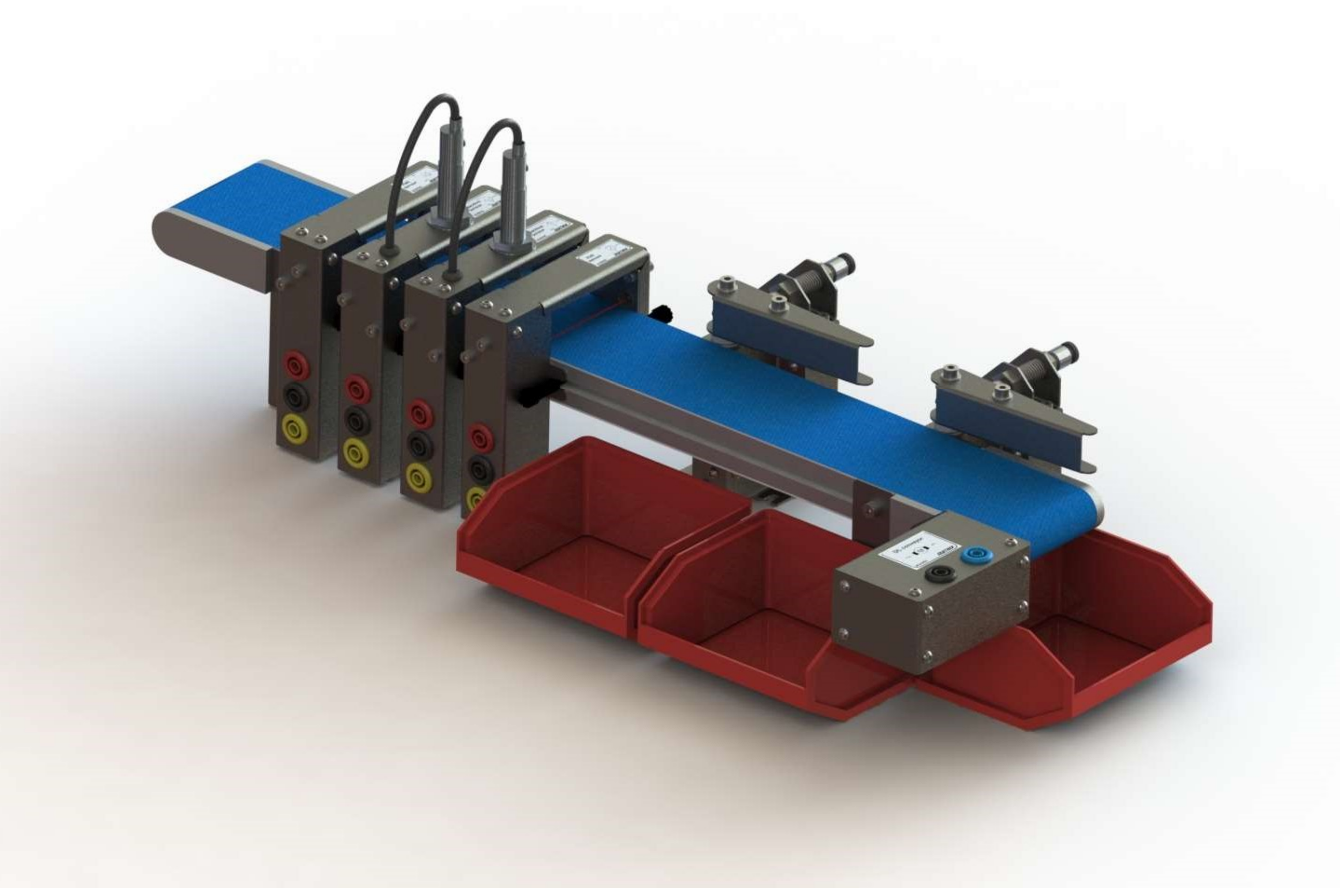
SMART FACTORY

Smart Factory

www.matrixtsl.com

Contents

Conveyer Worksheets



Worksheet 1

Understanding sensors

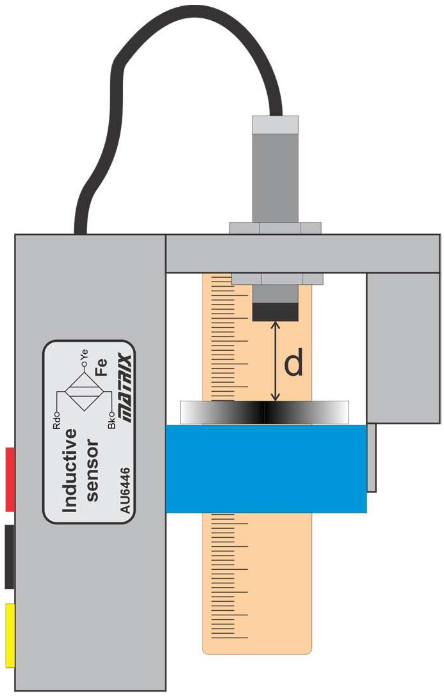
SMART FACTORY

Some digital sensors in machinery can be simple switches like the gantry limit switch in the smart factory. Other digital sensors have some kind of circuit which takes in an analogue signal and converts it into a digital one: the Hall sensor, Capacitance sensor and the infrared beam breakers on the conveyor system are all examples of this.

Over to you:

Inductive sensor

- Take the inductive sensor and apply power and ground to the red and black connectors respectively.
- Referring to the diagram: using a ruler measure the minimum distance, d, from the sensor at which the inductive sensor triggers for each metal counter: aluminium and steel. On some models of sensor there is an LED indicator. On others you will need to use a multimeter on the output to see when the output voltage changes.



	Capacitive sensor	Inductive sensor
Steel counter		
Aluminium counter		

So what?

The inductive sensor allows you to differentiate between different types of metal. So the inductive sensor needs setting up with some precision.

Over to you:

- Add the inductive sensor to the conveyor belt using the t-blots to secure the sensor to the sides of the conveyor. Set up the sensor so that the height of the sensor above the conveyor belt is 5.5 mm more than the height you measured for the aluminium counter. This is 1.5mm plus the height of the counter (4mm). This gives some small margin for error.

- Add power to the conveyor manually so that it runs.
- Place the aluminium and stainless steel on the conveyor and make sure that the sensor reliably detects the steel counter but not the aluminium one.

So what?

- The height of the conveyor varies slightly as it turns: there is a join in the belt that raises the counter slightly . You may need to increase the distance slightly between the sensor and the counter.

Over to you:

Capacitive sensor

- Set up the capacitive sensor so that the height above the conveyor is 2mm more than the trigger height you measured for the steel and aluminium counters. The counter thickness is 4mm so this should give a reliable indication of the presence of a metal counter.
- Add power to the conveyor manually so that it runs.
- Place the aluminium and stainless steel on the conveyor and make sure that the sensor reliably detects the presence of a metal counter beneath it.

So what?

You now have two sensors: the inductive sensor allows you to differentiate between steel and aluminium counters. The capacitive sensor allows you to differentiate between plastic and metal sensors. With a little programming logic you should be able to develop a programme that allows you to sort the counters.

Over to you:

Light gates

- Add a light gate to the conveyor using the T bolts.
- Add power to the conveyor manually so that it runs.
- Make sure that the light gate is triggered by a counter

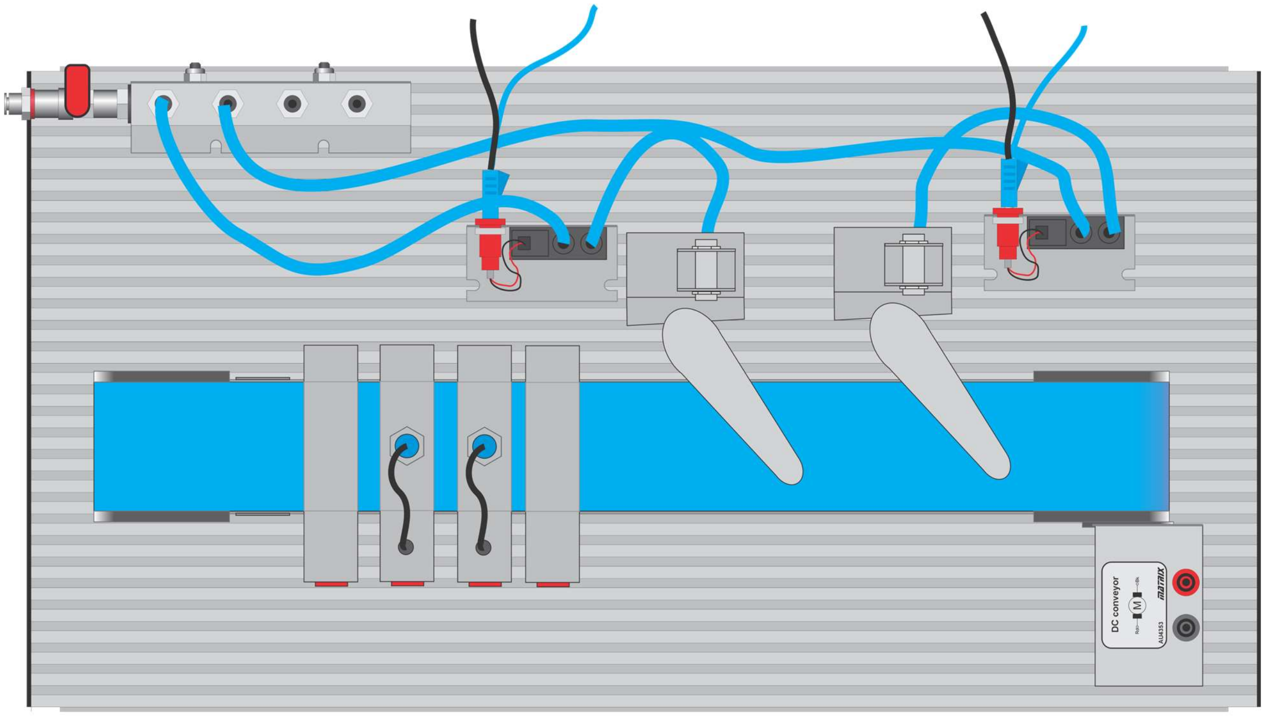
So what?

