KATS

By

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Abstract

This Thesis will describe the research, development and construction of Paul Nally's and Eddie Carroll's third year project. This Kit Assembly and Transport System (KATS) project was designed to work autonomously and with a second Automated Storage and Retrieval System (ASRS) project.

This project was accomplished by creating communication links between the ASRS Mitsubishi PLC and the KATS Modicon PLC. The Modicon PLC also had to communicate with the Mitsubishi RV-M1 robot and the Omron invertor.

Acknowledgements

We would like to extend our deepest gratitude to the following persons,

Mr Tom Bennett

For his support and guidance as a project supervisor and for his clear direction in helping us understand the fundamentals in fulfilling the objectives of this project.

Mr Christy Hopkins,

Mr Tommy Digan

Mr Joe Coyne

For providing us with the necessary equipment and materials required for this project.

Mr Padraig Cooke

For his assistance in matters relating to the PLC and robotic commands.

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1. Introduction

In completing this project we aim to have a fully operational system that will assemble a pre ordered kit from parts storage, upon assembling the kit it will deliver the kit via a transport system to a collection station. For the purpose of this project the kit will comprise of various parts that might be required to carry out a maintenance repair on a given machine in a plant. However this type of system could be used in assembling customer orders within an online organization.

- **Kit:** A combination of components required to carry out a preventative maintenance routine.
- **Assemble:** To compile the required components specific to each kit in a delivery vessel.
- **Vessel:** Mechanism used to contain and deliver kit components.
- **Delivery:** Each assembled kit will be delivered to a collection station.

The working prototype will link in with a project being developed by Rory Ryan, Pat McGuinness and Patrick Fallon to form an entire "goods to person/ ASRS".

The idea for this project developed from looking at a project by Brendan Smyth and Neville Pingo whom graduated in 2013. Their project included the development and construction of an Automated Storage and Retrieval System (AS/RS) capable of storing and retrieving items from a defined storage point. Our thoughts were to build on the ASRS and have an incoming delivery system of pre-assembled kits that could be used in a preventative maintenance department.

The project will include the initial development of an overall project plan and will include a Gantt chart for the entirety of the project. The plan will include different phases at which the project should pass through. These will include:

1. Research / Literature review
2. Design
3. Implementation
4. Testing/Debugging
5. Conclusion

1.1 Collaboration

Although this project will work autonomously it will, at the final stages, merge with the project being developed by Rory Ryan, Patrick Fallon and Pat McGuinness. This will include discussions on the design of each project both on a mechanical and on a communication level so as to ease the merging of both projects at the final stages and also to help create an overall efficient system.

1.2 Objectives

The objectives here are to research what types of systems are in place in industry at the moment and what is state of the art. Design will be one of the major objectives within this project; we need to be sure that our working model is fit for purpose and carries out the task set out in the initial specifications.

1.3 Learning Outcomes

The learning outcomes relate directly to the outcomes outlaid in the course manual

1. Develop experience in reviewing technical information
2. Compile a literature review
3. Appreciate the current best practice in relation to referencing material
4. Develop problem solving skills
5. Evaluate alternatives pertaining to engineering projects
6. Compile effective audio-visual presentations
7. Communicate technical information.
8. Develop technical writing and communicating skills
9. Work effectively in team

As it is shown above, there are nine points of learning that must be co-operated into this third year mechatronics project.

From the early research stage to the design stage there will be a lot of technical information obtained and this information must be reviewed intelligently to make the best decisions for our project, so that the project will function to the highest capabilities.

The project thesis must have an extensive literature review of all the state of the art kit assembly and transports systems. This information will lead the design of the project down the most effective path.

There will be a lot of information gathered from other people's work and experiences. This vital information will be referenced and the exact location to where this information was found will be noted.

When the project reaches the building stage, we envisaged a lot of problems within the programming of the selected equipment in our project and the ASRS group. Problem solving will be a required skill needed in this critical period.

In the initial and research stage of this project we will be looking at passed third year projects to congregate ideas from. We will also be looking at similar equipment from our local area and bigger projects on the internet.

When the final build is complete there will be a working video presentation to be orchestrated. This video will be broadcast, so others can view it.

After all the research and design that will be done in this project, there should be no issues with communicating any technical information.

With two orals, literature review and a thesis to be presented by the concluding end of the project, our technical and communicating skills should at a higher level than it is presently.

In our project group there are two group members, but as our group are working closely with a different three man group, there is potential for some group meetings to have five different opinions.

It involves the integration of Mechanical, Electrical, and Computer engineering. It also displays the ability to work within a team and also to link in with other teams. This will be very valuable as in the workplace a multi-vendor system can be very common.

1.4 Deliverables

The major deliverable here is to have a working prototype on completion of the project. The working system will assemble and deliver a predefined kit to the pickup station of the ASRS. This kind of system would reduce financial loss by having tighter control on spare parts inventory. It will also deliver the correct parts all of the time, every time. With the ability to order the kit remotely it will reduce man hours used going back and forth to spare parts bins.

1.5 Project Scope

The scope of the project can de directly related to the limits we may find within development.

Some of these may include:

1. Financial limits: There is a minimal budget for the project however there are many parts available to us from within AIT. Further research will shed more light on financial limits which might only be specific to the prototype.
2. Delivery Tote: The tote used on the existing carousel is of size L133 x B105 x H76mm. As this is integrated within the design of the ASRS it must also be integrated into the design of this project. This will supply limits to many aspects of the build and design of the system. One of these limits would be that amount of components that the tote could contain per kit. Although the tote dimensions are limited in this instance using a larger tote could remove the limitation of kit component size.

1.6 Budget/ Resources

The main budget of this project has yet to be decided as no decisions on what hardware or software will be used. Our own time will be the key resource in the project however we must adhere to the Gantt chart and project time line so as not to allow other areas within the project to suffer.

This project will be resourced by the two members Paul Nally, Eddie Carroll and AIT. Initially the workload division has been set out with Paul to research transportation systems and Eddie to research picking systems.

1.7 Measurement/ Evaluation

The main accomplishment of this project would be to have met all our deadlines with a high degree of professional and accurate results. It would be a major success if the end project worked as to the pre-planned stage and if the highest grades were obtained.

1.8 Possible Complications/Challenges

One of the biggest complications in this project is the communication between the ASRS and KATS. The ASRS and KATS will need to have the ability to know what has being ordered and what is being delivered at each station to make the operation run as smoothly as possible. The aim of our project (KATS) will have the capability to work autonomous to the ASRS; it will be able to function regardless of the ASRS working to its original plan.

A challenge that can/ will occur from this project is having two separate groups (ASRS & KATS) dealing with each other and agreeing on suitable communication languages and devices.

1.9 Responsibilities and Coordination

This project has only two members Eddie Carroll and Paul Nally, the work will be carried out as evenly as possible. Initially the research will be divided equally and once the final project design has been delivered the work load will be re-assessed and again divided evenly.

Team leader responsibility will be rotated on a monthly basis so as to give each member experience in project management as well as allowing a fresh set of eyes on the project progression.

1.10 Project Approval

Prior to approval of our project we had to complete the presentation process which was held on site here in AIT. The project was presented to three lecturers from AIT, Padraig Cooke, Tom Bennett and Nigel Flynn whom accepted the project proposal and granted approval after some discussions on clarity. It was found that prior to the presentation Nigel was totally unaware of what the project consisted of and was still a little unsure once the presentation was complete. He posed some questions which were readily answered; these answers gave greater definition to what the project consisted of.

2. Literature Review

2.1 Introduction

The literature review will examine the different types of equipment that could be used in the building of a kit assembly and transport system. It will also evaluate what is "state of the art".

2.2 Robotic Systems

2.2.1 Introduction

When deciding if or what type of robot to implement one must consider cost, quality and whether or not the system can be improved by removing the human element. The robotic can be tailored to the required specifications of the application. Depending on the application one needs to consider many options

- **Payload**
  Picking the correct payload for the specific application can be a large cost saving measure. An area for consideration is; can the robot meet the required spec without overshooting the payload range.
- **Training**
  Does the robot require large amounts of training per user? This can add up to large amounts of down time and increased travel costs.
- **Energy**
  Efficiency must be considered when choosing the correct robot. The efficiency of a given robot could be the deciding fact in whether to automate or not.
- **Controller**
  Compatibility of the controller can be a single point of failure if chosen incorrectly. The future integration possibilities must be included in the decision. Will the robot be integrated with a PLC or a vision system in the future?
- **Manufacturer**
  The reputability of the manufacturer should be researched as many cheaper robotics systems con prove costly in the long term

2.2.2 Gantry

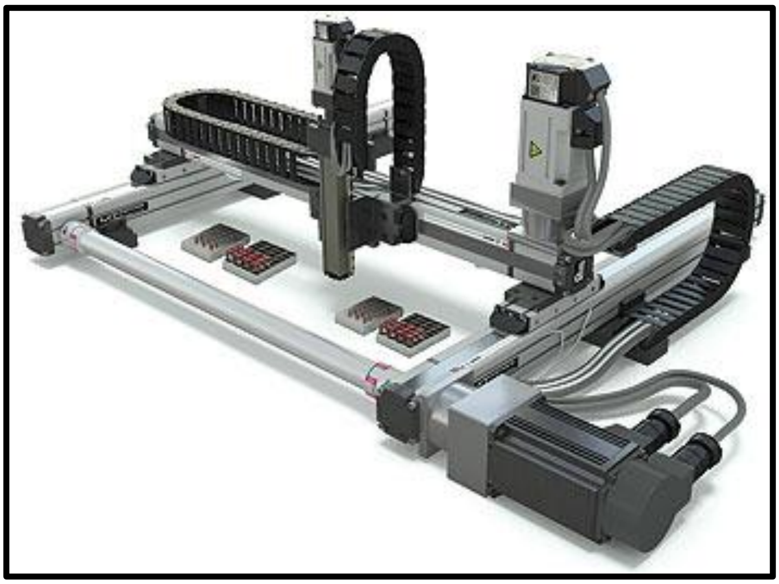


Figure 1 Gantry Robot [i]

The gantry robot, also known as a linear robot is one that operates on three linear axes with each axis at 90 degrees to each other. Although having a very rigid structure, the linear gantry robot tends to require a large working floor to operate. Typical uses for the gantry robot would a CNC machine or in a palletizing system.

2.2.3 Articulated

An articulated robot is one that has one or more rotary joints. The robot or robot arm can consist of sections close to that of the human arm, the axis numbering on the image below highlights the items listed below.[ii]

1. The Base (Waist)
2. The Shoulder
3. The Upper arm
4. The Forearm (Elbow)
5. The Wrist
6. The End effector (Hand)

Although 6, the end effector is not shown it is an integral fixture of the robotic arm and can be tailored to suit

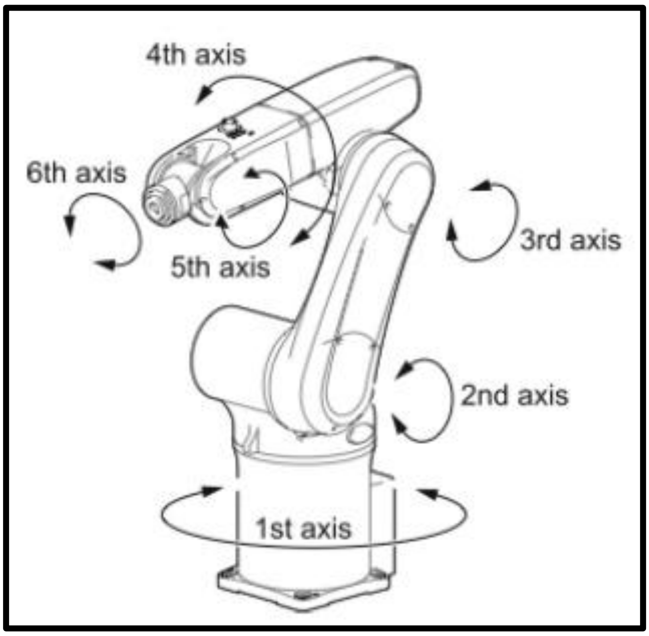


Figure 2 Articulated Robot

the application.

2.2.4 **Scara**

The SCARA robot or Selective Compliance Assembly Robot Arm to give its full title operates within a circular work envelope while having a relatively small footprint. Ideally suited to smaller pay loads and commonly used in a fast paced pick and place environment. [iii]

Figure 3 SCARA Robot

2.2.5 **Delta**

The delta robot, a type of parallel kinematic machine was initially developed in the eighties and was aimed at dealing with the movement of small, lightweight objects in a very high speed manner. Its precision and high speed accuracy has influenced industries such as food packaging and high precision assembly operations to implement the delta robot into their organisation. [iv]

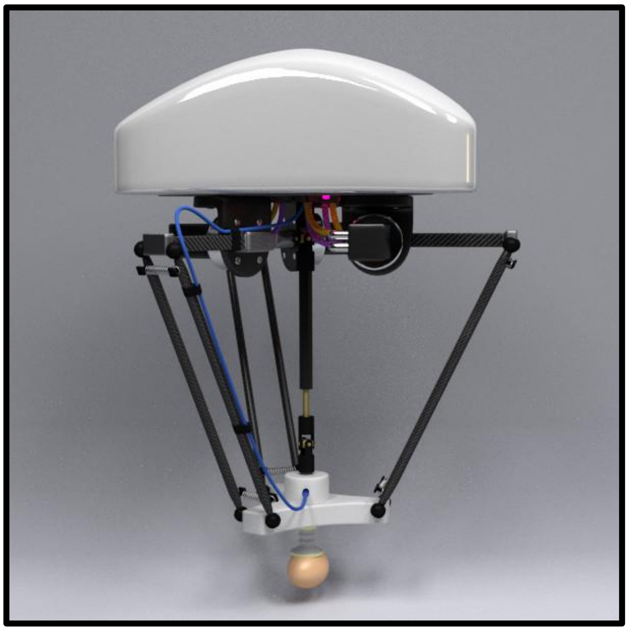


Figure 4 Delta Robot

2.2.6 **End Effectors**

As mentioned earlier the end effector is an integral fixture of the robotic arm and is chosen depending on the application.

Some typical types of end effector would be

- **Gripper**
  The gripper would be used in a pick and place operation where the arm would move to a defined point, close the gripper to pick up object and move to a predefined placement point.

- **Welder**
  A common place for welder to be chosen as an end effector is in automotive assembly. The precise positioning capability of the robot would allow exact welding along specific seem lines every time, all of the time.

- **Cutter** (plasma)
  When precession cutting is required a plasma cutter could be used as an end effector to precisely cut a material along a specified path defined with the robot code.

2.3 Pick and Place

For the project involved, the pick and place system must have the ability to handle three completely different size, shape and weight of objects.

2.3.1 Introduction

When using pick and place technology there are a number of factors that need to be considered

1. The cost
2. The complexity
3. The performance
4. Required accuracy
5. The shape and mass of the lifted objects
6. The distance to carried

2.3.2 Pneumatic

2.3.3 Introduction

Pneumatic pick and place systems can perform linear, swivel and rotary motions. Pneumatic systems use compressed air to control and to transmit energy. Pneumatic energy is safer than other typically used systems.

Although when choosing pneumatic system the initial cost is generally cheaper, this is not the only factor for considering these devices. When comparing pneumatics to electromechanical systems, pneumatics devices, they give a greater force of density, which makes similar devices, to be made smaller and lighter, reducing space needed. The amount of force produced is equal to the applied pressure multiplied by the cross sectional area.