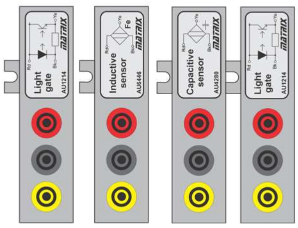
The light gates allow you to detect the presence of a counter reliably. Two light gates allow you to measure the speed of a counter on the conveyor belt. With a little programming you can now predict where a counter is on the conveyor belt once it has been through the sensors. This allows you to effectively programme the rejection mechanisms to direct the counters to the appropriate sorting bins.

Worksheet 1

Understanding sensors

SMART FACTORY





Over to you:

Now that you have understood the function of the different types of sensor you can set them up together on the conveyor properly.

Referring to the diagram above set them up as near to the start of the conveyor as you can in the following order:

1. Light gate
2. Inductive sensor
3. Capacitive sensor
4. Light gate

So what?

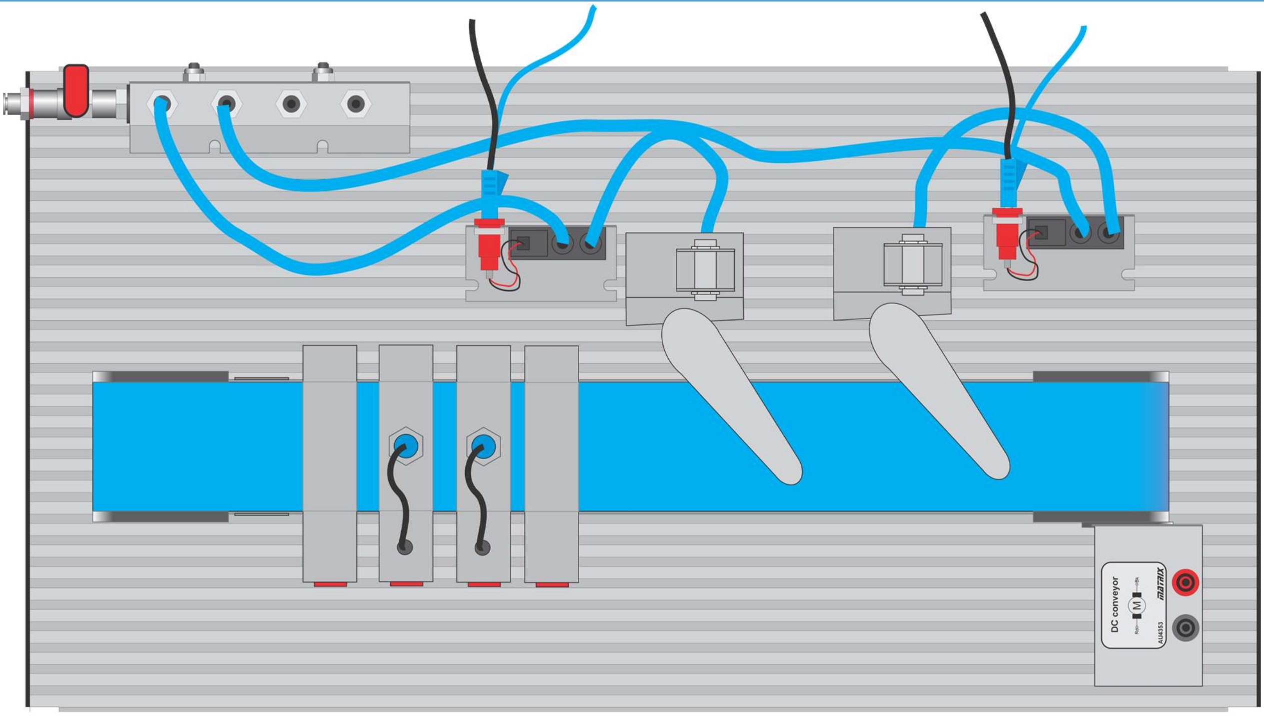
You are now ready to look at the reject mechanisms.

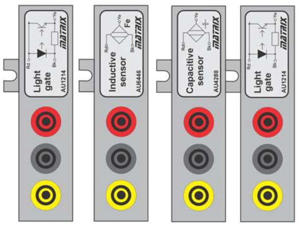
Worksheet 2

Reject mechanisms

Rotating machines provide much of the power needed in automation. However pneumatics are often used because of their longevity, their power, their speed of operation and their ability to provide linear movement. The rejection components on the conveyor are a good example of this.

Photograph shows a part on a conveyor belt.





Over to you:

- Add the reject mechanisms, the pneumatic manifold, and the two 3/2 electronic valves to your system.
- Connect the 3/2 valves in turn to the 24V line and make sure that the reject mechanisms are working satisfactorily with the metal and plastic counters.

Worksheet 3

Understanding the conveyor

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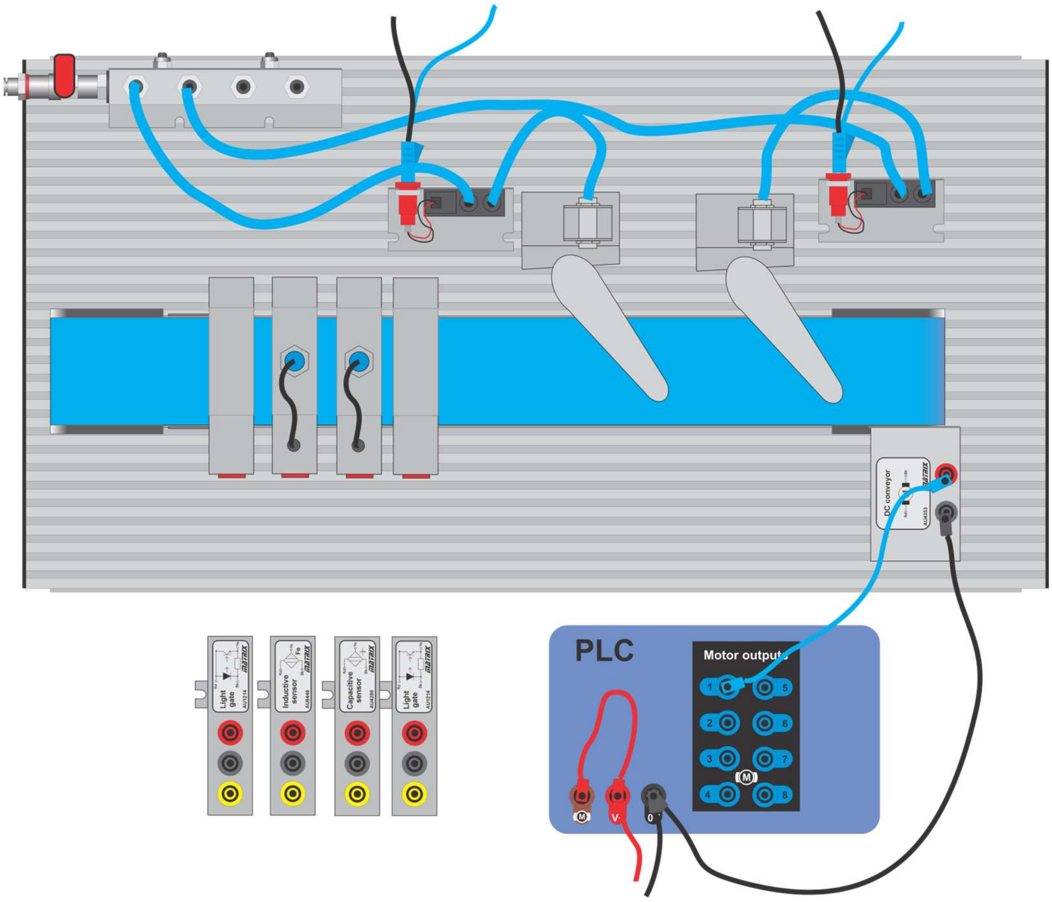
Conveyor belts are at the heart of many production lines moving items from one location to another allowing mass production of items from pills to drinks.

Photograph shows boxes on a system of conveyor belts that move and merge goods in a factory.



Over to you:

- Wire up the conveyor to your PLC or controller. You will need to use a motor output - these are also sometimes called 'transistor' outputs - for the conveyor.
- On some PLCs the supply line for the transistors is a separate input terminal to the PLC. This allows the transistor outputs to switch a different voltage to the PLC power supply if needed. On the diagram this is labelled as 'M' for motor. You need to put 24V into that terminal - as shown above.

Worksheet 3

Understanding the conveyor

- Write a simple program that switches 24V to the conveyor to make sure the conveyor works.
- Vary the mark space output of the transistor output between 10% and 100% in 10% steps and make a note of the sped of the conveyor. To do this you will need to use a ruler to measure the position of a counter and a stopwatch. Make a note of your answers in the table.

PWM %	Speed: m/s
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	

So what?

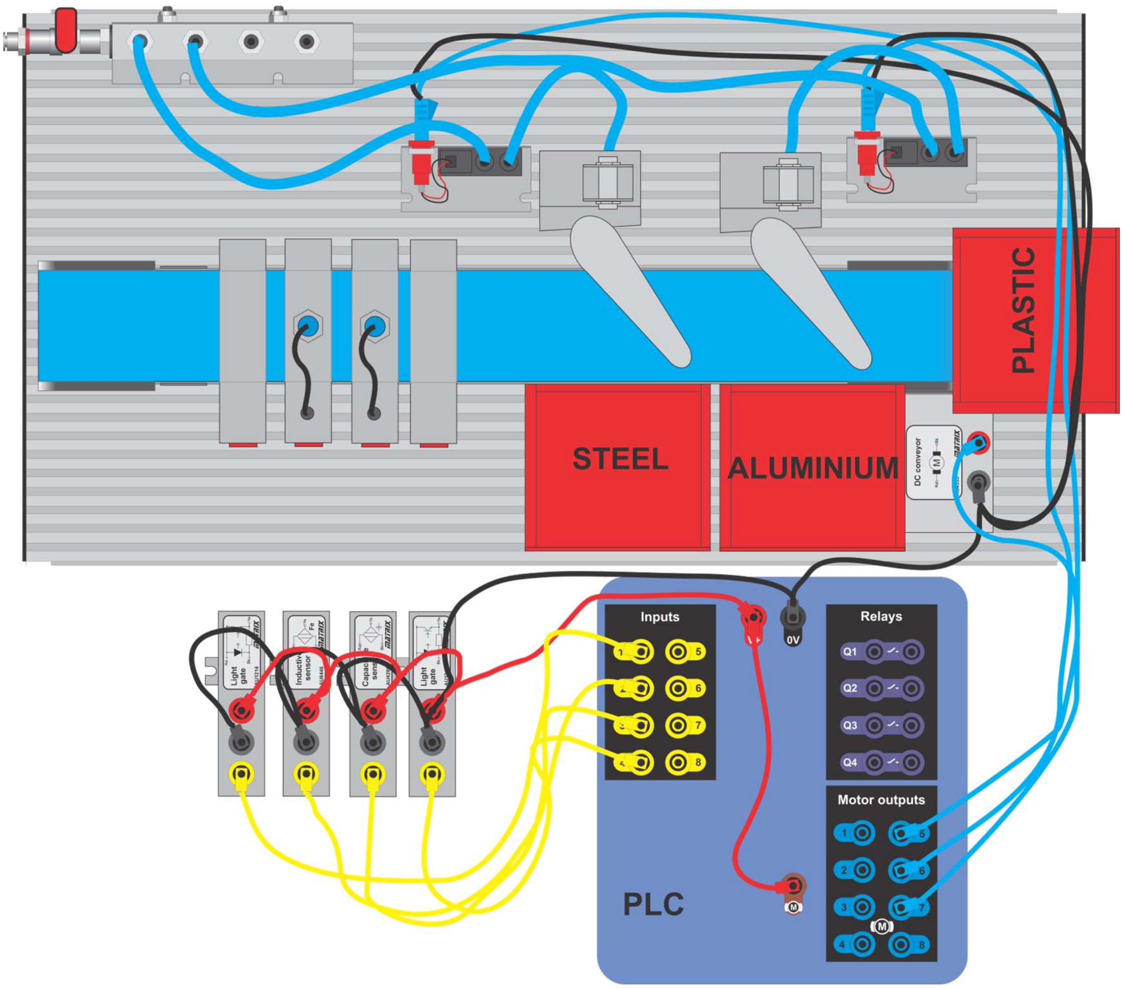
- Understanding the speed of the conveyor will be useful later on when you use the robot arm to move counters on and off the conveyor. If you understand the speed of the conveyor then you can accurately predict the position of a counter after it leaves the beam interrupter.

Worksheet 4

Sorting counters

Sorting components or products is a key part of many automated production lines. The types of component and sensors vary - but the principles are the same: we take in information from sensors and make decisions about what happens to an item on the production line.

Photograph shows a machine that sorts eggs on their



Over to you:

- Build the system you can see in the diagram above.
- The instructions for this task are simple: develop a program on your PLC or controller that can sort the counters into three types: steel, aluminium and plastic.

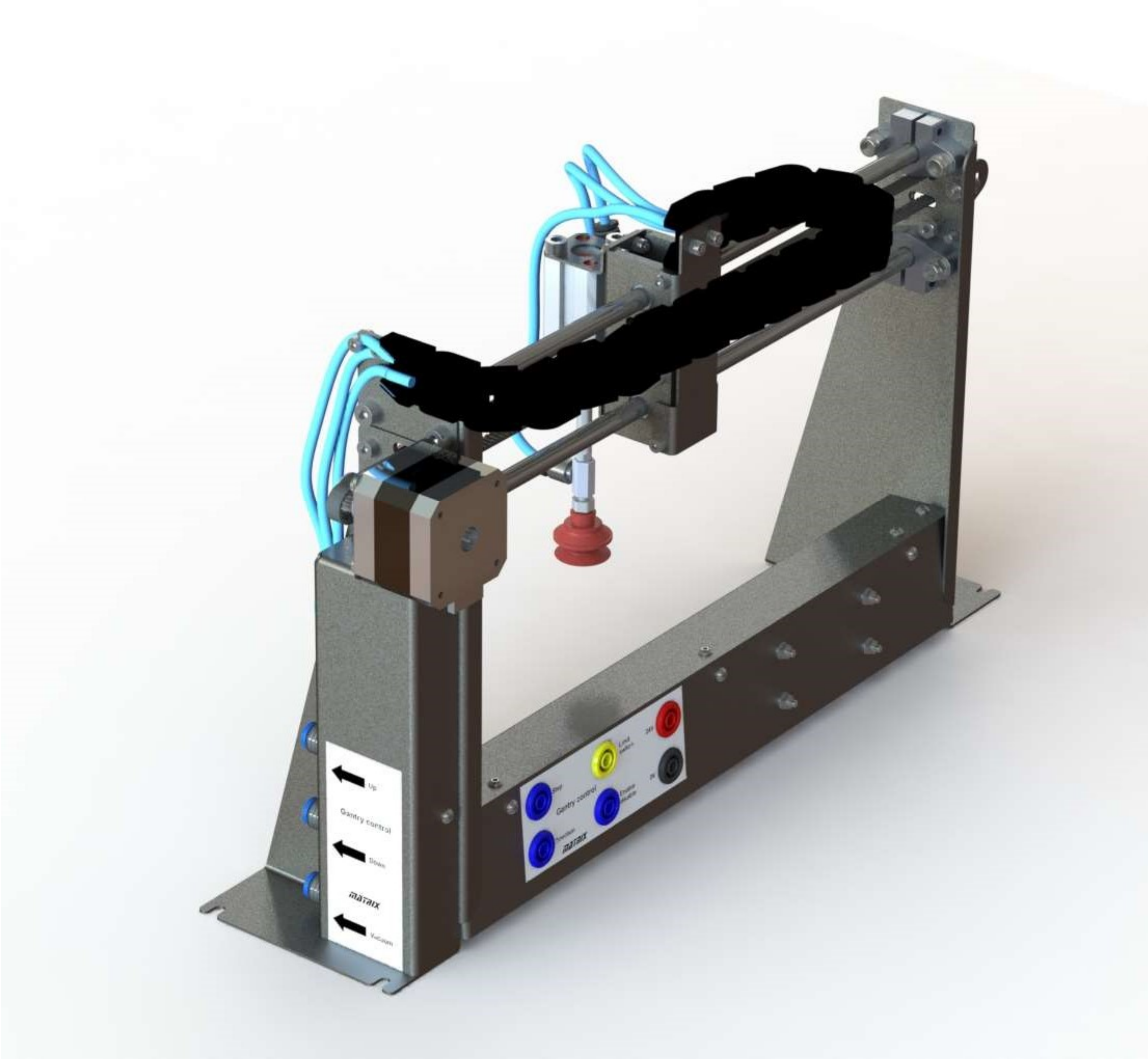
Worksheet 4

Sorting counters

- The Hall sensor detects the presence of steel. The capacitance sensor detects the presence of a metal.
- The beam interrupters detect the presence of a counter.
- You know the speed of the conveyor and can control it. You can detect when a counter is under each sensor. You know how the rejector mechanisms work. Armed with this knowledge you can develop a program that sorts the counters into the appropriate parts.