2.3.4 Attributes

The main attributes of pneumatic systems are the high durability, reliability, the simple design, its adaptability to harsh environments, safety concerns and economical concerns.

The limitations of a pneumatic system are relatively low accuracy, cannot drive large loads, irregular motion control and can be relatively noisy.

If the application only has a single fixed path to travel, doesn't have to be repositioned or doesn't have multiple positions to pick and place, then a pneumatic pick and place is the best system to consider.

Range of application

- Effective load up to 6 kg
- Stroke ranges up to 400 mm
- For applications where the gripper unit needs to be retracted from the area of activity.

Figure 5: Typical pneumatic picker [v]

2.3.5 **Hydraulic**

2.3.6 **Introduction**

Hydraulic pick and place systems are very similar to the pneumatic systems. Hydraulic systems can perform linear, swivel and rotary motions. Hydraulic systems use pressurised liquid to control and to transmit energy. This liquid is generally non-viscous oil. The hydraulic actuator can be controlled relatively precisely, due to liquids being nearly incompressible.

2.3.7 **Attributes**

In general hydraulic systems are used to drive larger loads than pneumatic or electromechanical systems. Hydraulic systems are in general more expensive than the pneumatic system.

2.4 Transport

For this project a mechanism is needed to move a tote from the KATS station up to the ASRS station and return it again as efficiently and as quickly as possible.

2.4.1 Introduction

For this section, conveyors systems will be investigated as there are used in most factory settings around the world to move objects from one point to another. This type of system can be very versatile and the least expensive in the modern factory.

This conveyor belt system will deliver a plastic tote to another group (ASRS). When the tote has being placed on the pallet by the KATS robot, the tote will travel to the other (ASRS) group. It will wait here until the tote has being removed from the pallet. Once the tote has being removed, the pallet must return back to the KATS robot to receive another tote.

2.4.2 Slat conveyor

Slat conveyors use spaced slats which do not overlap and are not interlocking. These slats are mounted on chains and are driven by electric motors. The slats can be made from wood or metal. These conveyors are generally used to carry objects that would damage a belt conveyor with shape edges, very heavy loads or materials at very high temperatures. Figure 6 shows a typical slat conveyor that is used in indstry.

Figure 6 Slat Conveyor [vi]

2.4.3 Roller conveyor

Roller conveyors as the name suggests uses various size rollers to transport wood, plastic, metal, pallets, containers, drums, bulky heavy unit loads. They can be used with motors or just simply with gravity. All the rollers can be connected together with chains or pulleys or modular based (they can be sectioned off), which can be helpful for buffering in some applications. These conveyors are simple, rugged, very efficient and highly reliable.

Figure 7 Roller Conveyor [vii]

2.4.4 Overhead conveyor

The overhead conveyor gets its name because of where it is generally found in factories or warehouses. This type of conveying system is quite useful at utilizing unused space; it also allows more space for machines and people to operate in. The overhead conveyor can carry loads that more conventional systems cannot carry due to due their shape. It is also very effective at carrying loads in harsh environment like spray booths, corrosive applications and heating and cooling environments.

Figure 8 Overhead Conveyors [viii]

2.5 Motors

2.5.1 Introduction

For the conveyor system to work to the project spec, it will need a motor that;

a) Is reversible
b) Capable of carrying a maximum load of 1Kg not including belt mass or gear ranges
c) It is essential to be able to work with (controlled by) a Modicon Telemecanique PLC
d) Single phase 230 volts supply or 24 volt supply at conveyor but can be altered to suit

There are a vast variety of motors; motors are constructed for alternating currents, direct currents and special motor types like the stepper or servo motor. For this section, two motors have being selected for further investigation the compound DC motor and the three phase induction motor

2.5.2 Compound DC Motor

The characteristics of a compound motor are that it utilizes the greatest aptitudes of the series and shunt DC motor. This means that one winding is in series and one is parallel with the armature. This winding is in general wound similarly to that of a series wound motor. The field winding is generally limited to restrict no-load speed; if the field windings were too large the motor could run of control when no force is being applied to the rotor.

Figure 9 Typical DC motor

Error! Reference source not found.[ix] and Figure 10[x] Show the dimensions and the physical view of the 24 volt Bosch motor. This motor is a compact and powerful device and comes with a built-in transmission which would make it ideal for the conveyor belt operation. The price of this motor which was valued on E-Bay is €80 plus €10 for delivery, which is within the project budget.

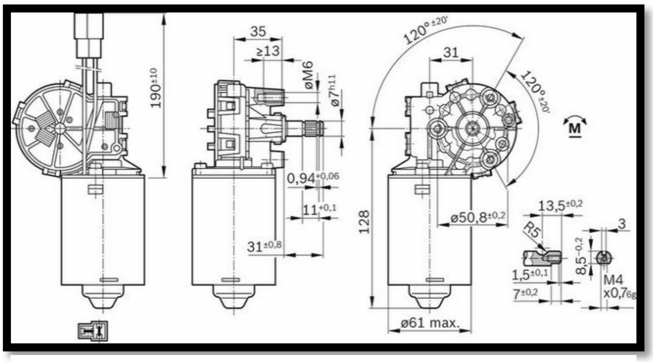


Figure 10 Dc Motor

2.5.3 Induction Motor

The induction motor chosen for review here is a three phase squirrel cage motor as it the most commonly used motor within industry. Single phase induction motors would be more commonly found in appliances throughout the home. The three phase squirrel cage motor has found its place as a stalwart of the industrial environment due to its reliability, cost effectiveness as well as its ruggedness.

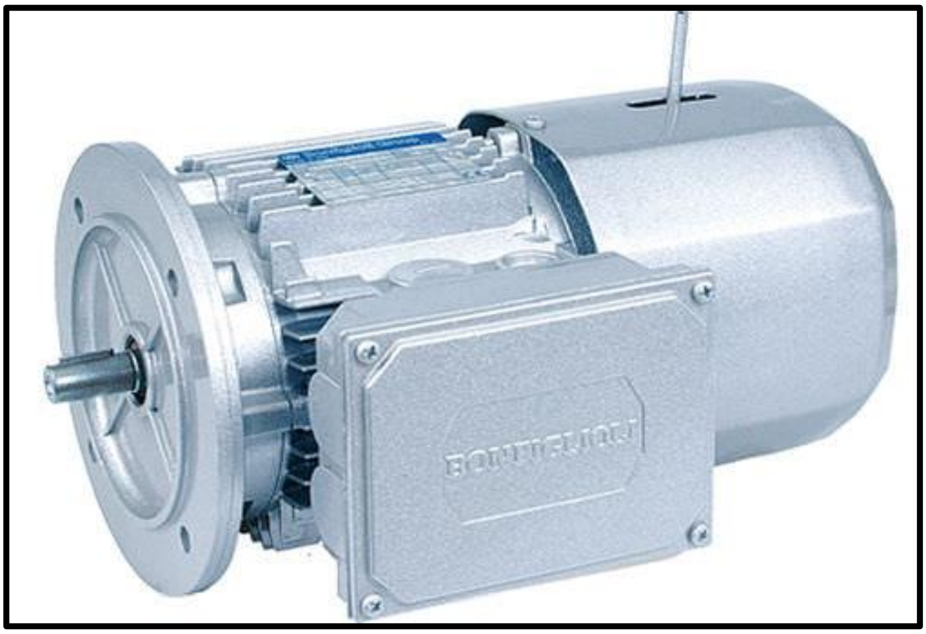


Figure 11 : 3 Phase Induction Motor [xi]

Although the maximum required load to be transported is 1Kg, choosing this motor would allow for future use if the transportable load was to be increased.

As the spec of the project required a motor that could operate at 230v single phase, choosing this motor would require the implementation of an inverter so as to change the mains supply to a three phase supply as there is no three phase supply available.

2.5.4 Inverter

If a three phase motor was chosen to control the conveyor belt an inverter would have to be implemented. Choosing the correct inverter could permit the motor to operate at variable speeds as well as travel in a bidirectional mode. Using an inverter would also allow easy communication between a PLC and the motor.

2.6 Sensors

2.6.1 Introduction

For this project it is envisaged that some type of sensors will be needed while the tote is moving or being moved from station to station. Also there are possibilities that a robotic system, a conveyor system and a hydraulic/ pneumatic system will be used. All these systems will need to identify when and where the tote is, before filling and moving the tote.

2.6.2 Proximity Sensor

Proximity sensors detect the presence of an object without physical contact. These sensors are used to detect metallic and non-metallic objects. A capacitive proximity sensor can detect almost any type of material, while an inductive type will detect metallic materials.

2.6.3 Limit Switch

Limit switches are devices that use physical contact to make or break a circuit. They can be very useful to indicate when a component has reached a certain point.

2.6.4 Reed switch

A reed switch is basically another type of proximity switch that operates on a magnetic basis. The internals of the switch consist of two contact reeds that will close upon the influence of a magnetic field. They are a very robust switch and are useful in high speed switching applications as they have an average switching time of 0.2 ms.

3. Design

This section aims to deliver a detailed description of the overall design of the KATS mechatronics project. It will contain a step by step description of the flow within the project as well as including drawings and early sketches of the project. It will incorporate the devices and components that were studied from the literature review section. It will explain how and why the project was designed the way it was.

3.1 Introduction

Within this project the KATS team has to assemble three different types of kits, each kit had pre-defined components, as shown in Figure 14.When a kit is ordered from the ASRS team, the KATS team would receive a signal to replenish the kit that has being ordered. After this signal has been received by the KATS team, it will go through the stages of assembly to produce the kit that has taken from the ASRS carousel and deliver it to the collection station.

3.2 Overview

The initial design was developed with a very basic 3 stage process in mind, as shown below. The kit was ordered from an external source; the system then compiled the kit and delivered it to a predefined point.

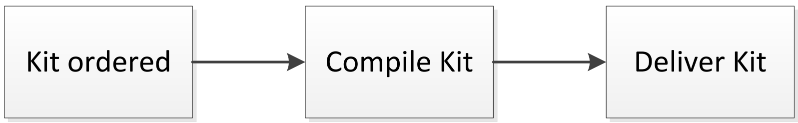


Figure 12 Basic Flow

3.3 Design Flow

Below is a flow chart depicting the flow of the process from start to finish. The initial decision diamond is to decipher which kit is ordered. Whichever kit is ordered, 1, 2 or 3, is the direction of flow. Each branch is colour coded to match the colour of the Kit box identity label that will be used in the process. These colours will be used as an identification method in a separate project.

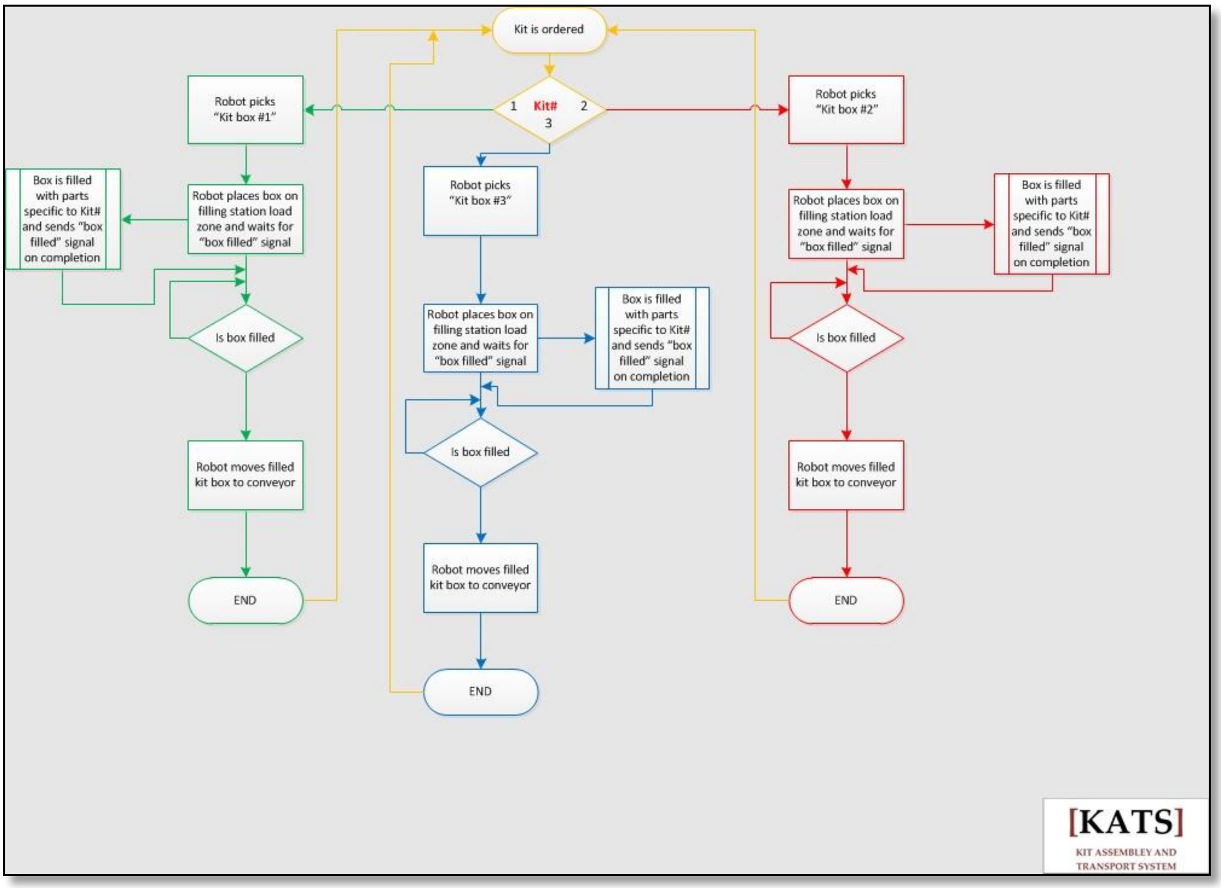


Figure 13 Kit design flow

3.4 Kit Components

Kit Components List	[KATS] KIT ASSEMBLEY AND TRANSPORT SYSTEM		
	Kit 1	Kit 2	Kit 3
Item	Qty.	Qty.	Qty.
Bearing (st01)	1	1	2
Bearing Dowel (st02)	1	2	1
Dowel base (st03)	1	1	1

Figure 14 Kit Components

Bearing

The bearing will be delivered from station 1 (st01) to the loading station by means of an air actuated rotary picker. The rotary picker will place the bearing on a delivery chute which has an exit point located over the loading station. The bearings will be gravity fed to a pick up position by means of a pre-loaded slide.

Figure 15 Bearing

Bearing Dowel

The bearing dowel will delivered from station 2 (st02) to the loading station by means of an air actuated magazine ejection system. The bearing dowel will be ejected from the magazine onto a delivery chute which has an exit point located over the loading station.

Figure 16 Bearing Dowel

Dowel Collar

The dowel collar will be delivered from station 3 (st03) to the loading station by means of an air actuated ejector. Each individual collar will be ejected from a vertical magazine using a linear actuated ejection system.

Figure 17Dowel Collar

3.4.1 Assembled Kits

Below are images representing a fully assembled kit with all its components. Each kit has the components as per Figure 14. These are the final assembled kits that will be delivered to the collection station.