Gantry Worksheets

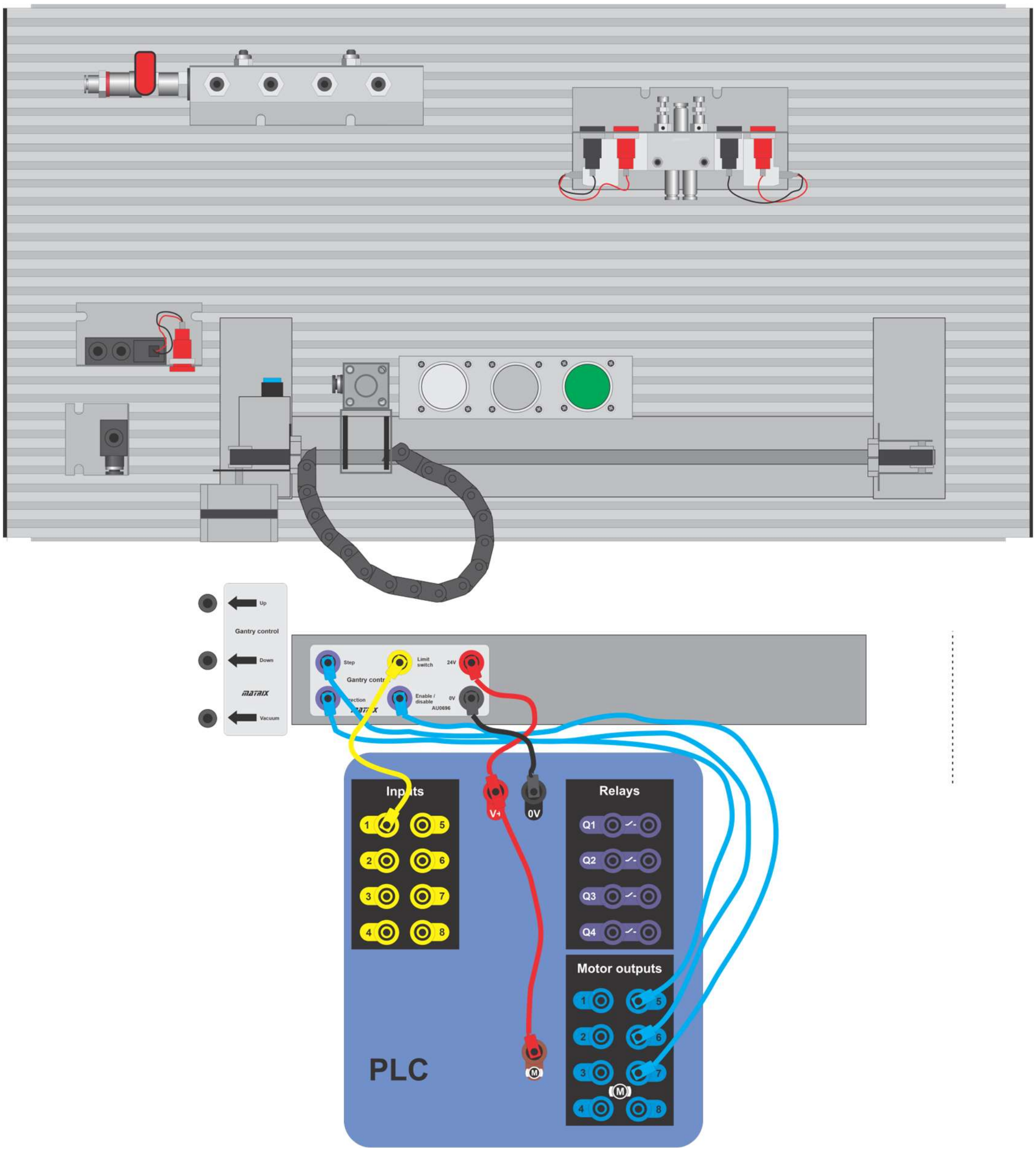
SMART FACTORY



Worksheet 5

Driving the stepper motor.

There are many situations in which we need to know the position of a part of a machine in an automated system. The gantry makes use of a limit switch: when the switch is triggered then the mechanism knows that the actuating mechanism has reached a defined position. If movement from that point can be measured then we always know the position of the actuator.



Worksheet 5

Driving the stepper motor.

SMART FACTORY

- The stepper motor on the gantry has three inputs: direction, step and enable/disable.
- DIRECTION should be 0V to move towards the home position, +24V to move away from home.
- DISABLE is normally 0V (or disconnected) to enable/power the motor, 24V to disable it. Disable can be left disconnected and the system will function. When DISABLE is high then the current is removed from the stepper motor. This makes it easy to move the gantry by hand. When the motor is enabled there are still holding currents in the windings when it is stopped. This is useful to stop the gantry moving due to pressure from the "pipe-work".
- STEP is normally low (0V). Pulse high and back low to step.
- The ‘step size’ for this motor is 1.8 degrees. It will require 8 pulses (micro steps) to make a single step.
- The number of teeth on the stepper cog is 20.
- The pitch of the teeth on the drive belt is 2mm. You can now calculate the distance the gantry mechanism moves for each step and microstep (pulse).

Over to you:

- Wire up the gantry mechanism to your PLC as shown above.
- Develop a program with your PLC that moves the stepper motor forwards and backwards.
- Refine this program so that on power up, or the first movement, the stepper motor moves left to the point where the gantry hits the limit switch and internally marks this as ‘0’.
- Lock the counter holder down on the platform. Create a table that shows the position of each counter storage area.

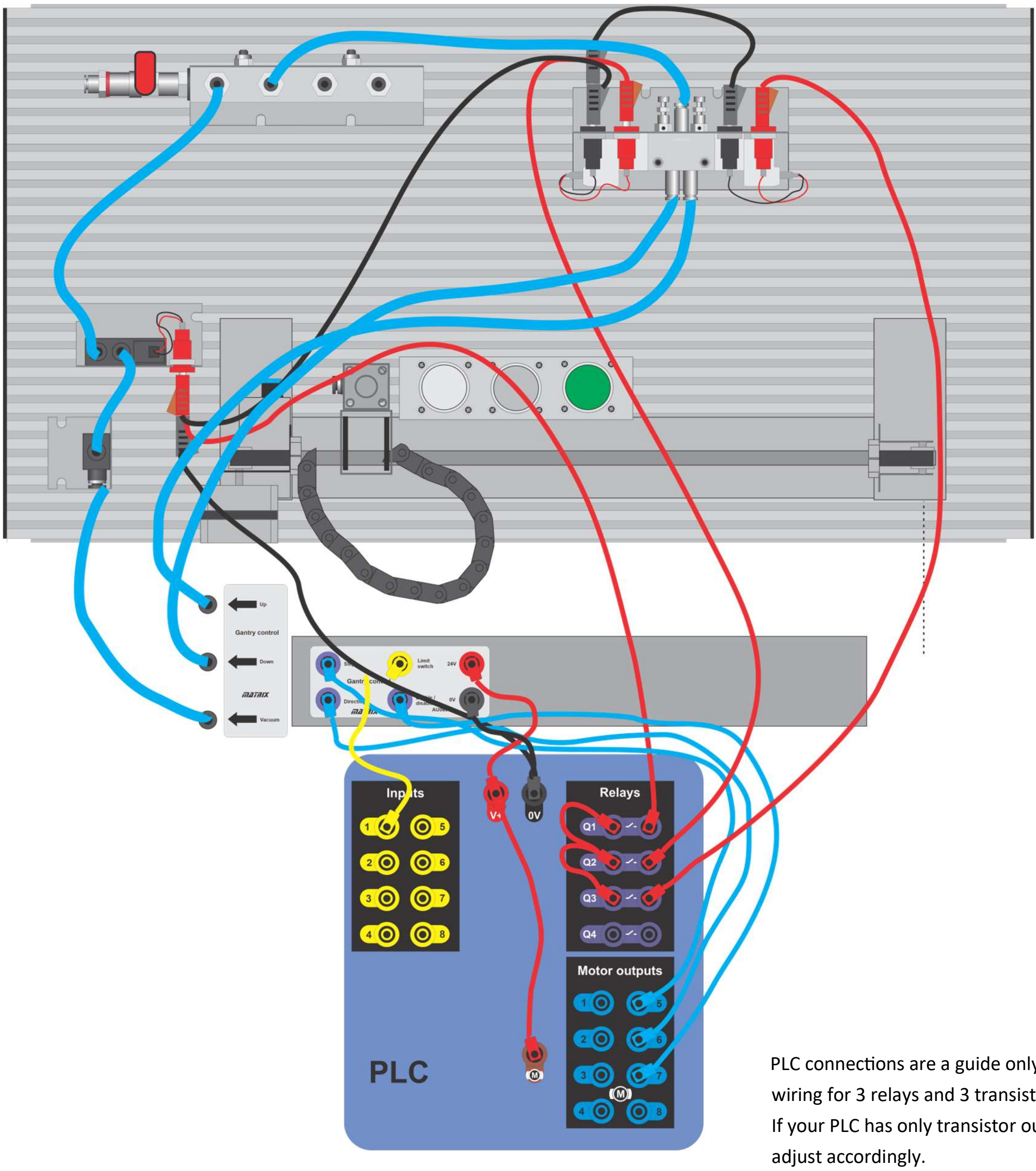
	Column 1	**Column 2**	**Column 3**
mm			
Steps from home			

Worksheet 6

Understanding the plunger

Pneumatic actuators are great tools for picking and placing objects in production lines. Whilst it takes time to get the part setup accurately at the design stage, they will work for millions of cycles in factories before any maintenance is needed.

Photograph shows a suction device in a production cell.



PLC connections are a guide only and show wiring for 3 relays and 3 transistor outputs. If your PLC has only transistor outputs then adjust accordingly.

Worksheet 6

Understanding the plunger

SMART FACTORY

Over to you:

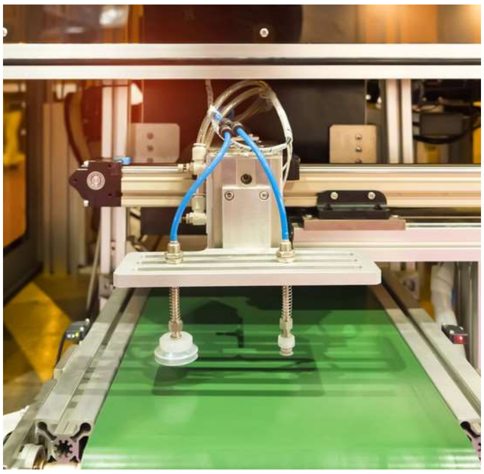
- Wire up the gantry mechanism to your PLC as shown above.
- The plunger is a simple push out, push in mechanism. The 5/2 valve is used to channel the flow of air pressure to first push the plunger piston out and then to push the piston in.
- In the circuit we have shown relays used to switch 24V to the 5/2 valve for the plunger control. If your PLC has spare transistor outputs then you can use those.
- Develop a simple program to make sure that the default position of the plunger is in and make sure you can push the plunger up and down.
- Vacuum for the suction cup on the end of the plunger is generated by a special vacuum unit. This connects to the plunder via a simple solenoid valve.
- Develop a program that allows you to turn the suction on and off.
- You now have control of the stepper motor, the plunger and the suction cup.