- Kit 1 which is always in the blue tote comprises of one bearing, one dowel and one dowel collar.

Figure 18 Kit 1 Actual

- Kit 2 which is always in the green tote comprises of one bearing, two dowels and one dowel collar.

Figure 19 Kit 2 Actual

- Kit 3 which is always in the red tote comprises of one bearing, two dowels and one dowel collar.

Figure 20 Kit 3 Actual

3.5 Design Drawings

In this section it will illustrate some sketches that it was thought were plausible to achieve the objectives that were set out.

3.5.1 First Project Design

The first drawing displays a double conveyor belt. One conveyor is for the KATS to deliver a tote to the ASRS and the other adjoining conveyor would be used for delivering the tote to the operator from the ASRS. A robot would be mounted on the conveyor system which would give maximum access to the pneumatic actuators and the kit totes. After a kit had being called the robot would select the correct tote type. The robot would move the tote to the three pneumatic actuators to be filled with the three components as to the spec. After the last component was placed into the tote, the robot would transfer the tote to the conveyor and sent it to the ASRS pick up station.

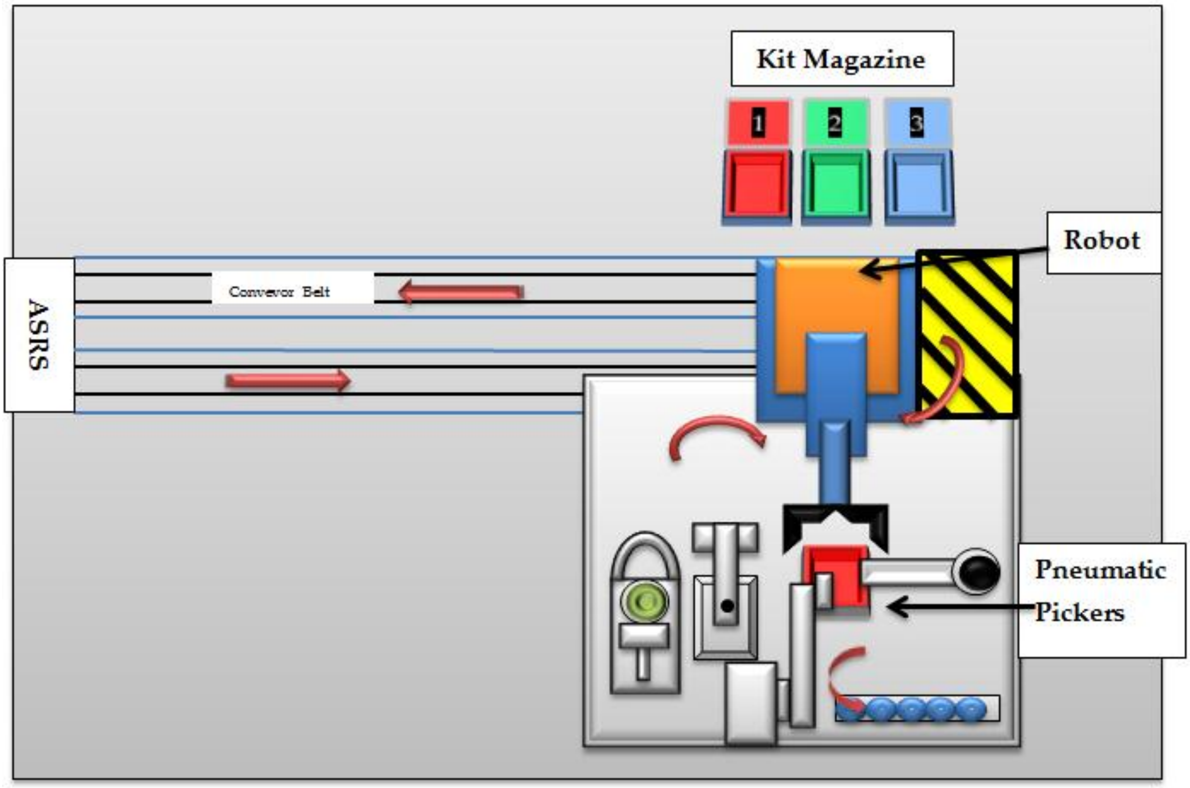


Figure 21 Design mock up #1

3.5.2 Second Project Design

The second drawing illustrates a double conveyor system also. It has a parts conveyor that the components can be dropped or pushed onto. The part conveyor moves them to an awaiting tote. When a kit has being called, the kit "push out actuator" would push a tote on the main conveyor. When the tote would reach the part conveyor the stop block would stop the tote and wait till it had being filled with parts. When the kit was satisfied the stop block would move to allow the tote to continue to the ASRS pick up.

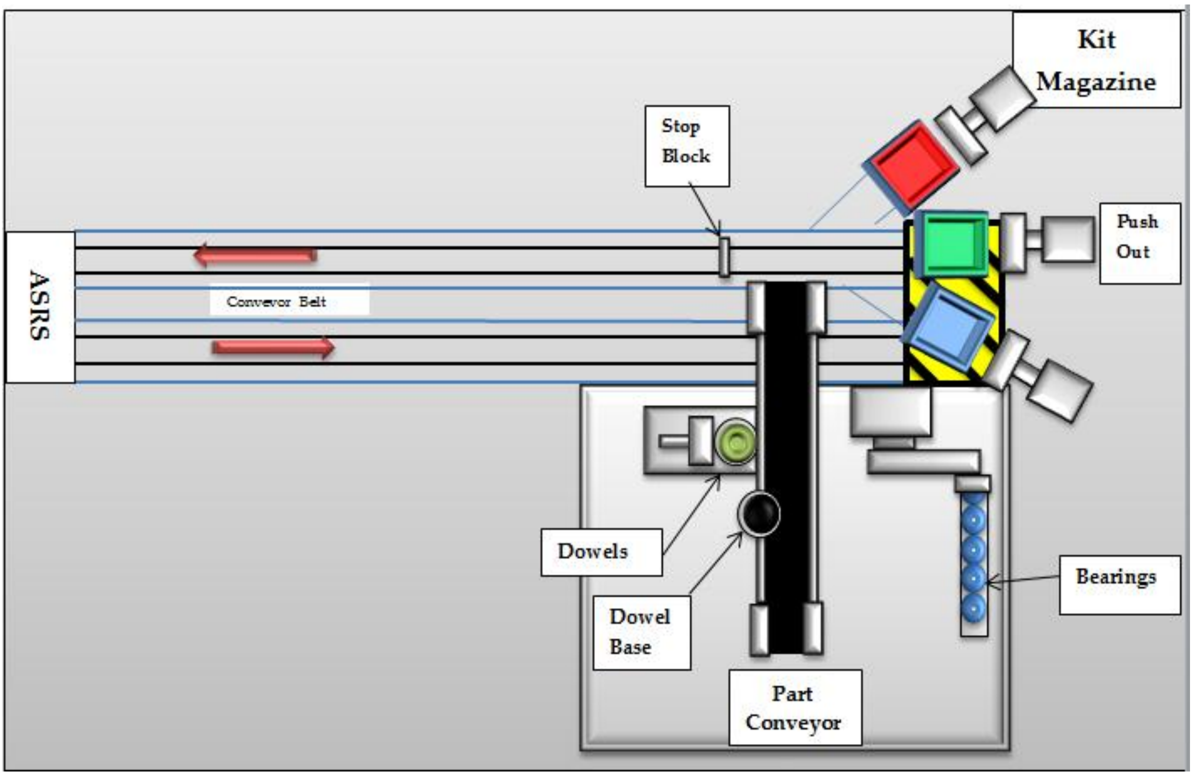


Figure 22 Design Mock up #2

3.5.3 Bearing Slide and Collection Area Design

The bearings were one of the components that were needed to fulfil a kit. A pneumatic rotational arm with a pneumatic picker was going to pick the bearing. A piece of apparatus was designed so that the bearing could sit into it. This device was designed to let the force of gravity to push the bearing towards the collection area. This “slide” could hold up to eight bearings at a time and could be easily reloaded.

The collection area was designed to make sure that the bearing would be in the precise location every time. The bearing would slide into the collection area from its own force, when it reached the collection area, side walls would direct the bearing to the pickup area where the pneumatic arm could drop across it. The pneumatic picker would then squeeze the bearing and lift it onto the tote.

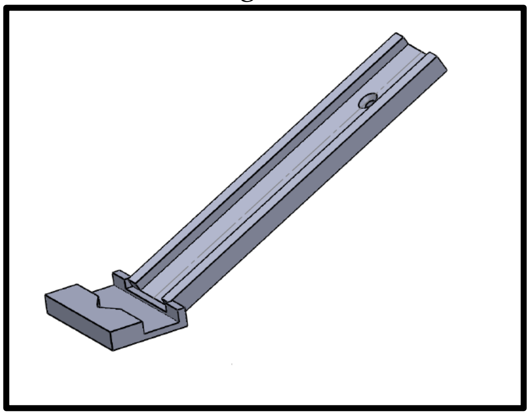


Figure 23 Bearing Slide

3.5.4 **Robot Mandible Design**

The robot mandibles were drafted in solid works using dimensions taken from the tote and the mounting tabs on the end effector. When designing the mandibles the aim was to design an item that would offer maximum grip on the surface of the tote while being made of a relatively light material. Aluminium was the chosen material as it proved to be the lightest available while still being quite durable.

3.5.5 **Tote Vessel Design**

The tote vessel was designed as a device that could deliver a tote within plus or minus 2mm. The ASRS Mitsubishi robot gripper had a very small tolerance and as the tote had to travel on a conveyor, a method for carrying this tote to the precise location every time was needed to be designed. The KATS robot Mitsubishi RV-M1 had a poor accuracy and the design would need to take this into consideration also.

The tote had an irregular surface which made designing a device more difficult. After some deliberations, it was decided to try to utilise the uneven underneath surface of the tote as an advantage. There is a cavity towards the front end of the bottom of the tote. One of the KATS members had used a vacuum forming machine in previous projects in the college and it was thought to be a good device to create the fit that was needed.

The problem with the vacuum forming machine was that a mould is needed to produce to the required shape. The main problem with creating a mould for this project was the time and the preciseness that is needed for accuracy. If the mould was to be moulded from a wooden block, as most moulds are, it would be very challenging to create the shape that was desired. One idea that came about was to use the tote itself as the mould. The greatest problem with this idea was that with vacuum forming the plastic sheet would constrict the tote and it would be too difficult to remove or to insert a tote in the vessel.

The plastic sheet that is used for the vacuum forming was 1mm thick; the four sides of the tote were cut out in sheet. These edges were taped onto the tote which gave a 2mm clearance around the tote.

3.5.6 Project Name Plate

The project name plate was developed from the original KATS logo. The logo file was imported into solid works and a CNC file was created from this. Once the file was created the logo plate was placed in the CNC machine and the logo was etched onto the plate.

Figure 24 KATS name plate

3.5.7 Conveyor System

The conveyor system that was designed for this project was a dual conveyor. This conveyor was located on the college premises. This conveyor system was a perfect fit for this project as it could cater for both groups and was suitably sized for the tote that would be travelling along it. Prior to locating this conveyor system the KATS group had considered a similar type conveyor and had contacted IO Systems in Athlone about older conveyors that they were not using.

After a discussion between the KATS and ASRS group it was found that this conveyor system was perfect for this application as it would take up less floor area than two separate conveyor systems. This system would also save on time in the build phase and would give the overall appearance of the project to be very processional.

3.6 Program sequence

1. Signal received from ASRS by PLC/MOVEMASTER to send specific kit.
2. Send Kit 1
   2.1. Robot picks up Box#1 from storage and moves box to loading station.
   2.2. Loading station receives signal confirming “box in position”.
   2.3. With box in position, items for Kit 1 are loaded into box.
   2.4. Robot receives signal that “filling is complete”.
   2.5. Robot moves box to start station on conveyor, releases box and returns to nest.
   2.6. “Box present lower” sensor on conveyor acknowledges box presence.
   2.7. Conveyor runs upstream after 5 sec delay(to allow robot clearance)
   2.8. Box reaches “box present upper” sensor at unload station
   2.9. “Box present upper” sensor acknowledges box presence and turns off belt
   2.10. System waits for signal from ASRS
3. Send Kit 2
   3.1. Robot picks up Box#2 from storage and moves box to loading station.
   3.2. Loading station receives signal confirming “box in position”.
   3.3. With box in position, items for Kit 2 are loaded into box.
   3.4. Robot receives signal that “filling is complete”.
   3.5. Robot moves box to start station on conveyor, releases box and returns to nest.
   3.6. “Box present lower” sensor on conveyor acknowledges box presence.
   3.7. Conveyor runs upstream after 5 sec delay(to allow robot clearance)
   3.8. Box reaches “box present upper” sensor at unload station
   3.9. “Box present upper” sensor acknowledges box presence and turns off belt
   3.10. System waits for signal from ASRS
4. Send Kit 3
   4.1. Robot picks up Box#3 from storage and moves box to loading station.
   4.2. Loading station receives signal confirming “box in position”.
   4.3. With box in position, items for Kit 3 are loaded into box.
   4.4. Robot receives signal that “filling is complete”.
   4.5. Robot moves box to start station on conveyor, releases box and returns to nest.
   4.6. “Box present lower” sensor on conveyor acknowledges box presence.
   4.7. Conveyor runs upstream after 5 sec delay(to allow robot clearance)
   4.8. Box reaches “box present upper” sensor at unload station
   4.9. “Box present upper” sensor acknowledges box presence and turns off belt

4.10. System waits for signal from ASRS

3.7 Final project design

After a lot of meetings between the two KATS member and discussions with the ASRS group, a final detailed project design was finalised. This finished design was close to the opening ideas that were put forward.

The main idea behind this design was to keep the overall project as neat and compact as it was possible. The room in which the project was going to be located was also used as classroom and the overall system had to fit into the room without over powering the area.

After the research of the different methods of how to pick the parts, it was decided the pneumatic actuator was going to be the best option for this project. Pneumatics actuators were small and tidier and as the room in which the project was to be located had a compressed air line supply, it made the best decision.

To keep the working envelope as compact as possible and as there were three different tote types to be stored in the KATS area, an articulated type robot was thought to deal with the above issues the best. The college had three different types of articulated robots, the ASRS had already decided to use the Mitsubishi RV-3SB and the Mitsubishi RV-2AJ was used for classroom activities. It was decided to use the Mitsubishi RVM1, this robot had a good reach and it could be mounted onto the conveyor belt which would keep the working area compact. The biggest issue with this robot was that it could not store a new program on the EPROM; every time the system had to be started the new program would have to be downloaded onto the RAM, which would be very time consuming.

To mount all the pneumatic equipment, a FMS table was found to have qualities that we were looking for. This table would easily be mounted to the conveyor belt, the PLC and the robot controller would fit under the table giving it tidier appearance.

4. Project Procedure

4.1 Introduction

This section will give a detailed account of the build phase. It will also detail a safety procedure that was adhered to during the build phase. At the initial phase of the project, a project time line was constructed and this will be considered in this section to demonstrate how the project is behaving at the half way stage of the project.

4.2 Gantt chart

The Gantt chart shown below gives a detailed overview of the project phases and timelines. These timelines were constructed at the beginning of the project. The Gantt chart is an invaluable tool that gives a pictorial calculation of how and where the project is at any moment in time. The Gantt chart was up-dated on a weekly basis and this showed if the project was up to data or behind of the pre-arranged dates.