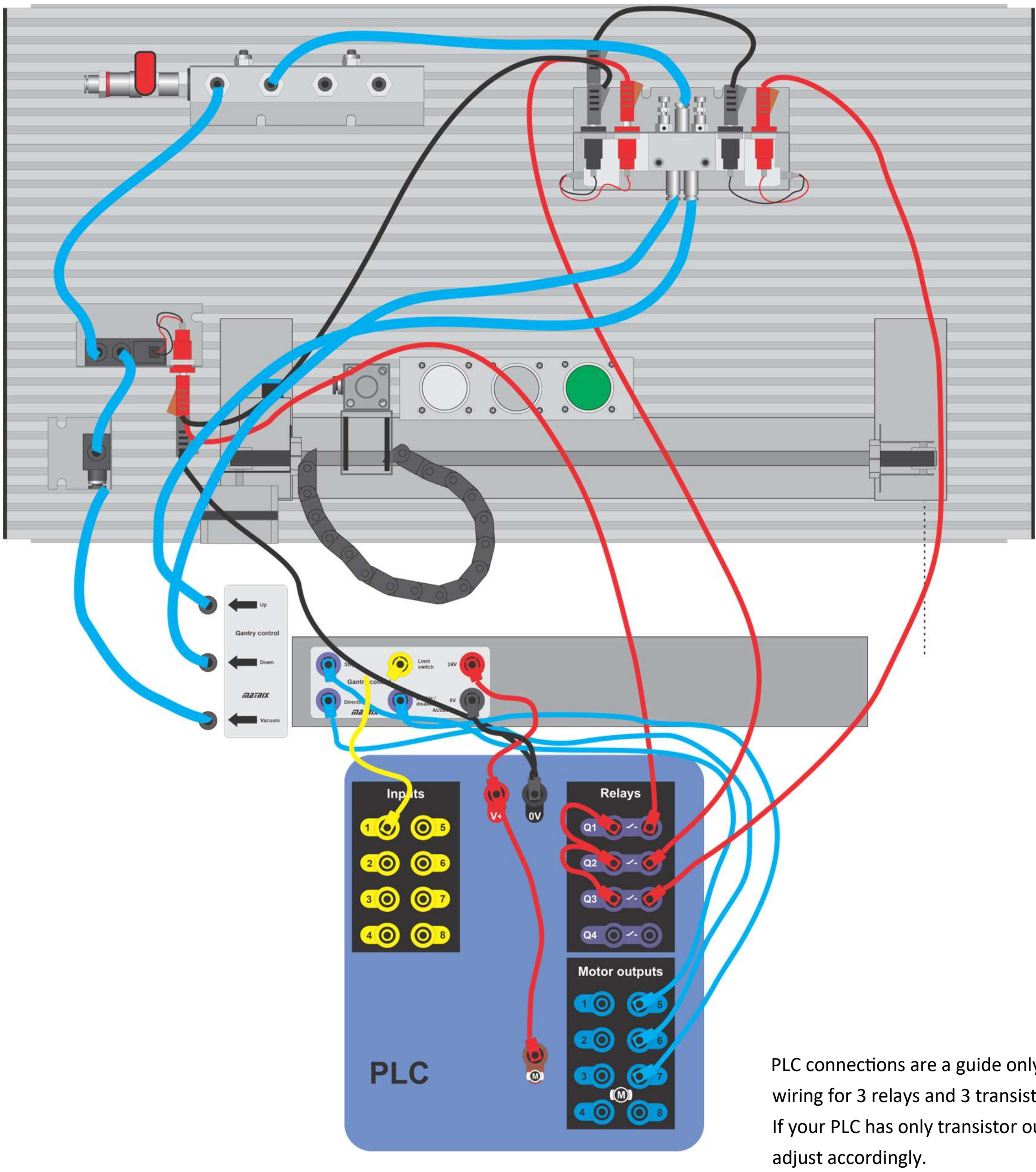
Worksheet 7

Delivering counters

XY gantries with suction devices are often used to move a production part from one operation to another. Now that you have understood the movement of the stepper motors, the plunger, and the suction cup you can put all this together to produce a system that picks up counters from the counter storage unit and places them on the Conveyor.

Photograph shows a suction cup and sensor on a production line.





PLC connections are a guide only and show wiring for 3 relays and 3 transistor outputs. If your PLC has only transistor outputs then adjust accordingly.

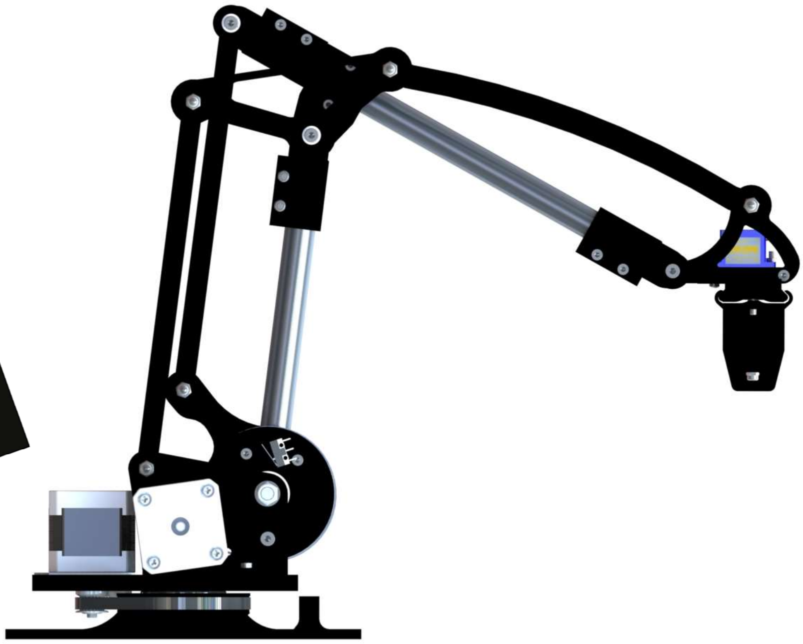
Worksheet 7

Delivering counters

Over to you:

- You are now ready to put the gantry program together.
- Develop a program that can deliver 9 counters - 3 from each storage area - to the 'conveyor belt'. You will have to assume 9 counters are always present as there is no feedback from the plunger mechanism.
- Of course at this stage the gantry is not connected to the conveyor belt so you will simply release the counter at an appropriate point.

Robot Arm Worksheets



Over to you:

- Find the robot arm curriculum pack on our web site.
- Go through worksheets 1, to 3 to make sure you can program the robot arm using the pendant programming tool and G code.
- The G code editor will allow you to detect an input and then start a routine. You can use this to allow the PLC to trigger an action on the robot arm.
- If you want to use the colour sorter then you will need to use a proper programming language and the robot arm Application Programming Interface.
- If you are planning a full Industry 4.0 implementation then you will need to use a programming language that has the ability to create internet based communications such as Flowcode App Developer.

Worksheet 8

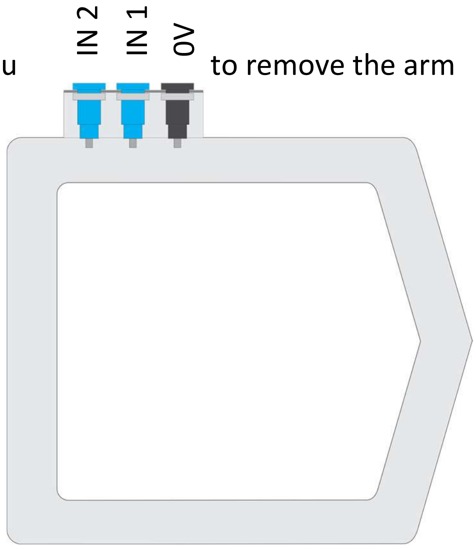
Robot arm I/O

In a robot work cell there will be several programmable robotic modules that need to work together. This can be achieved by sending messages from one module to another, or it can be achieved by a much more simple method of using spare input outputs as ‘flags’ to indicate certain actions can be taken.

Photograph shows a work cell with a robot arm loading a CNC lathe.

Over to you:

A registration plate is supplied with the robot arm. This allows you to remove the arm easily and yet still know exactly where the arm is with respect to the other parts of the Smart factory.



The registration plate contains three 4mm connectors: 0V, INPUT1 and INPUT2. You can use the INPUT1 and INPUT2connections to send messages to the arm: for example when to start a routine to go and pick up a counter and put it in a parts bin. The 4mm connectors are soldered to a wire and connector that plugs into the robot arm circuit board.