		Task Mode	Task Name	Duration	Start	Finish	Predecessor	Resource Names	% Complete
1			**3rd Year Mechatronics Project**	**170 days**	**Tue 03/09/13**	**Mon 28/04/14**			**99%**
2	✓		Weekly diary	170 days	Tue 03/09/13	Mon 28/04/14			100%
3	✓		Supervisor meetings	33 wks	Tue 03/09/13	Mon 21/04/14			100%
4	✓		**Semster 1**	**59 days**	**Tue 03/09/13**	**Fri 22/11/13**			**100%**
5	✓		**1st phase team and project proposal**	**37 days**	**Tue 03/09/13**	**Wed 23/10/13**			**100%**
6	✓		Team proposal	0 wks	Tue 03/09/13	Mon 14/10/13		Eddie,Paul	100%
7	✓		Project proposal	20 days	Tue 17/09/13	Wed 23/10/13	6	Eddie,Paul	100%
8	✓		Project Team proposal interview	1 day	Tue 03/09/13	Tue 03/09/13		Eddie,Paul	100%
9	✓		**2nd phase research and design**	**29 days**	**Tue 15/10/13**	**Fri 22/11/13**	**5**		**100%**
10	✓		Research	10 days	Tue 15/10/13	Mon 28/10/13	7	Eddie,Paul	100%
11	✓		Project design	19 days	Tue 29/10/13	Fri 22/11/13	10	Eddie,Paul	100%
12	✓		Initial project design, costings and bill of materials	0 days	Mon 04/11/13	Mon 04/11/13		Eddie,Paul	100%
13	✓		Final project design, costings and stategies	0 days	Thu 14/11/13	Thu 14/11/13		Eddie,Paul	100%
14			**semster 2**	**76 days**	**Mon 13/01/14**	**Mon 28/04/14**	**4**	**Eddie,Paul**	**99%**
15	✓		**3rd phase project build and debug**	**47 days**	**Mon 13/01/14**	**Tue 18/03/14**			**100%**
16	✓		Project build	64 days	Mon 25/11/13	Thu 20/02/14	11	Eddie,Paul	100%
17	✓		Debugging	18 days	Fri 21/02/14	Tue 18/03/14	16	Eddie,Paul	100%
18	✓		**4th phase submissions**	**61 days**	**Mon 03/02/14**	**Mon 28/04/14**	**15**	**Eddie,Paul**	**100%**
19	✓		Completed individual student paper	5 days	Mon 03/02/14	Fri 07/02/14		Eddie,Paul	100%
20	✓		Submission of 1st draft team report	5 days	Mon 17/03/14	Fri 21/03/14		Eddie,Paul	100%
21	✓		Submission of project video	5 days	Mon 31/03/14	Fri 04/04/14		Eddie,Paul	100%
22	✓		Submission of final project video	5 days	Mon 07/04/14	Fri 11/04/14	21	Eddie,Paul	100%
23	✓		Completion week	4 days	Wed 23/04/14	Mon 28/04/14		Eddie,Paul	100%

Figure 25 Gantt chart snapshot

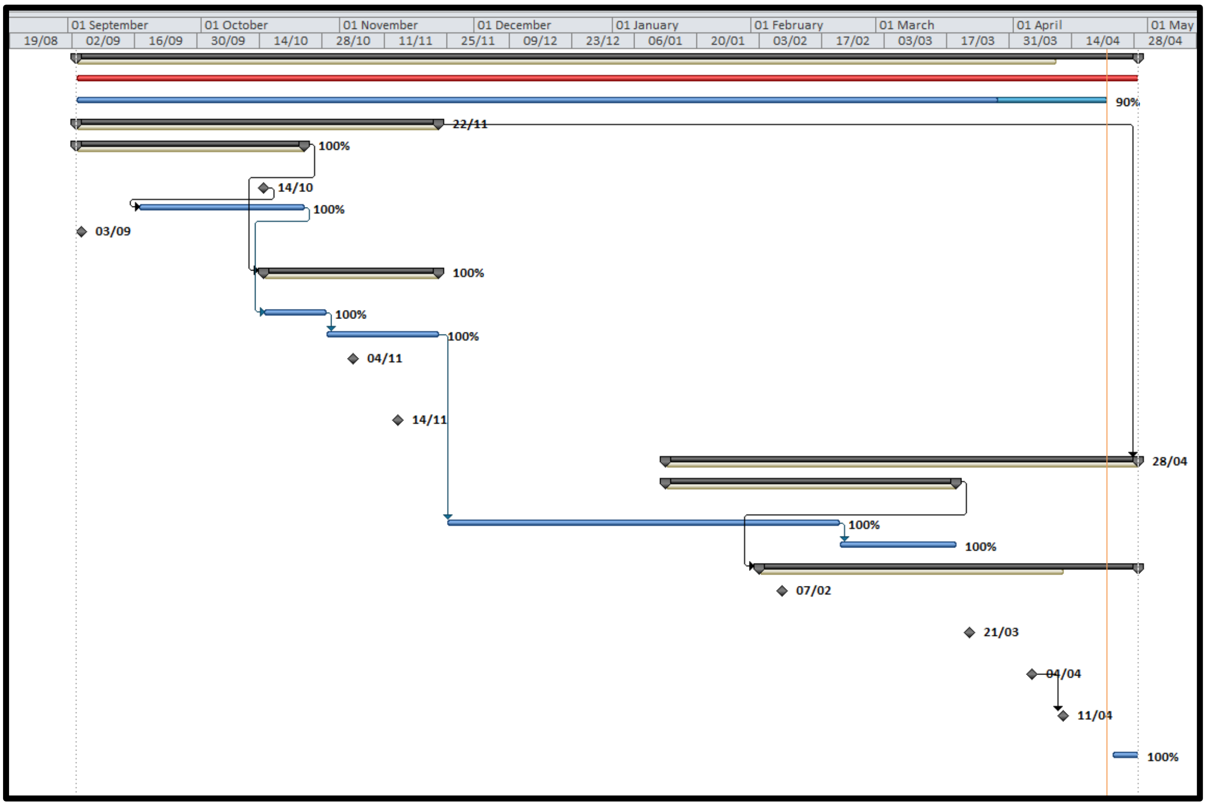


Figure 26 Timeline snapshot

4.3 Risk Assessment

4.3.1 Introduction

This section will outline the risks associated with this project. During the design, build and test phases of this project there will be risks, the document below gives the operators and other people that will be involved in the project area, a detailed assessment of the dangers that could occur.

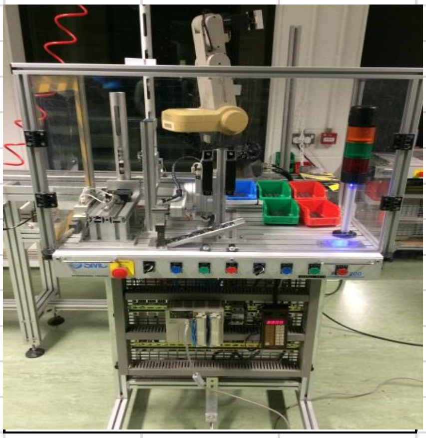
4.3.2 Risk assessment output

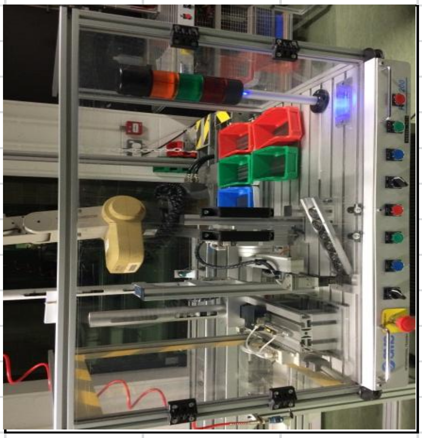
A risk assessment was carried out by Mr Bobby Hewitt who works as a risk assessment officer. Mr Hewitt worked in conjunction with Eddie Carroll and Paul Nally to help to identify all the risks that could be involved in the KATS project. After the risks were identified, the risks were classified from the lowest risk 'slightly harmful' to the highest risk 'intolerable risk'. Upon completion of the risk assessment all the risks and the controls that were associated with the project were deemed to be acceptable "Acc".

4.3.3 Risk assessment photo form

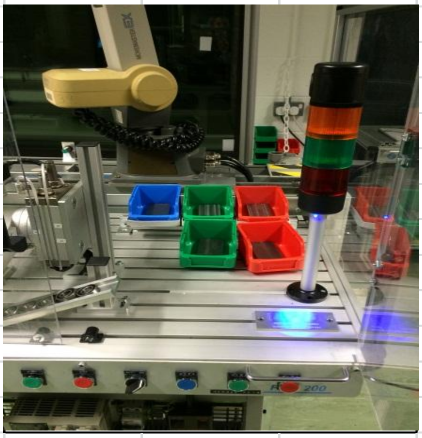
The following section adds a visual to the risks found during the risk assessment. Each risk that was identified has been allocated a risk identifier number which can be found underneath each the photo in the form that follows.

KATS /RA1.01 Ref No.0001

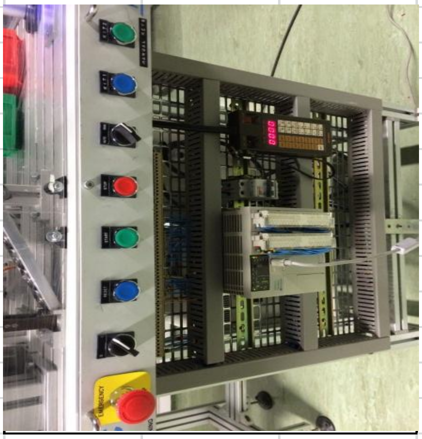


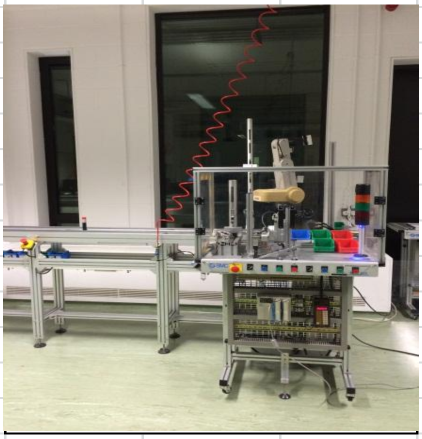


Hazard No	1	Hazard No	2



Hazard No	3	Hazard No	4

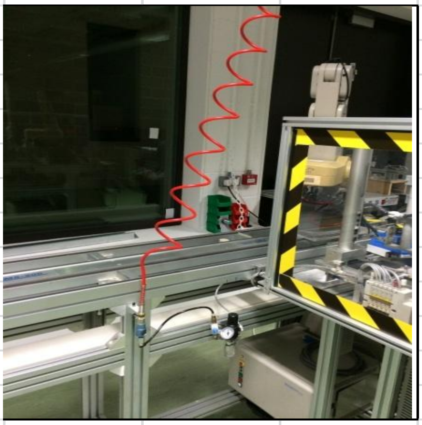




Hazard No	5	Hazard No	6

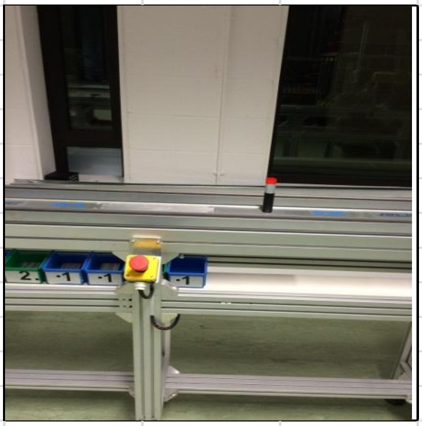
Figure 27 Risk assessment photo reference 1-6

KATS /RA1.01 Ref No.0001



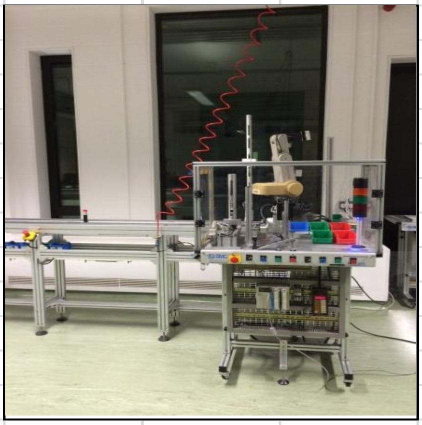
Hazard No	7

Hazard No	8



Hazard No	9

Hazard No	10



Hazard No	11

Figure 28 Risk assessment photo reference 7-11

4.3.4 Risk assessment form

KATS Risk Assessment			
Date: **25/3/14**	Location: **Athlone AIT**	Assessor: Bobby Hewitt	Signed : *Bobby Hewitt*
Ref No: **0001**	Person Responsible: Eddie Carroll & Paul Nally	Resources Required: Staff, Equipment, Finance	
Table 1 A Simple Estimator of Risk Level			
Consequence / Likelihood	Slightly Harmful	Harmful	Extremely Harmful
Highly Unlikely	Trivial Risk	Acceptable Risk	Acceptable Risk
Unlikely	Trivial Risk	Acceptable Risk	Moderate Risk
Likely	Acceptable Risk	Moderate Risk	Substantial Risk
Highly Likely	Moderate Risk	Substantial Risk	Intolerable Risk
Table 2 A Basis for Prioritising Action and Putting Controls in Place			
Risk Level	**Action and Timescale**		
Trivial Risk	No further action required, only this record of assessment to be kept		
Acceptable Risk	No further action required, monitor to insure controls are maintained		
Moderate Risk	Reduce risk within 3-6 months, carry out further risk assessments		
Substantial Risk	Reduce risk within 1-3 months on existing work, do not do new work without risk reduction		
Intolerable Risk	Work should not be started or continued until the risk level has been reduced, there is an absolute duty to reduce the risk		
(red) = Substantial/Intolerable Risk	(amber) = Moderate Risk	(green) = Acceptable/ Trivial Risk	
Abbreviations: C = Consequence; L = Likelihood; RL = Risk Level; EH = Extremely Harmful; HL = Highly Likely; Int. = Intolerable; H = Harmful; UL = Unlikely; HUL = Highly Unlikely; Acc = Acceptable; STF = Slip Trip Fall			

Figure 29 Risk assessment guide

Hazards									
No	**Hazard**	**Risk**	**C**	**L**	**R L**	**Controls**	**C**	**L**	**RL with controls**
1	Exposure in working area of KATS	Injury Catching hands, limbs, fingers, clothing in machine	EH	HL	Int	Erect guard around KATS Ensure Guarding cannot be opened accidently Ensure PPE is relevant and fitted correctly i.e. no trailing clothing Ensure operative has no jewellery or artefacts exposed	EH	HUL	Acc
2	Guard door opening un expectedly	Injury	EH	L	Sub	Erect a fail-safe system when door opens Erect a secure locking system on door	EH	HUL	Acc
3	Replacing Kit Box	Injury Catching hands, limbs, fingers, clothing in machine	EH	HL	Int	Erect a fail-safe system when door opens Ensure Guarding cannot be opened accidently Ensure PPE is relevant and fitted correctly i.e. no trailing clothing Ensure operative has no jewellery or artefacts exposed	EH	HUL	Acc
4	Exposed cables	STF	EH	L	Sub	Ensure cables are neatly stored at rear of machine	EH	HUL	Acc

Figure 30 Risk Table 1 -4

5	Electricity	Electrocution	EH	L	Sub	Ensure circuit breakers and RCD's are in place, in good working order and within current legislation Ensure all electrical components and fittings are within current EU regulations	EH	HUL	Acc
6	Unauthorised access to KATS	Injury Member of public operating KATS Sabotage	EH	L	Sub	Restrict access to work area Only trained staff to operate KATS At least one trained staff member to be operating KATS at any one time	EH	HUL	Acc
7	Operating KATS	Injury Damage Loss of productivity Manual handling	EH	L	Sub	Only trained staff to operate KATS Operative to have valid permits to work Operative to have valid manual handling cert	EH	HUL	Acc
8	Compressed Air	Injury Explosion Line falling from attachment	EH	L	Sub	Ensure airlines are fitted correctly Ensure all airlines are to current standards	H	HUL	Acc
9	Conveyor Belt	Injury	EH	L	Sub	Erect operating warning lights Attach multiple emergency stops Operatives to wear appropriate PPE	EH	HUL	Acc
10	Workstation falling over	Injury Being crushed	EH	L	Sub	Secure workstation at multiple points Proper conduct to be adhered to at all times e.g. no horseplay	EH	HUL	Acc

Figure 31 Risk Table 5 -10

4.4 Construction (build)

4.4.1 Introduction

The construction "build" phase of the project, involved a lot of assembly of components such as the pneumatics, sensors, and the FMS table. There was also some machining of raw materials to create items, such as the robot mandibles, a receptacle for the bearings and a pallet for the tote to sit into during the transport on the conveyor belt.