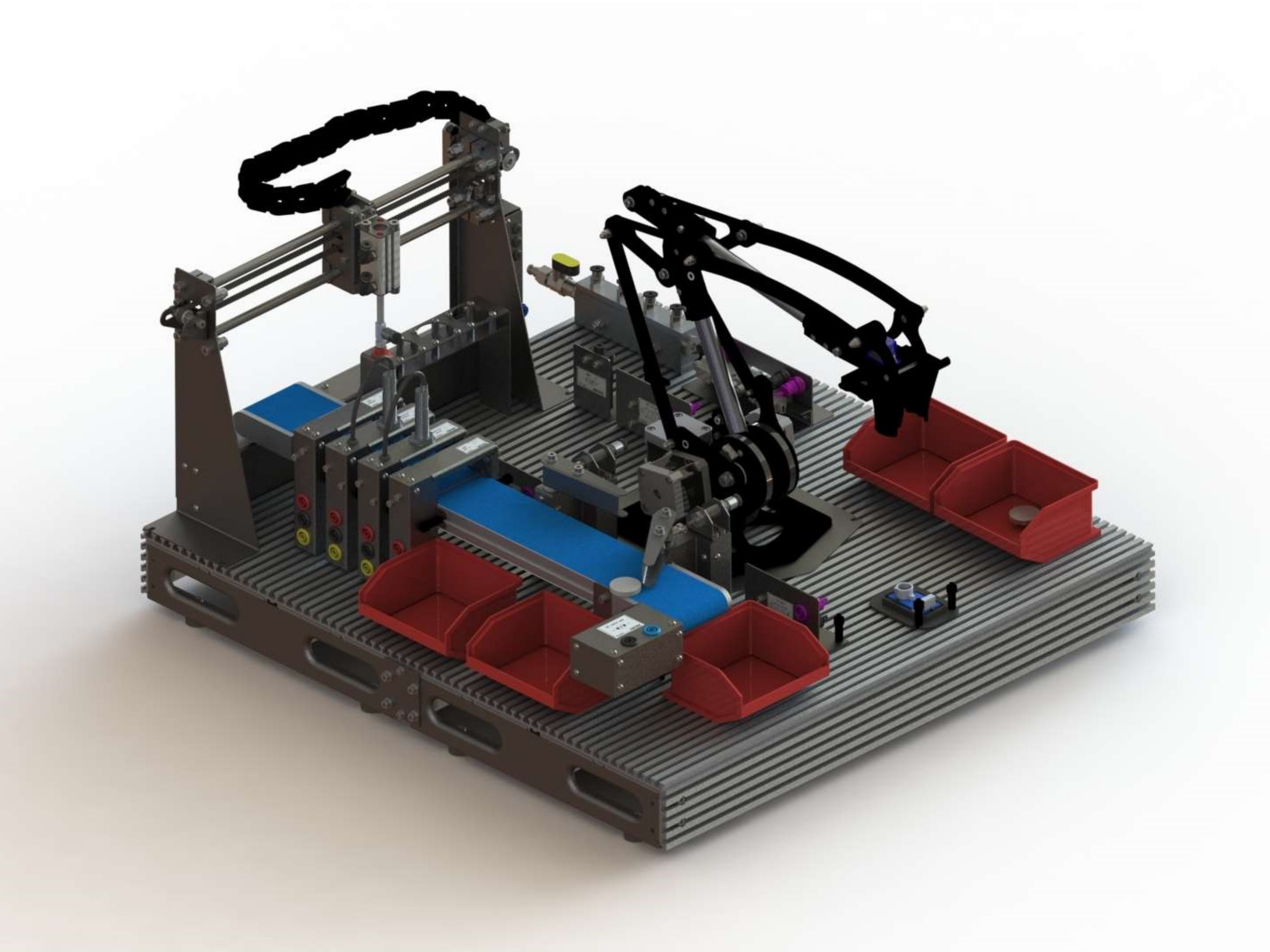
1) Connect the robot arm up to the registration plate using the connector provided.
2) Using the G code editor write some test programs that interface with INPUT1 and INPUT2. For example write a program that waits for INPUT1 or INPUT2to go high and then moves in a different sequence depending on whether INPUT1 or INPUT2 goes high.

So what?

Next you will develop a program that will get the arm to pick up a counter at the end of the conveyor and place it into a bin. The PLC you program will need an extra output which will be used to tell the robot arm what to do using INPUT1 and INPUT2.

Complete smart factory

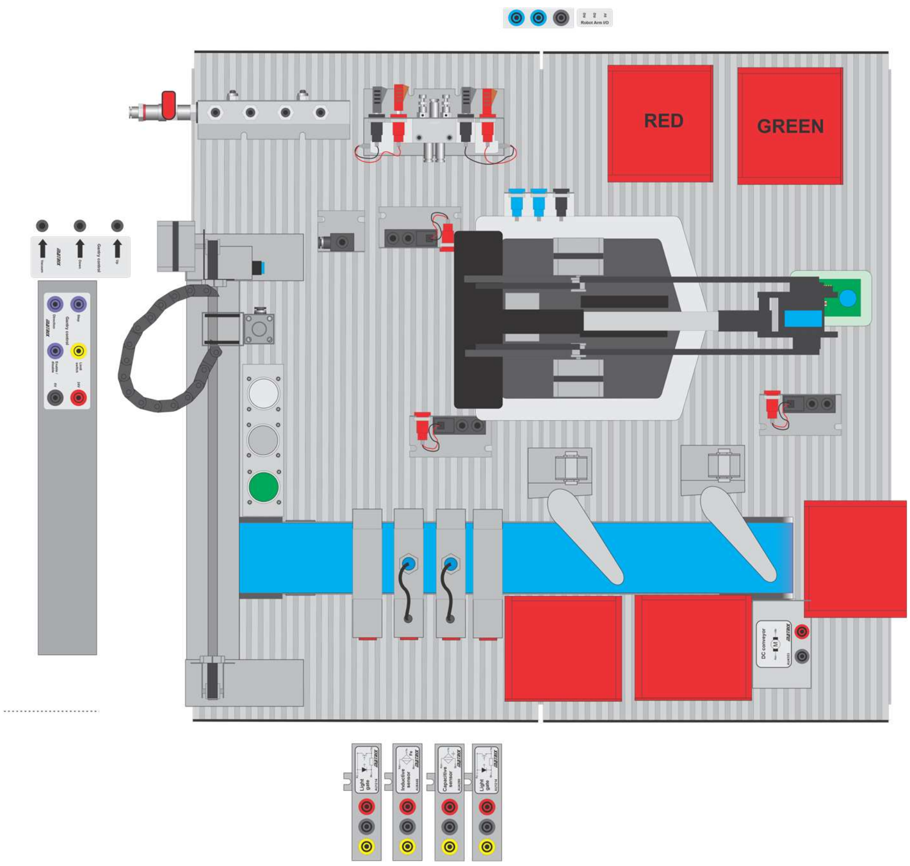
SMART FACTORY



Commissioning the cell

The development of a production line will involve many engineers and many sets of technology. Now that the individual parts of the smart factory have been commissioned individually its time to bring all the parts together.

Photograph shows two robots in a packaging work cell.



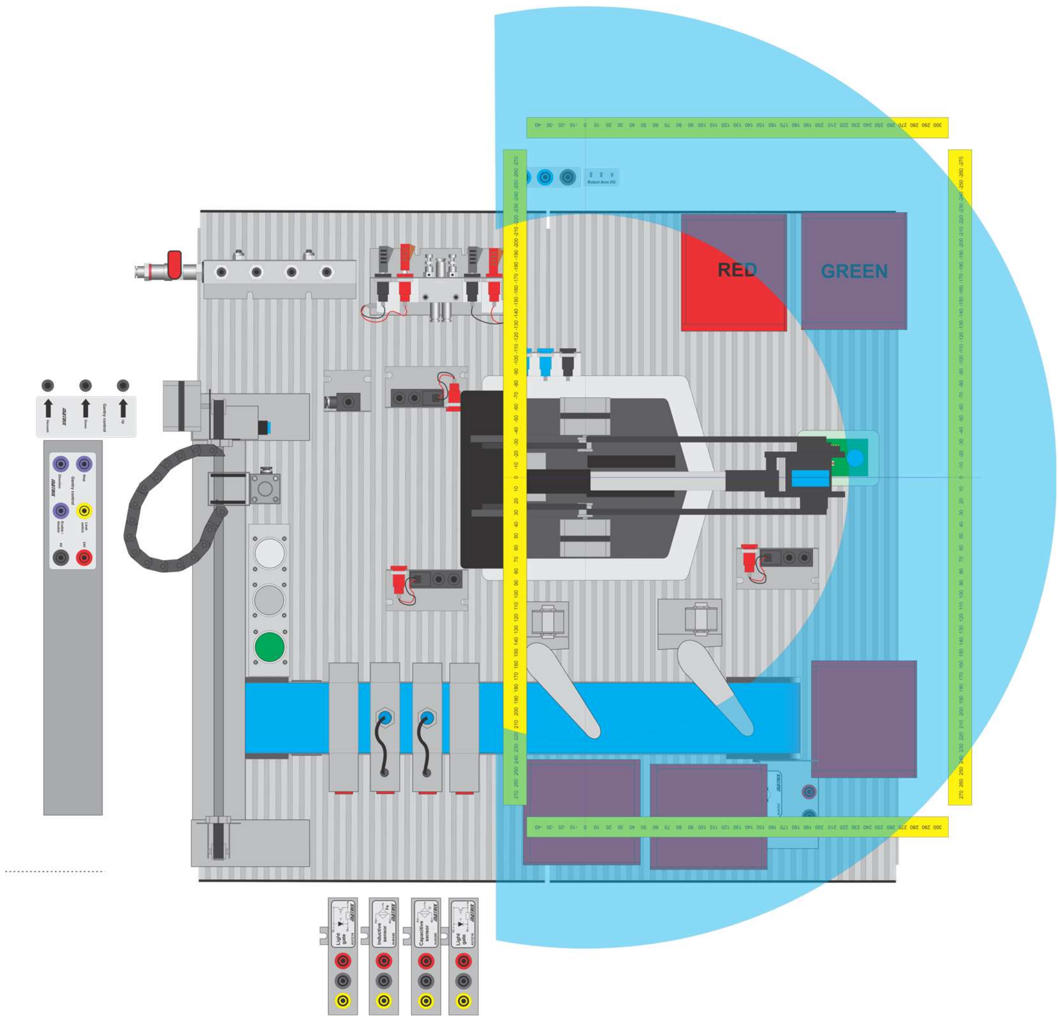
Over to you:

- Bolt the two platforms together.
- Rearrange the Gantry and the Conveyor onto the platforms as shown above.
- Position the robot arm onto the centre of the two platforms. You can use the registration plate to mark the position of the arm so that it can be removed from the system and easily put back in the right place.