4.4.2 Bearing slide and holding area

The bearing slide and the holding area had to be machined to the spec shown in the appendices. It was decided that both pieces would be machined from aluminium as this material would blend in with the other apparatus on the FMS table. Both pieces were machined on the milling machine in the workshop of the AIT. During the milling process coolant was used to insure a good quality surface finish and to protect the cutting tool. After the cutting had finished, the mounting holes were drilled and countersunk.

Once the machining process had finished on both pieces, they were cleaned and all edges were filled down. The holding area was bolted onto the FMS table. The slide was slotted into the holding area and mounted onto aluminium upright; the slide was set to a thirty degrees angle.

Figure 32 Bearing Slide and holding area

4.4.3 Robot Mandibles

The mandibles were machined as per the drawings shown in the appendices. The stock material was set up on the milling machine in the AIT workshop and milled to spec. Mounting holes were also drilled through on the milling machine and were countersunk on the drop drill afterwards. A light file was used to remove and burrs from the finished product.

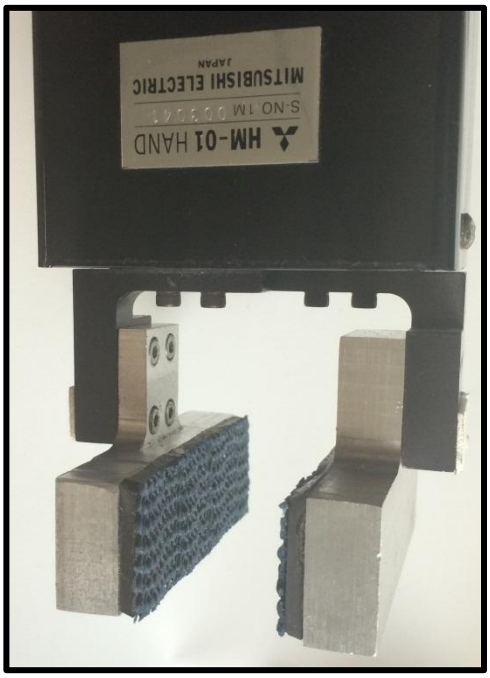


Figure 33 Robot Mandibles mounted on end effector

4.4.4 Tote Vessel

The tote vessel was created by the use of a vacuum former. Before the forming could start the mould had to be prepared. As the complexity of the tote surface it was found to use the tote itself to be a good option. A 1mm thick plastic sheet was cut to the exact shape of all four edges of the perimeter of the tote. These edges were then taped securely onto the tote.

The vacuum forming machine was heated up to the required temperature. The mould was placed into the mould plate of the machine. Next the thermoplastic sheet was clamped into the machine and heated. When the plastic reached the necessary temperature the mould was pushes into the soft plastic and the vacuum was turned on as shown in the figure below.

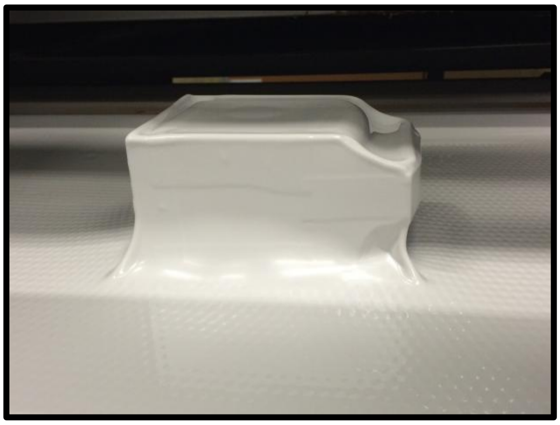


Figure 34 Vacuum forming the tote vessel

After when the plastic had cooled the new tote vessel was trimmed and the edges were arched out at the top. This was done to cater for the Mitsubishi RV-M1 poor accuracy. This plastic vessel was next clued onto a wooden pallet; this pallet was measured to the exact width of the conveyor. This overall unit was very secure on the conveyor and provided the accuracy that was needed.

4.4.5 Pneumatic Actuators

The pneumatic actuators that are being used for this project had being used on previous projects within the college. The pneumatics actuators were arranged as to the design that was laid out. Once all the actuators were mounted in the correct positions on the FMS table, the pneumatics pipe lines were installed from the IP convertor unit to the actuators. These pipe lines were tied down with cable ties and wire wrapping to keep the FMS table as tidy as possible and for safety reasons.

4.4.6 Sensors

There were ten sensors used in this project. There were five proximity sensors, three limit switches, one reed switch and one air pressure sensor. Most of these sensors needed brackets to be constructed to hold these in place. At the design stage of this project it was not fully clear on what size or to the exact location of these sensors. For this reason the brackets were constructed as the sensors were being fixed to the different areas on this project.

4.4.7 Robot and Controller

The robot was mounted to the conveyor top using the aluminium mounting plate which was already fabricated for a previous project. Mounting the robot here gave a close reach for accessing the totes as well as loading stations. The robot controller was mounted underneath the conveyor on aluminium frame bars from the FMS table. When mounting the controller here it was important to position it so it was accessible for maintenance or reprogramming.

4.4.8 Conveyor System and FMS Table

As this system had being previously used by the college for demonstration purposes, the overall system was stripped back to its simplest form. This conveyor had a lot of sensors and pneumatic actuators assembled on it which was of no use to the ASRS or KATS design. When the stripping down was completed the conveyor moved into a pre-agreed location. The conveyor was levelled by adjusting the conveyor feet.

5. Program Development

5.1 Introduction

Program development will take a detailed inspection of the programming techniques used with the Modicon PL7 Pro PLC and the Cosirop programming suite for the Mitsubishi RV-M1 robot. In this project there were two different software packages used. This section will demonstrate how the different software's can communicate together and how they were written to meet their objectives. There was also an Omron invertor used to control the conveyor system.

5.2 Programmable Logic Controller (PLC)

For this project it was decided to use the Telemecanique Modicon PL 7 Pro. This PLC type has being used on projects in the college in previous years.

5.2.1 About Modicon PL7 Pro

The Modicon PL7 Pro TSX 3710 is a compact and module type PLC. Each TSX 3710 configuration comprises a rack which integrates a power supply (24 V or a 100/240 V), a processor including a 14 Kword RAM memory (program, data and constants), a Flash EPROM backup memory, a real-time clock, a discrete I/O module (28 or 64 I/O) and available slot which can accept:

- Standard format discrete I/O module of any type.
- Half format discrete I/O, safety, analogue I/O or counter modules. TSX 3710 PLCs can connect to the Ethernet network TCP/IP or to a Modem via the TSX ETZ 410/510 external stand-alone module. (www.stevenengineering.com, n.d.)

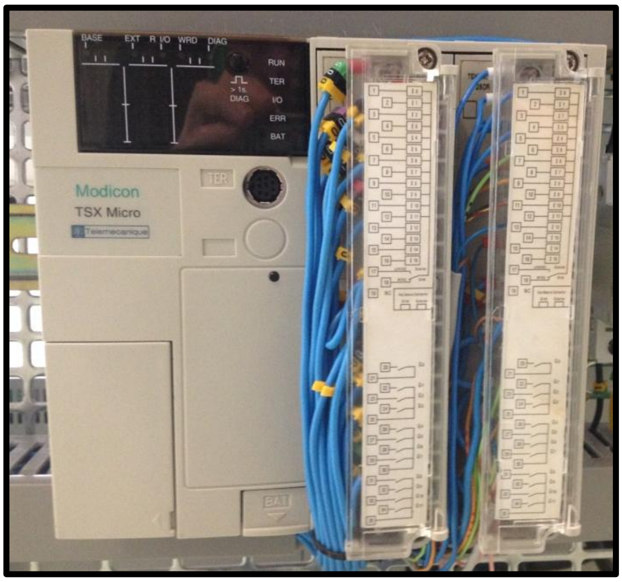


Figure 35 Modicon TSX Micro

This software had many different methods for programming. The method that was used for this project was ladder logic. The reason for selecting this method was as ladder logic had already being thought to programmer with the Siemens software in previous years leading up to the project. There were two main programming windows that were used to help to control the system, to the format that was laid out in the design phase. The first window was called "Prl"; this worked with ladder logic and behaved practically the same as OB1 in the Siemens package. The second window was called "Grafcet", this window have strong similarities to that of the Siemens graph (FB1).

For this project two slots are being used, in each slot a TSX DMZ 28 DR card is being used and this allows for sixteen sourcing/ sinking inputs and twelve relay output.

The card could only be sourcing or sinking and a switch had to be pre-selected prior to the card are installed into the PLC unit. The figure below shows what slots and what type of card are installed into the PLC for this project. The PLC had no spare slots but extra slots could be added if the system was expanded.

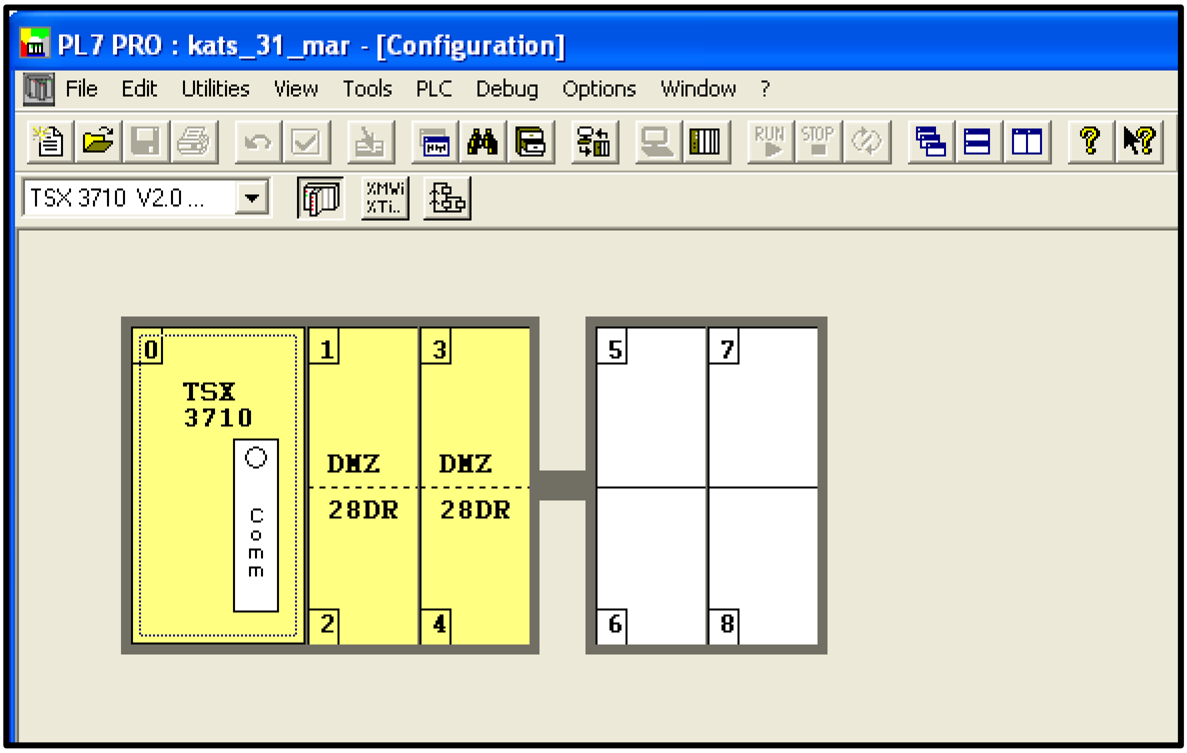


Figure 36 PLC configuration

5.2.2 PLC Programme

At the initial stage of the programming of this PLC, there were a couple of minor programs wrote as so the programmer had a better understanding of how the language performed. The first piece of logic that was written was for the conveyor system. This was written in the Grafcet window and was tested to see if the code would work as the programmer thought. The PLC programme was written in different sections and tested. The program has being altered on several occasions to either to help the equipment to run smoother, to shorten the amount logic that is being used or to where better solutions to the program were found to aid the systems characterises.

The following section will give a brief description of the finished code that was written for the KATS project. It will describe the code in the "Prl" window firstly and will then describe the "Grafcet". The Grafcet window was very useful for the control of the conveyor and made the programming of the pneumatic actuators a lot easier, as each actuator is used in a sequence.

5.2.3 Prl code

The code below is used to indicate that a tote has being removed from the vessel. The tote has to be manually placed back into the vessel. When any one of the three totes has being removed from the vessel, an indicator lamp will flash the colour of the tote that needs to be replaced. If after fifty seconds the tote has not being replaced the sounder will beep on/ off every one second.

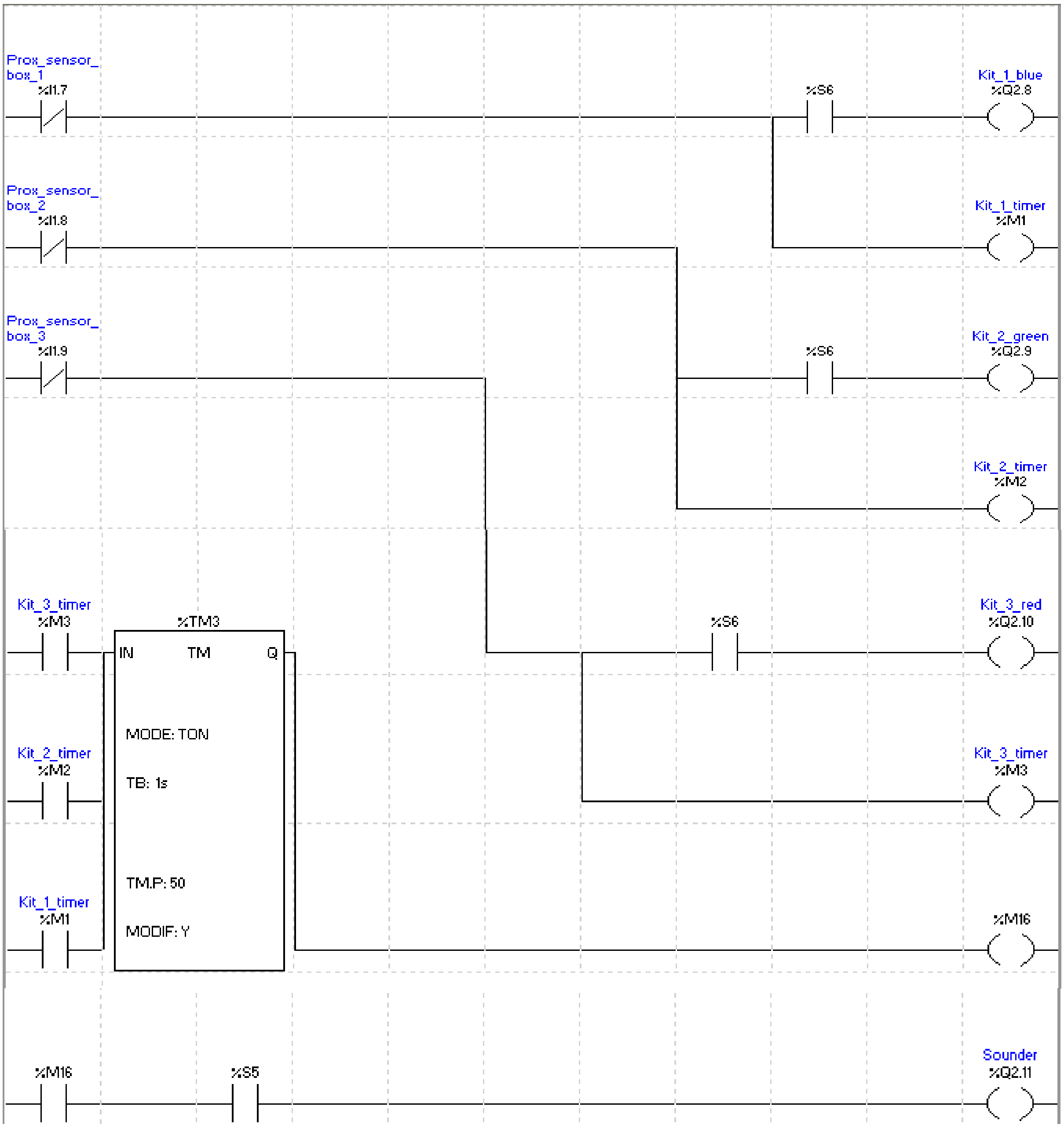


Figure 37 Tote removal code sample

When the stop button is pressed or the pneumatic pressure goes to a low reading, the robot would halt in the step it is in and memory bit %M7 will be reset and memory bit %M59 will be set. At any duration when the reset is pressed it would make %M10 become true.

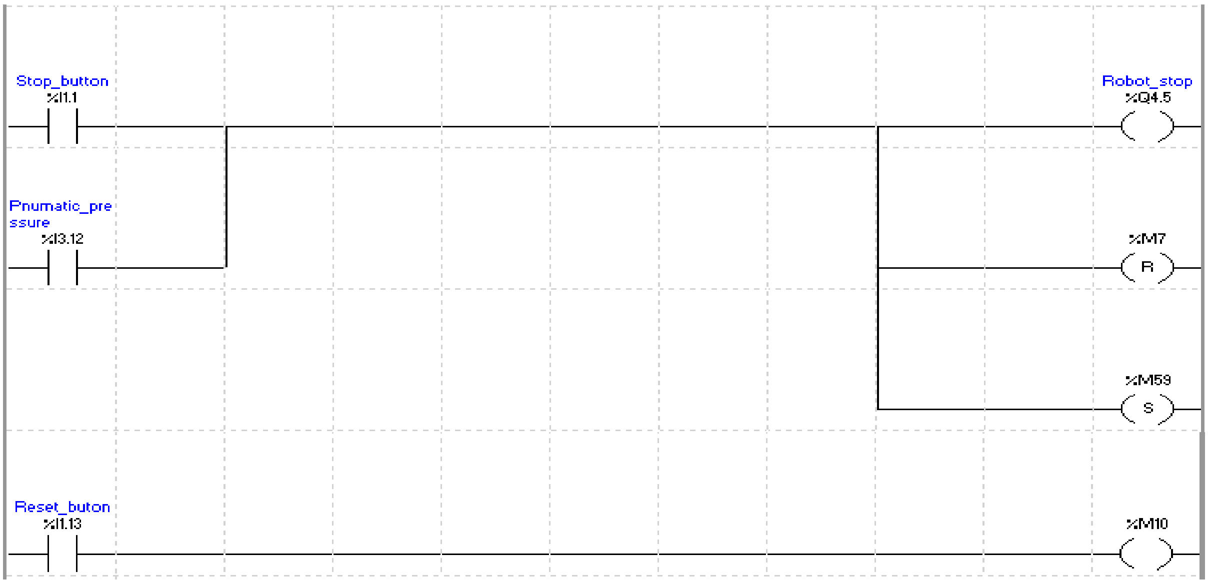


Figure 38 Stop sequence

If the pallet is not at the KATS robot end of the conveyor belt the robot will not get a signal through port %Q4.8. When the start button has being pressed, it gives the robot controller a signal to start up. The robot will not be activated until the start button is pressed. Also after the start button has being pressed, memory %M7 and %M15 are set and %M59 is reset.

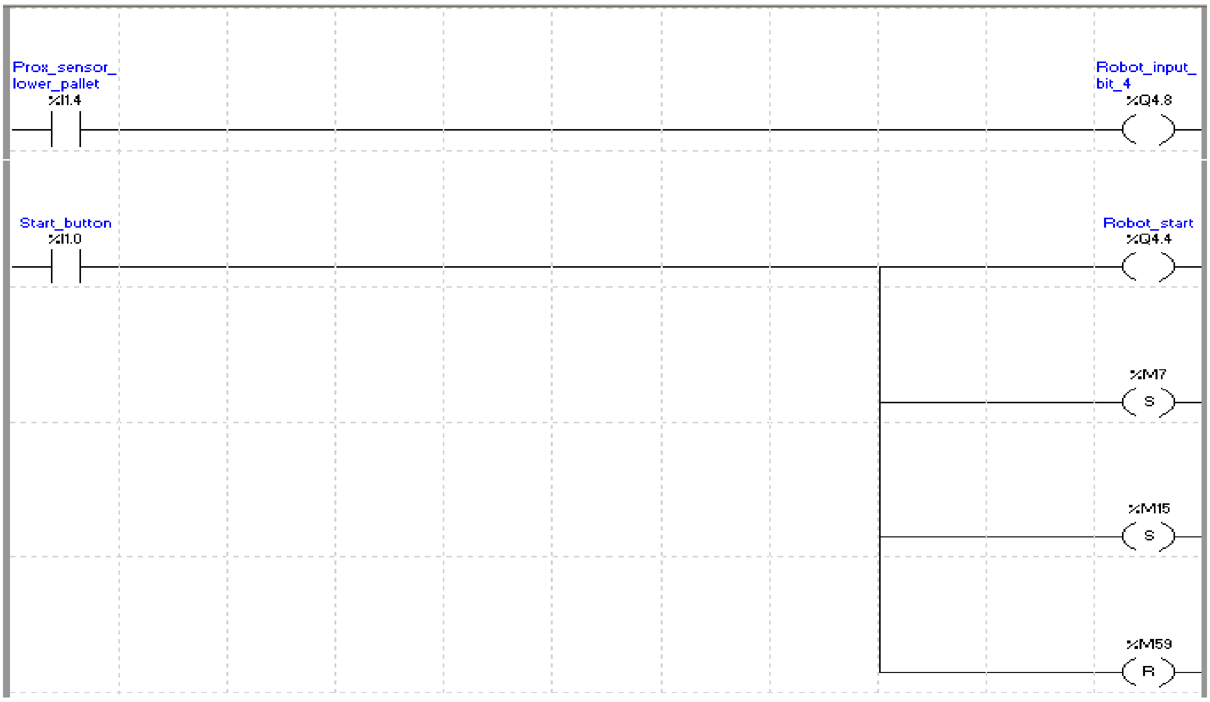


Figure 39 Robot comms

Figure 40 shows the screen where counting; either manually or via the ASRS group takes place. Kit two and kit three are programmed similar to that of kit one which is shown in Figure 40. At the initial start up of the program when the start button is activated the counters are reset to zero and %M7 is set high. The system could either work autonmosly or in conjuction with the ASRS team by selecting either manual or automatic. If the value in the counter (CV) is greater than zero M4 would be set high. Upon the completion of a kit the robot will send a signal to the PLC via %I3.5 and this will decrease the value in the counter by one. When %M4 and if %I1.7 were satisified, a signal would be delivered to the robot to tell it of what kit has being selected and %M30 would become true which sets a bit in Grafcet window.

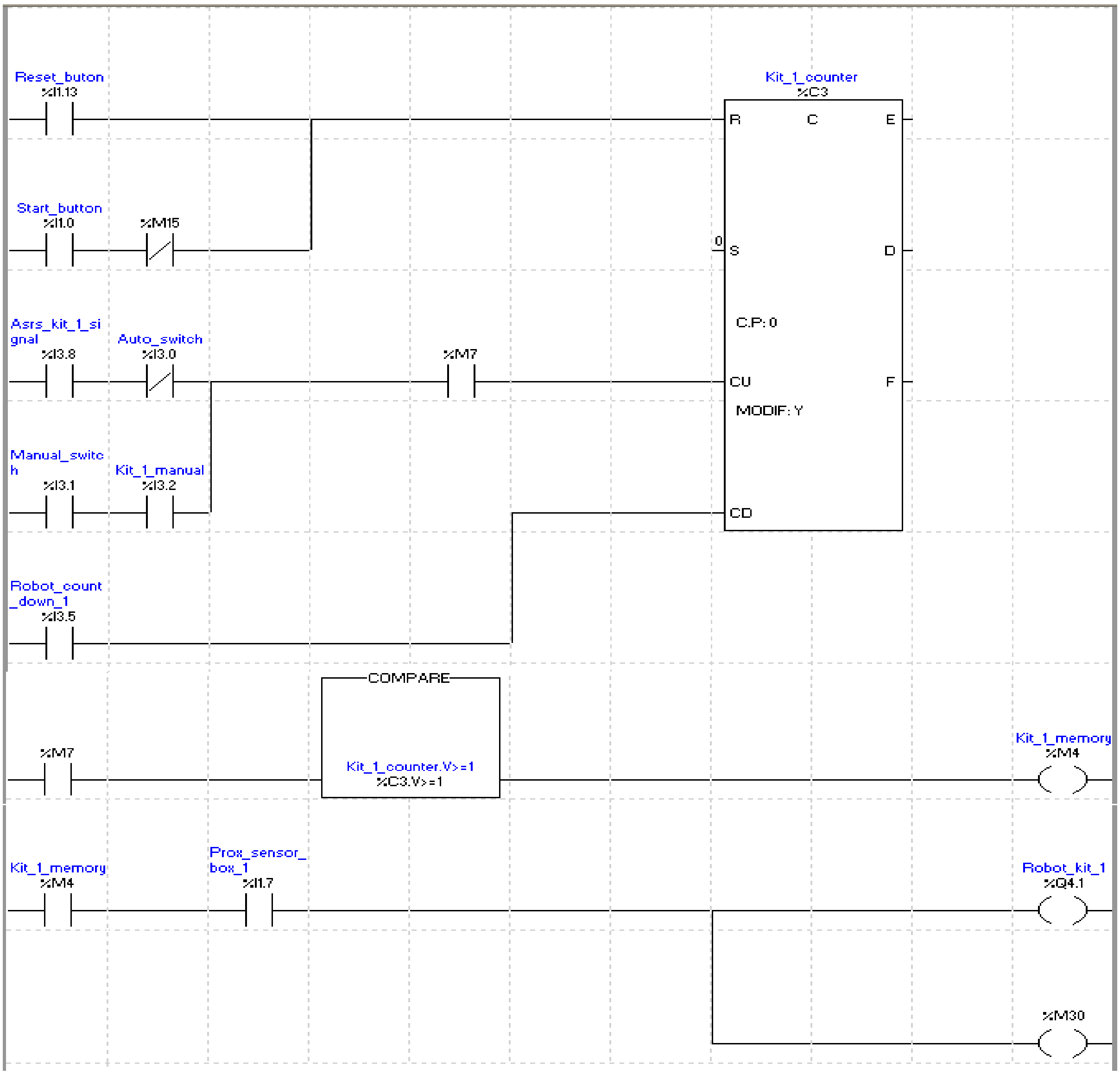


Figure 40 Order counting sequence

When M8 is true %S6 will pulse every one second, which in turn will flash the conveyor run lamp. If M59 becomes true, %S23 will freeze Grafcet %M60 will become true and the robot will stop it its current step. When %M60 becomes true, it resets %M8 and %Q2.2.