Worksheet 9

Commissioning the cell

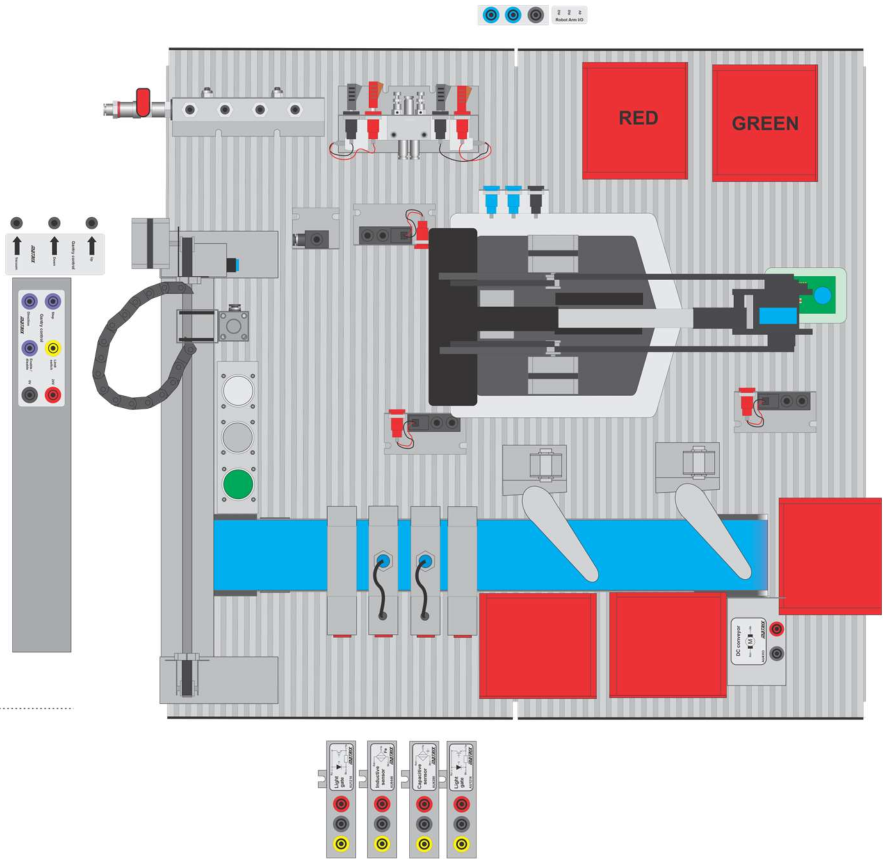
- Gantry: fine tune the program you wrote earlier to deliver 9 counters in succession to the conveyor.
- Gantry and Conveyor: make sure that the Gantry and Conveyor programs work together to delivery and sort 9 counters of varying types. For now there is no communication between the conveyor and the gantry: just use appropriate timing. You can use an extra input and output on your controller to develop communications between the Gantry and the Conveyor.
- Robot arm: Alter the counter sorting program you wrote earlier to pick up a plastic counter from the end of the conveyor, test its colour with the colour sensor, and deposit it into the 'RED' or 'GREEN' bin on the workspace. You can see the workspace plan in the image below. You can do this with the G code editor program. If you want to use the colour sorter to differentiate between colours then you will need to use a more sophisticated programming language (like Flowcode App Developer). To make your programming task easier you will need to develop a measuring system so that you know the locations of the conveyor, colour sensor and bins.



Worksheet 10

Completing the Smart Factory

Many factories now make use of web based control systems. This offers lots of benefits including remote system monitoring, maintenance and even programming - allowing technicians to work on systems without being there. Because IP technology is so widespread the boundaries between building based and world based systems is becoming more indistinguishable.



Over to you:

- You now need to bring all the parts of your Smart Factory together. You can do this locally with a number of PLCs or a single large PLC. Or you can use web based communications to communicate between the three parts of the Smart Factory.
- Frist develop communication between the Gantry and the Conveyor so that when the Gantry has delivered a counter it notifies the Conveyor which can move the counter through the sensors.

Worksheet 10

Completing the Smart Factory

- Next develop your Conveyor program so that when a plastic counter is detected it stops at an appropriate point so that the robot arm can pick up the counter and sort it. You will need to connect an output of your PLC to the IN1 or IN2 input on the robot arm.
- Develop a robot arm program to pick the counter, pass it over the colour sensor and sort it by red/green colour. You will need to initialise this manually as there is no communication between the arm and the other parts of the system.
- The robot arm is fitted with Wi-fi connectivity and has a full Application Programming Interface that allows it to communicate with other LAN/Wi-fi connected products. Develop communications between the arm and the other parts of the system so that the Smart factory works in a fully automatic mode to sort the workpieces.

Teacher’s notes

Introduction

The Smart Factory is a series of practical assignments that students can carry out to learn about and understand the problems that designers of industrial work cells face and how to overcome them. Students have to understand the operation of three distinct modules and bring them together to form a small automation system involving a variety of sensors and actuators.

The three modules are:

- Conveyor system
- Gantry system
- Robot arm system

How this is used in the classroom

A single student could complete all the assignments here. Alternatively this can be run as a group project with 3 students working on individual modules and then coming together to complete the whole task. The tasks are as follows:

Step 1: Pick a variety of workpieces from a storage area using a pick and place gantry. Learning objectives:

- Stepper motor drives
- Limit switches
- Rotational to linear movement with stepper motors
- 3/2 and 5/2 electropneumatic valves
- Vacuum suction systems
- Positional control

Step 2: Use a conveyor system to transport and sort workpieces. Learning objectives:

- DC motor control using Pulse Width Modulation
- Rotational to linear movement with DC drives
- Inductive and capacitive sensors
- Light gates
- Positional control with DC motors using timing
- Reject mechanisms

Step 3: use a robot arm to pick, sort and place workpieces. Learning objectives:

Teacher's notes

- Robot arm workspace and planning
- Robot arm movement
- Pendant and G code programming

If you want to sort workpieces by colour then this work will need to be extended by using the API programming interface.

Timings

The budget times for the activities - assuming a reasonable level of competence - is as follows:

Worksheet 1 - Understanding sensors	1
Worksheet 2 - Reject mechanisms	1
Worksheet 3 - Understanding the conveyor	2
Worksheet 4 - Sorting counters	4
Gantry worksheets	
Worksheet 5 - Driving the stepper motor	2
Worksheet 6 - Understanding the plunger	2
Worksheet 7 - Delivering counters	2
Robotic arm worksheets 1 to 3	**5**
Smart factory	
Worksheet 8 - robot arm I/O	2
Worksheet 9 - commissioning the cell	2
Worksheet 10 - completing the smart factory	4 (not including full handshaking)

So when a single student completes all basic modules it would take around 27 hours. If 3 students are tasked with the problem it would take them around 12 lab hours.

The great advantage of the system is that it can be split into three parts so that all students are really participating in solving the problem.

PLC choice

The system makes use of standard 24V control signals. Nearly all PLCs will be 24V compatible so you have a choice of a wide range of PLCs.

Reference

If 3 students are working on the project you will need up to 3 PLCs for the Conveyor system, the robot arm and the Gantry system.

The robot arm has a full Application Programming Interface in it so that it is compatible with any programming system with an internet connection and the appropriate software. You can use a PLC for this purpose or you can use Matrix Flowcode software which has software components inside it for controlling the robot arm.

The number of PLC inputs and outputs needed is as follows:

	Inputs	Outputs
Conveyor	5	4
Gantry	2	7
Robot Arm	0	0

(Note that this assume that and input and output on each of the Gantry and Conveyor are used for handshaking.)

Using Siemens PLCs

If you don't have a Siemens PLC and want students to work separately on the Conveyor and the Gantry then we suggest you purchase this Siemens PLC:

6ES7212-1AE40-0XB0

If you want a single PLC then we suggest you use this PLC:

6ES7214-1AG40-0XB0

Using Matrix MIACs

Matrix MIAC controllers are ideal for use with the Smart Factory and are Flowcode compatible with Wi-fi built in. The system can be admirably controlled by two dsPIC MIACS product code MI-0007.

Programming language

If you are using an industrial PLC then there will be a choice of programming languages available to you.

<u>Level 1 functionality</u>

Completing the Smart factory to a point where the gantry and conveyor function properly can be done in around 12 hours of lab time. At this point the Gantry will communicate with the Conveyor to notify it of when a counter is on the conveyor and ready, the robot arm will be able to take a plastic workpiece from the end of the conveyor and sort it by colour. However there will be no communication between the Gantry/Conveyor and the robot arm.

Reference

If you are using Matrix MIAC controllers then we would recommend that you use Flowcode. Flowcode is supplied with all necessary software libraries to drive the Conveyor DC motor, the gantry stepper motor and the robot arm.

Level 2 functionality and Industry 4.0

The three parts of the system can be made to work to level 1 with any PLC for the Gantry and conveyor and the Pendant programming software (which uses G code) supplied with the robot arm. At this point there will be no communication between the Conveyor and the Robot arm to notify the arm when a plastic workpiece is ready. Modifying the program slightly and using IN 1 and IN2 of the robot arm will allow the PLC and arm to communicate so that the arm can e integrated with the rest of the Smart Factory.

The robot arm is fitted with a Wi-fi module and a full Application Programming Interface. Details of this interface are documented in the Robot Arm manual.

Handshaking between the robot arm and the Gantry / Conveyor will also be possible using Internet based communications between the robot arm and the other modules.

The PLC or programming system you use will need a LAN/ Wi-fi connection and the robot arm programming language you use will need to have the capability to issue internet based API calls.

Matrix PLC adaptors

Matrix makes available a number of adaptors for PLCs to allow them to be used with 4mm 'banana' connectors. We supply two types of adaptors which have slightly different numbering conventions and slightly different connection systems. The adaptors have a number of screw terminals which connect to the 4mm connectors differently. The tables below show you the connections so that you can decide which are best for you.

HP6711 Power module

General controllers - including Matrix MIAC

Part	Description	Numbering	Screw Terminals	Comments
HP6700	Input Module	1-8	I1, I2, I3, I4, I5, I6, I7, I8	
HP6723	Motor Module	A, B, C, D	A, G, B, G, C, G, D, G	G = common

Reference

Other controllers

Part	Description	Numbering	Screw Terminals	Comments
HP8042	Input Module	0-7	I0, I1, I2, I3, I4, I5, I6, I7	
HP7035	Motor Module	0-7	Q0, Q1, Q2, Q3, Q4, Q5, Q6, Q7	

These parts are needed for Siemens , Omron and other controllers that start output numbering with 0.

Setting up the inductive sensor

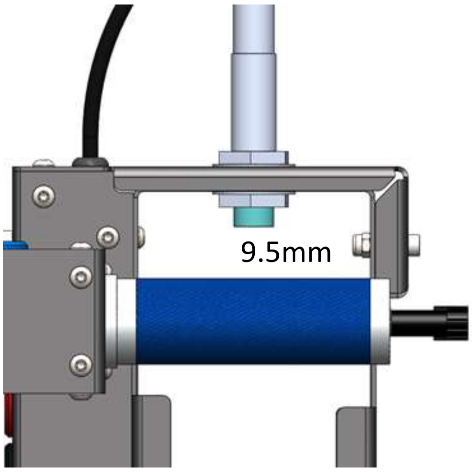
The inductive sensor can detect different types of metal due to the difference in the magnetic field changes between materials.

This sensor has a scaling factor to the distance of detection depending on material.

- Steel – 1
- Stainless steel – approx. 0.8
- Aluminium - approx. 0.45
- Copper – approx. 0.4
- Brass – approx. 0.4

This will vary slightly from one sensor to the other. In our experiments the trigger distance for different types of metals is:

Aluminium:	4mm
Stainless steel	6mm
Mild steel	8mm



Adjusting the height of the sensors

Use the M12 nuts on the top and bottom of the sensor to adjust the height of the sensor. This will move the sensor up and down relative to the conveyor.

Adjust the height of the inductive sensor to the conveyor so that it is roughly '9.5'mm distance away from the conveyor belt.

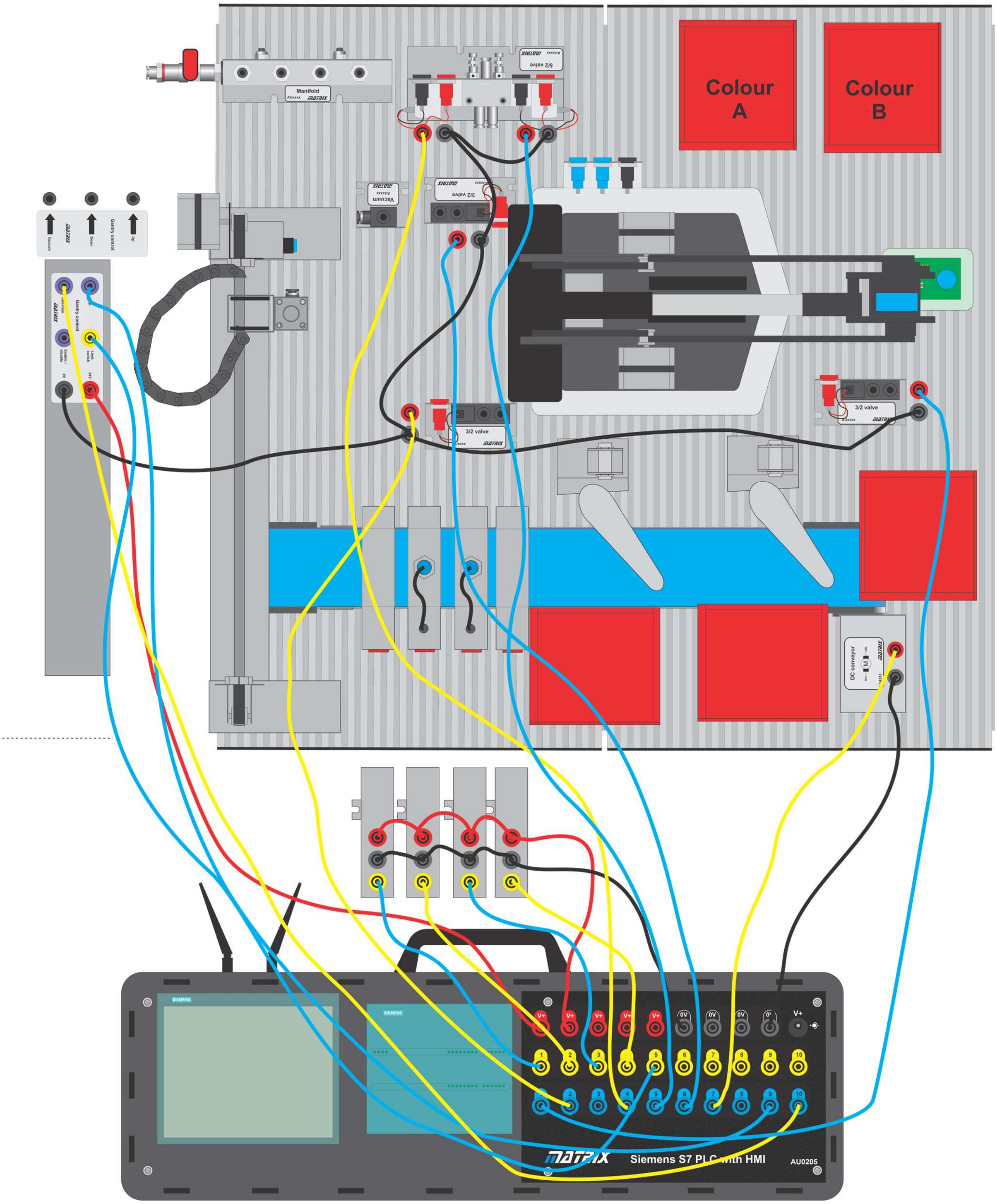
This should mean that when a stainless steel counter passes under the sensor it activates, but when the aluminium counter passes, it does not.

This is due to the scaling factor distance of the two materials.

Setting up the capacitive sensor

The capacitive sensor needs to be around 6mm away from the surface of the counter under test. It should activate when a metal counter is underneath it but not with a plastic one. The capacitive sensor is fitted with a potentiometer for sensitivity adjustment. The distance from the sensor surface to the counter can be adjusted with the M12nut.

Smart factory Siemens S7 wiring diagram



Bill of Materials

Code	Description	Qty
AU9318	Automatics platform	2
AU0696	Gantry mechanism	1
AU4353	DC conveyor	1
AU6004	Manifold	2
AU2834	5/2 Valve	1
AU9633	3/2 valve	3
AU1443	Vacuum generator	1
AU6446	inductive sensor	1
AU4280	Capacitance sensor	1
AU1214	Light gate	2
AU8046	Reject mechanism	2
AU7654	Red plastic bin	4
AU0358	Workpiece holder	1
RB6231-3	Robot arm	1
COM6654	24V DC power supply	2
COM5825	UK 24V PSU adaptor	2
AU3052	Steel counter	4
AU5694	Aluminium counter	4
AU7482	Plastic counter red	5
AU9925	Plastic counter green	5
LK5604	Lead - black 4mm to 4mm unshrouded	10
LK5603	Lead - red 4mm to 4mm unshrouded	12
LK5609	Lead - blue 4mm to 4mm unshrouded	8
LK5607	Lead - yellow 4mm to 4mm unshrouded	8
AU1072	Plastic tubing - blue	1
AU1070	Plastic tubing - red	1
AU1080	Tubing cutter	1
AU1060	Pack 50 T bolts	1
AU5775	Registration plate	1
AU0847	Pneumatic pipe tidy	10
	Control option 1 - MIAC	
MI3494	dsPIC cased MIAC with wi-fi	2
	Control option 2 - PLC generic - numbering from 1	
HP6700	PLC adaptor - inputs	1
HP6723	PLC adaptor - transistor module	2
HP6711	PLC adaptor power module	1
HP6822	PLC bracket for the smart factory	1
	Control option 3 - Siemens etc - numbering from 0	
HP8042	PLC adaptor - inputs	1
HP7035	PLC adaptor - transistor module	2
HP6711	PLC adaptor power module	1
HP6822	PLC bracket for the smart factory	1
	Non UK options	
COM5826	EU 24V PSU adaptor	2
COM5827	US 24V PSU adaptor	2

Version control

SMART FACTORY

26 03 21 first release

08 06 21 changes to sensors

24 06 21 information on PLC adaptors added

28 07 21 Update for robot arm changes

21 09 21 PLC connections table page 21 updated

31 03 22 Updated worksheet 1 a little.

28 07 23 Reformatted to new style

02 10 23 Added Siemens S7 wiring diagram page 31