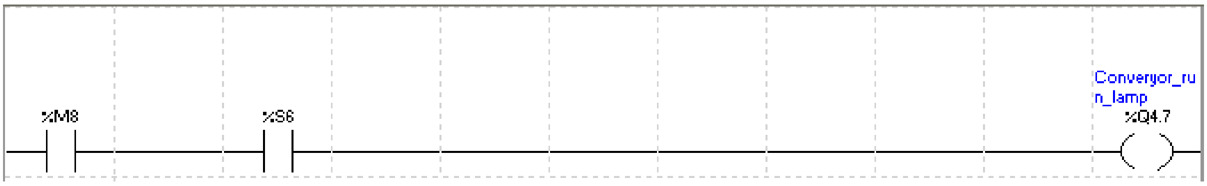


Figure 41 Conveyor lamp

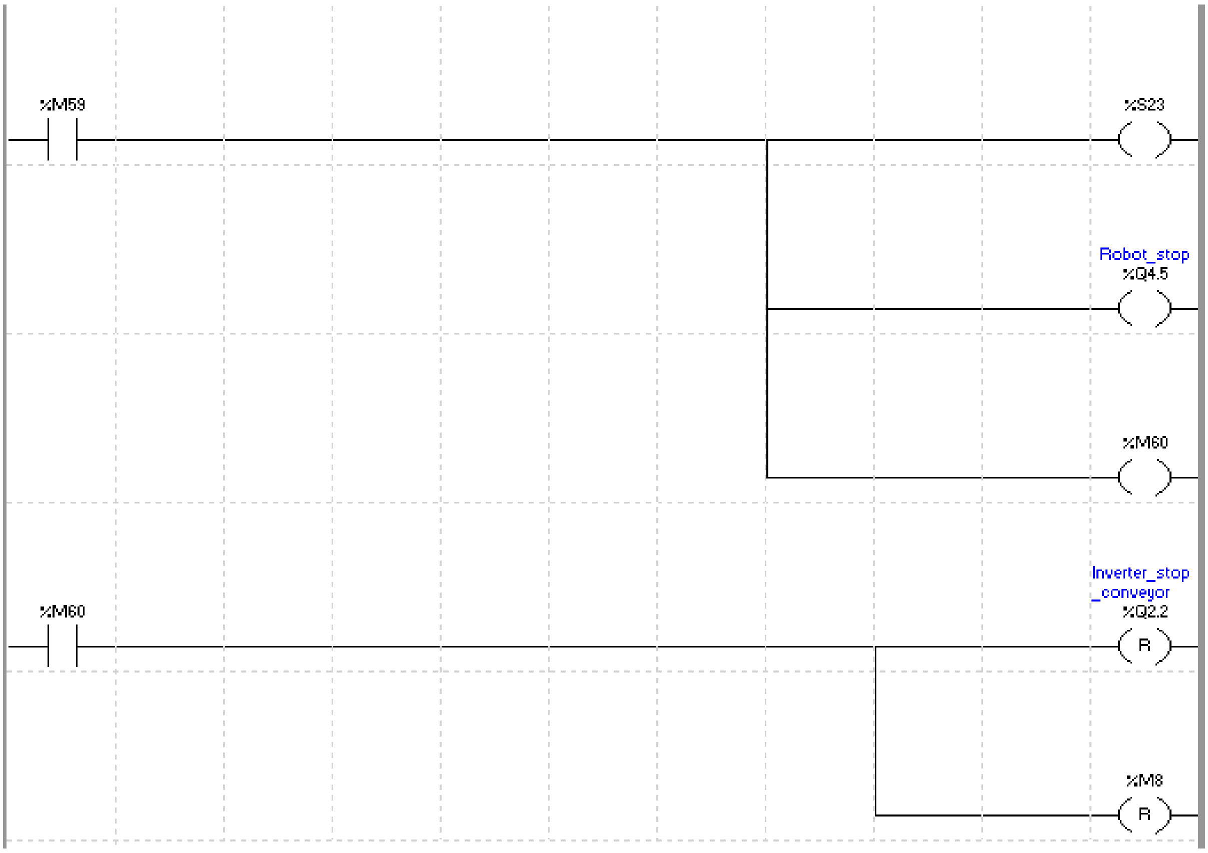


Figure 42 Robot stop

5.2.4 Grafcet code

Figure 43 is Grafcet code that works in a step by step mode. The initial step 12 resets all the actuators to their home positions. After a press from the start button the program sits in step 0 until %M30, %M31 or %M32 would become true. Each route has different characteristics to control the pneumatic actuators and robot to meet the required components in each kit. The program would continue through the route as the transitions are met. Upon completion of step 25, 7 or 11 the program jumps back to step 0.

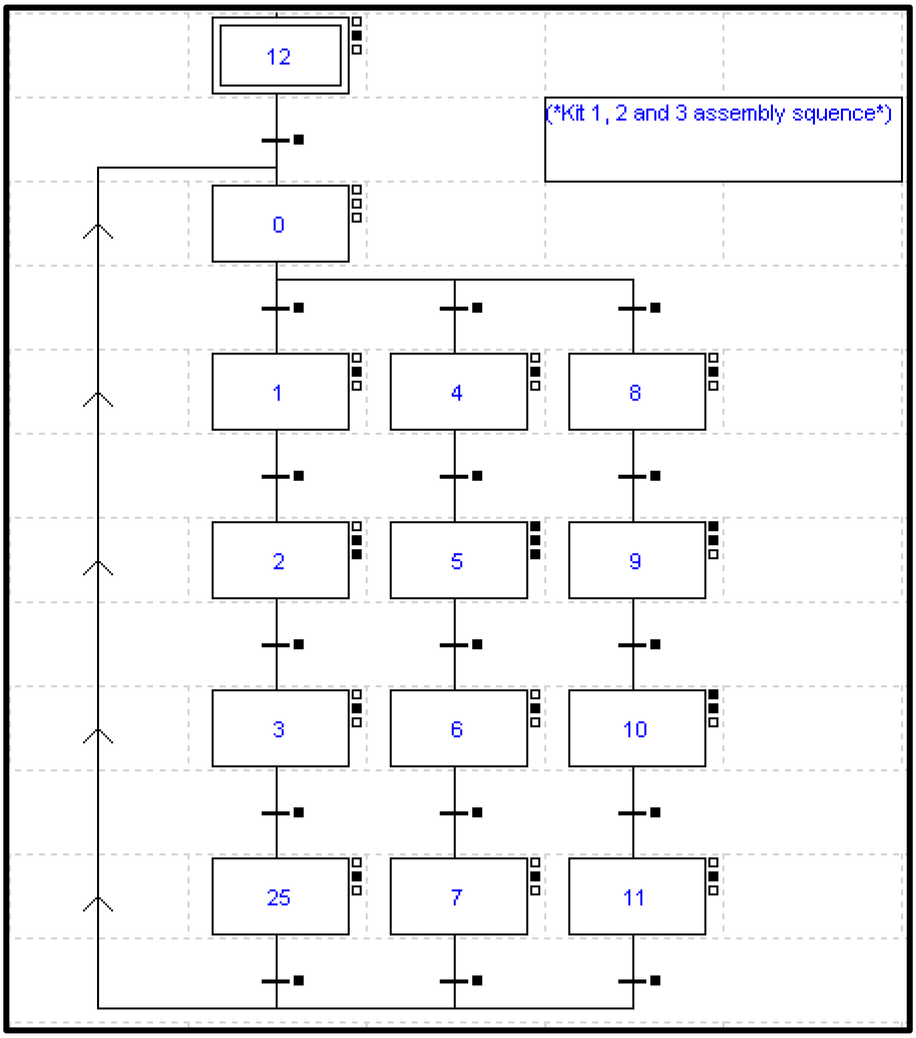


Figure 43 Grafcet

The Grafcet program in Figure 44 is the code that is used to communicate with Omron invertor. Step 19 resets all the conveyor inputs, during this step the conveyor will be off. The start button moves the program from step 19 to step 20. Step 20 sets the 'power on' lamp. Upon the sensor tote on the (%I1.2) and the sensor pallet in home position (%I1.4) the program will move to step 21. After a time delay of fifty seconds the conveyor is set on in forward mode and %M8 is set. When the pallet and tote reach the sensor at the ASRS pick area, the program jumps to step 22. This step resets the %M8 and turns off the conveyor. After when the tote leaves the pallet the program transfers to step 23, in this step %M8 is set and the conveyor is set into the reverse position. When the pallet arrives back at the home position %I1.4 is true which makes the transition from step 23 to step 24. This step reset %M8 and stops the conveyor belt returns to step 20.

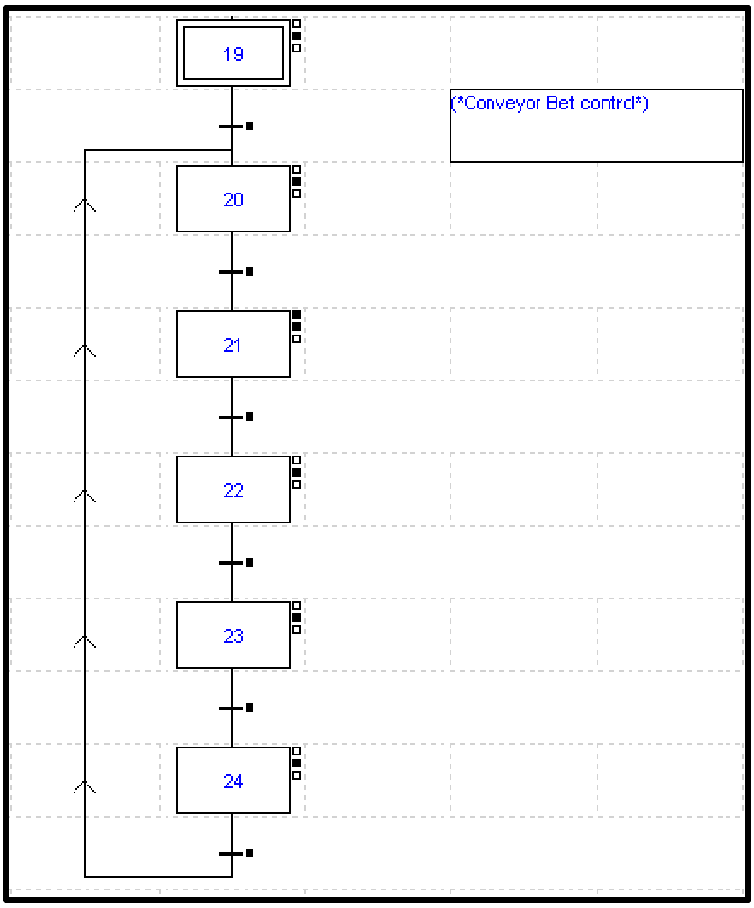


Figure 44 Conveyor Grafcet

5.2.5 I/O Symbols lists

The input and output list shown in the table below is from the Modicon PL7 Pro PLC, all the inputs are odd numbers and the outputs are even numbers. There was also memory bits, system bits, timers and counters used for this project.

	Address	Symbol / Name
	%I1.5	Ejector_sensor
	%I1.6	Prox_sensor_upper
	%I1.7	Prox_sensor_box_1
	%I1.8	Prox_sensor_box_2
	%I1.9	Prox_sensor_box_3
	%I1.10	
	%I1.13	Reset_buton
	%I3.0	Auto_switch
	%I3.1	Manual_switch
	%I3.2	Kit_1_manual
	%I3.3	Kit_2_manual
	%I3.4	Kit_3_manual
	%I3.5	Robot_count_down_1
	%I3.6	Robot_count_down_2
	%I3.7	Robot_count_down_3
	%I3.8	Asrs_kit_1_signal
	%I3.9	Asrs_kit_2_signal
	%I3.10	Asrs_kit_3_signal
	%I3.11	Reed_switch_dowel
	%Q2.0	Ip_dowel_magazine
	%Q2.1	Inverter_start_conveyc
	%Q2.2	Inverter_stop_conveyc
	%Q2.3	Inverter_reverse_conv
	%Q2.4	Ip_axel_dowel
	%Q2.5	Ip_swivel_arm
	%Q2.6	Ip_close_jaws_bearing
	%Q2.7	Spare
	%Q2.8	Kit_1_blue
	%Q2.9	Kit_2_green
	%Q2.10	Kit_3_red
	%Q2.11	Sounder
	%Q4.0	Power_lamp
	%Q4.1	Robot_kit_1
	%Q4.2	Robot_kit_2
	%Q4.3	Robot_kit_3
	%Q4.4	Robot_start
	%Q4.5	Robot_stop
	%Q4.6	Robot_reset
	%Q4.7	Converyor_run_lamp
	%Q4.8	Robot_input_bit_4
	%Q4.9	Robot_dowel_sensor

Figure 45 Symbols list

5.1 Robotics

This section will examine the instruction set used with the Mitsubishi RV M1. It will look at the different tools used in teaching the robot positions as well as sending direct instructions as a method of testing. The following sections will also look at the hardware components themselves such as the robotic arm, controller and teach box.

5.1.1 Robotic Arm

The robotic arm used in this project was the Mitsubishi RV M1 vertical, articulated robot. It offers 5 degrees of freedom not including the hand or end effector. The robot arms movements are conducted using DC servo motors and has a lifting capacity of 1.2 kg including the hand. Its positioning system uses limit switches and encoders which can deliver a position repeatability of +/- 0.3 mm. The maximum path velocity of the robotic arm is 1000mm per second. [xii]

Figure 46 Mitsubishi RV M1

5.1.2 Robotic Controller

Figure 47 Movemaster controller

The robot controller is made up of an overall power supply as well as the drive unit for the robot. Connection between the drive unit and the robot is made via RS-232C and Centronics interfacing cables. The unit itself has the ability to store up to 629 positions which are programmable using the teach box or by using the Jog operation within the Cosirop software. As well as positioning ability the drive unit has a digital I/O interface for data and bit processing which provides 16 inputs, 16 outputs and an emergency stop. The I/O interfacing is possible by using the Centronics output at the rear of the drive unit. The unit employs the use of photo detectors and encoders to facilitate position detection. [xiii]

5.1.3 Teach box

The Teach box is a 28 button hand held control used to operate and program the robot without interfacing it with a personal computer. The teach box provides the ability to jog the robot through pre-set positions as well as jogging through particular Cartesian coordinates. It also allows the user to write a program to the on-board EPROM from the ram within the drive unit. The teach box also features an emergency stop located at the top right of the box which operates as per the emergency stop on the main drive unit. The on/off switch must be in the on position when using the teach box and in the off position when interfacing the unit with a personal computer.

Figure 48 Mitsubishi Teach Box

5.1.4 Software

The software used to develop the program for the robot was COSIROP. The program has the ability to interface with the robot using the RS-232C. The COSIROP software is a development suite that is operational with all Mitsubishi robots and depending on the choice of robot during setup will depend on the features it offers the user. With more modern robots such as the RV-2AJ, the software would allow the user to compile code using the MELFA language set, whereas using the older RV-M1 the software will only offer the MOVEMASTER Basic language set. The software allows the user to input positions directly and add comments relevant to each position. The positions can be entered by jogging through the various joints or by entering the Cartesian coordinates directly.

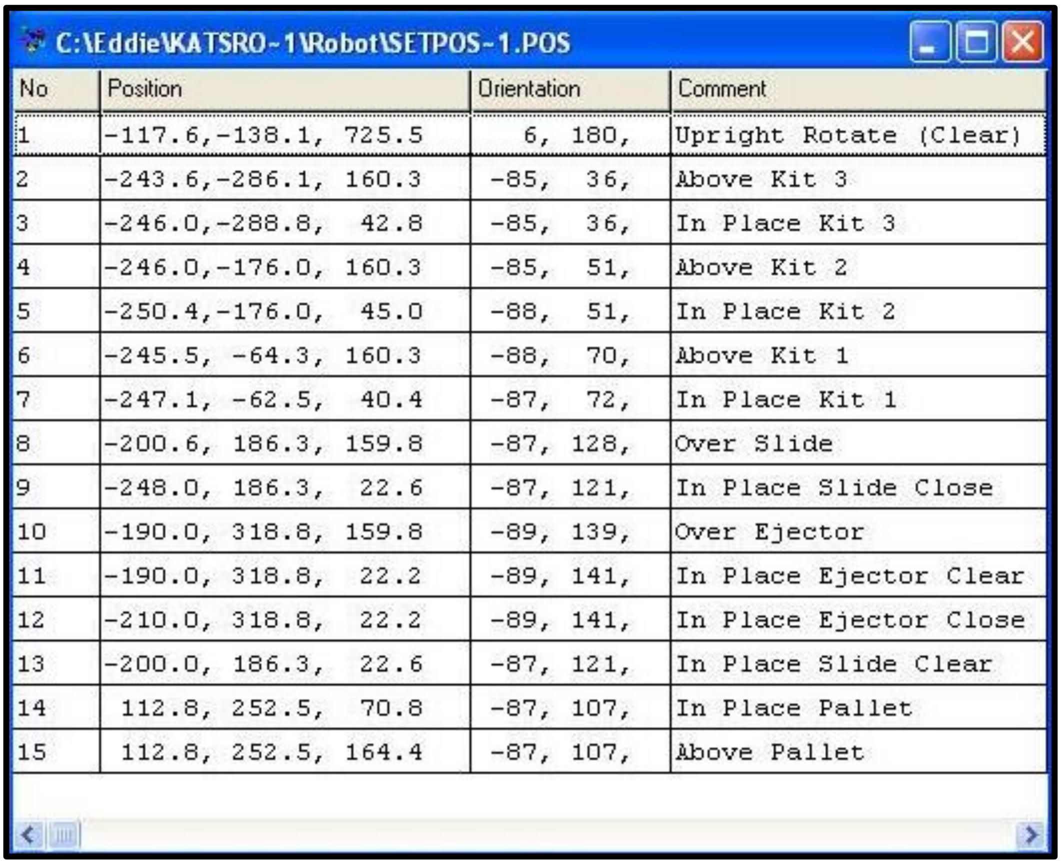
Figure 49 Cosirop Jog operation

5.1.5 **Positions**

When entering or storing positions within the software one must exercise the correct coordinate labeling system

Taking position 1 below as an example the coordinate labeling system is as follows

Position number	X-axis coordinate	Y-axis coordinate	Z-axis coordinate	Pitch angle	Roll angle
1	-117.6	-138.1	725.5	6	180


C:\Eddie\KATSRO~1\Robot\SETPOS~1.POS

No	Position	Orientation	Comment
1	-117.6,-138.1, 725.5	6, 180,	Upright Rotate (Clear)
2	-243.6,-286.1, 160.3	-85, 36,	Above Kit 3
3	-246.0,-288.8, 42.8	-85, 36,	In Place Kit 3
4	-246.0,-176.0, 160.3	-85, 51,	Above Kit 2
5	-250.4,-176.0, 45.0	-88, 51,	In Place Kit 2
6	-245.5, -64.3, 160.3	-88, 70,	Above Kit 1
7	-247.1, -62.5, 40.4	-87, 72,	In Place Kit 1
8	-200.6, 186.3, 159.8	-87, 128,	Over Slide
9	-248.0, 186.3, 22.6	-87, 121,	In Place Slide Close
10	-190.0, 318.8, 159.8	-89, 139,	Over Ejector
11	-190.0, 318.8, 22.2	-89, 141,	In Place Ejector Clear
12	-210.0, 318.8, 22.2	-89, 141,	In Place Ejector Close
13	-200.0, 186.3, 22.6	-87, 121,	In Place Slide Clear
14	112.8, 252.5, 70.8	-87, 107,	In Place Pallet
15	112.8, 252.5, 164.4	-87, 107,	Above Pallet

Figure 50 RV- M1 position table

5.1.6 Code with comments

The following section intends to explain briefly the operands and operators within the code used. Each line of code is followed by a short comment that gives a brief description of what the line instructs.

```
10 nt               ; moves to nest position
20 id               ; look at inputs for change
30 sp 5             ; set speed to 5
40 tb +1,80         ; jumps to line 80 if input bit 1 is high
50 tb +2,180        ; jumps to line 180 if input bit 2 is high
60 tb +3,280        ; jumps to line 280 if input bit 3 is high
70 gt 20            ; goes to line 20
80 ob +1            ; sets output bit 1 to high
90 mo 1             ; moves to position 1
100 mo 6            ; moves to position 6
110 sp 2            ; sets speed to 2
120 mo 7,o          ; move to position 7 with gripper open
130 mo 6,c          ; moves to position 6 with gripper closed
140 gc              ; close gripper
150 gs 380          ; goto sub routine 380
160 ob -1           ; sets output bit 1 to low
170 gt 20           ; goto line 20
180 ob +2           ; sets output bit 2 to high
190 mo 1            ; moves to position 1
200 mo 4            ; moves to position 4
210 sp 2            ; sets speed to 2
220 mo 5,o          ; move to position 5 with gripper open
230 mo 4,c          ; moves to position 4 with gripper closed
240 gc              ; close gripper
250 gs 380          ; goto sub routine 380
260 ob -2           ; sets output bit 2 to low
270 gt 20           ; goto line 20
280 ob +3           ; sets output bit 3 to high
290 mo 1            ; moves to position 1
300 mo 2            ; moves to position 2
310 sp 2            ; sets speed to 2
320 mo 3,o          ; moves to position 3 with gripper open
330 mo 2,c          ; moves to position 2 with gripper closed
```

```
340 gc              ; close gripper
350 gs 380          ; goto sub routine 380
360 ob -3           ; sets output bit 3 to low
370 gt 20           ; goto line 20
380 sp 4            ; sets speed to 4
390 mo 8,c          ; moves to position 8 with gripper closed
400 sp 3            ; sets speed to 3
410 mo 9,c          ; moves to position 9 with gripper closed
420 sp 2            ; sets speed to 2
430 mo 10,c         ; moves to position 10 with gripper closed
440 ti 30           ; timer waits in current position for 3 seconds
450 mo 9,c          ; moves to position 9 with gripper closed
460 sp 3            ; sets speed to 3
470 mo 8,c          ; moves to position 8 with gripper closed
480 sp  4           ; sets speed to 4
490 mo 11,c         ; moves to position 11 with gripper closed
500 sp 3            ; sets speed to 3
510 mo 12,c         ; moves to position 12 with gripper closed
520 sp              ; sets speed to 2
530 mo 13,c         ; moves to position 13 with gripper closed
540 id              ; look at inputs for change
550 tb +5,570       ; jumps to line 570 if input bit 5 is high
560 gt 540          ; goto line 540
570 mo 12,c         ; moves to position 12 with gripper closed
580 mo 11,c         ; moves to position 11 with gripper closed
590 sp 4            ; sets speed to 4
600 mo 15,c         ; moves to position 15 with gripper closed
610 sp 2            ; sets speed to 2
620 id              ; look at inputs for change
630 tb +4,650       ; jumps to line 650 if input bit 4 is high
640 gt 620          ; goto line 620
650 mo 14,c         ; moves to position 14 with gripper closed
660 mo 15,o         ; moves to position 15 with gripper open
670 sp 5            ; sets speed to 5
680 nt              ; moves to nest position
690 rt              ; program returns from sub routine
700 ed              ; program ends
```

6. Debugging

6.1 Introduction

The following section aims to convey an understanding to the reader of the errors found in both the hardware and software within the overall project. Each debugging issue will have its own heading regardless of its extremity.

6.2 EPROM

Erasable Programmable Read Only Memory

This section will examine the issue with maintaining the robot positions and program in the robot controller after the robot controller is powered off. Initially it was thought that the robot and controller were of an age where re writing data on the EPROM was not an option as the robot was too old; and to carry out repairs was going to prove too costly. Continuing with this scenario would lead to having a personal computer permanently assigned to the robot controller.

The EPROM chip is one that retains its memory or data on the chip after the power supply has been turned off. Unlike its successor the E^2PROM, also called "Double E prom" it cannot be electrically erased. [xiv]

Figure 51 Typical EPROM chip

Erasing of an EPROM is done by applying UV light to the die of the chip, the die is the green piece of semiconducting material centrally located within the circular window on the chip above. In general the erasing process must be done away from the unit it is being used in as it is not recommended to apply large amounts of UV light to an entire board.

An EPROM eraser was purchased on EBAY for €11 and multiple tests were carried out with storing and erasing various programs. This procedure was found to be an overwhelming success and was implemented immediately.

6.3 I/O Centronics

Interfacing the robot with the PLC required the use of the I/O feature on the robot drive unit. As the correct Centronics cable was not available to interface the PLC to the robot controller a Motor power cable was used. Using the incorrect cable led to a mismatching of wire colours to pin assignments. This required a full pin out test and match to be carried out on the motor power cable to correlate the correct colours as per the I/O spec on the controller. Once the pin out operation was carried out a full table was complied.

PIN	COLOR	DASH	SIGNAL		PIN	COLOR	DASH	SIGNAL
1	GREY/RED	ALL	Out port Power in		26	GREEN/RED	3	Out port GND OUT
2	PINK/RED	3	Out port Power in		27	ORG/RED	1	Out port GND OUT
3	GREY/BLK	ALL	OB 0		28	GREEN/BLK	3	OB 1
4	PINK/BLK	3	OB 2		29	ORG/BLK	1	OB 3
5	GREY/RED	1	OB 4		30	ORG/RED	3	OB 5
6	BLUE/RED	2	OB 6		31	GREY/RED	3	OB 7
7	GREY/BLK	1	RDY		32	ORG/BLK	3	ACK IN
8	BLUE/BLK	2	OB 8		33	GREY/BLK	3	OB 9
9	GREY/RED	2	OB 10		34	GREEN/RED	ALL	OB 11
10	BLUE/RED	3	OB 12		35	ORG/RED	ALL	OB 13
11	GREY/BLK	2	OB 14		36	GREEN/BLK	ALL	OB 16
12	BLUE/BLK	3	WAIT OUTPUT		37	ORG/BLK	ALL	RUN OUT
13	BLUE/RED	1	ERROR OUTPUT		38	GREEN/RED	1	START IN
14	PINK/RED	1	STOP INPUT		39	PINK/BLK	1	RESET IN
15	BLUE/BLK	1	IB 15		40	GREEN/BLK	1	IB 14
16	ORG/RED	2	IB 13		41	PINK/RED	ALL	IB 12
17	BLUE/RED	ALL	IB 11		42	BLUE/BLK	ALL	IB 10
18	ORG/BLK	2	IB 9		43	PINK/BLK	ALL	IB 8
19	PINK/RED	2	BUSY OUT		44	PINK/RED	4	STB IN
20	BLUE/RED	4	IB 7		45	BLUE/BLK	4	IB 6
21	PINK/BLK	2	IB 5		46	PINK/BLK	4	IB 4
22	GREEN/RED	2	IB 3		47	ORG/RED	4	IB 2
23	GREEN/RED	4	IB 1		48	GREY/RED	4	IB 0
24	GREEN/BLK	2	Input port Power in		49	ORG/BLK	4	Input port GND OUT
25	GREEN/BLK	4	Input port Power in		50	GREY/BLK	4	Input port GND OUT

6.4 Robotic arm

After finding large levels of play in the robotic arm that was in position on the conveyor it was decided to swap the arm out with another arm that was available in the college. Swapping out this arm with the replacement gave far greater repeatability and accuracy.

6.5 PLC system bits

When compiling the code within the Modicon software it was found that certain bits were automatically assigned to specific functions. Initially the S1 system bit was used for the selection of kit 1 within the sequence. It was discovered during testing that the S1 system bit is permanently allocated to be used as a cold restart. Consequently memory bit M4 was used for Kit 1 selection.

6.6 Port assignment

When connecting the PC to the PLC it was found that the required port on the PC was reserved by the last connected device from the I/O port on the rear of the PC. This in turn would not allow the PLC to connect to the PC. The solution to this issue was a reboot of the PC which freed up the I/O port.

7. Conclusion

7.1 Project Conclusion

The objectives of this project was to have a working prototype of a fully operational system that will assemble a pre ordered kit from parts storage, upon assembling the kit it will deliver it via a transport system to a collection station. This project will work autonomously and at the final stages it will merge with the project being developed by another group called ASRS.

It can be seen from the workings of the equipment in room X107 and all the material in the above sections that the project worked as to the spec that was laid out. From the initial stages of this project, it was clear that there was a substantial amount of work to be covered to have this project operating to the standards that were agreed upon. The hours that were permitted to do this project by the college would not have being anywhere close enough to the time that was needed to finish this project. For the build stage, this time was taken into account and the two members associated with this project came back to college a week earlier in term and worked on late in the evening to have the construction phase completed earlier in the term.

7.2 Possible Project Expansion

In this section it will show where it the project could be expanded. The expansion could have being in many areas including a tote magazine, a safety door, a buffering system on the conveyor and extra sensors to show that the magazines are empty.

7.2.1 Tote Magazine

As a tote is removed from the three holders by the robot, the totes have to be manually replaced at its current operation. This was something that was looked into for this project, but with the awkward shape of the totes it was difficult to come up with a solution that did not take too much fabrication. The extra build and extra code would have being too time consuming for the two members involved.

A possible solution to this would be to have a magazine with an actuator at the bottom pushing the tote up for collection in the same area each time. This could have constructed on the conveyor across from the FMS table. This could have being made to hold four totes of each kit which would cut out with the operator reloading each time.

Another solution to this, would be stack the totes on top of each other and have sensors at each level to show which tote is at the top of each kit type. When the robot would come to pick the tote it would know which level to go to.

7.2.2 Visual Display Unit

In the projects current operation, the operator of the KATS system will not know how many of kits have being ordered. The system will work away as to the spec but the operator cannot see how kits have yet to be assembled. This could cause problems if the components that were to be assembled were running low or if a problem had being caused in the code counters.

A solution to this would be to mount a digital display unit on the front of the FMS table. This display unit could show to value in each counter and could display other database information to aid the operator.

7.2.3 Buffer System

With the projects current operation the conveyor belt can only handle one kit at a time. The ASRS group have giving priority to delivering kits, so if the ASRS robot will not pick the tote from the conveyor until the orders have being satisfied. The KATS system will continue to fill a second tote but it will wait with the kit until the pallet arrives back. This system can be quite slow and not very time efficient.

A better solution to this problem would be to have a buffering station build onto the conveyor. This would allow the totes to be assembled and wait in line until the ASRS robot was ready top pick the kit from the conveyor. The buffer could be constructed from pneumatic stop blocks along the conveyor that could stop the totes at different sections of the conveyor.

7.2.4 Magazine empty sensors

When the components in the magazines would run out the operator or the system would not know. This would be a problem when the system would think it is assembling a kit, when no components were entering the tote.

Sensors could be mounted on the end of the magazines which could be displayed on the visual display unit as discussed above, also if any component went low the system could be halted and a lamp could indicate which magazine is empty.

7.2.5 Safety Door

A wire mesh safety guard stops personnel from entering the work space to the rear of the overall KATS system. There are two easily removable braces which allow access for maintenance purposes.

This mesh could be mounted as a door type guard and incorporate an interlock as an extra safety measure.

8. Personal Reflection

In completing this project the work was carried out as evenly as the time line allowed. The work involved in the building and wiring of the entire system was equally distributed between Paul Nally & Eddie Carroll. As the build stages were nearing completion the programming was divided between the two team members. Eddie Carroll carried out the programming on the Mitsubishi Robot while Paul Nally carried out the programming on the Modicon PLC.

8.1 Eddie Carroll

Working on this project has dramatically improved my understanding of Mechatronics as a discipline. The overall project gave a true insight as to how an idea can develop into a working system given the right tools and direction. It also gave a reassurance into how important time lines are within a project. The actual building and programming of the project along with the Mechatronics Practice module were fundamental in giving a true feel for the hands on side of developing a project. I feel that the team work within KATS was fundamental to the project's success and regular meetings along with open discussions were integral to the completion of the project. The self-learning involved in programming the Mitsubishi robot gave me a great confidence boost in my ability to adapt to new systems. With no prior knowledge of the Robot or the programing knowledge involved I felt it was a great achievement to have a working system upon completion of the project.

8.2 Paul Nally

During this project I gained many different aspects of Mechatronic Engineering, aspects from teamwork to timelines to the finished working project all gave a true feel of how a project would develop from start to finish.

The greatest learning out come during this project was how to work within teams. I really enjoyed this element of this project when dealing with hardware and software issues, working through different types of solutions with my group member and solving the problems; this gave great satisfaction to both members and also helped the project to progress.

In writing of the program in the Modicon PLC gave me greater confidence of using different PLC languages. As I had being taught Siemens language in other modules, having the ability to start and finish a different PLC program has given me a great sense of achievement.

9. Appendices

9.1 Design Drawings

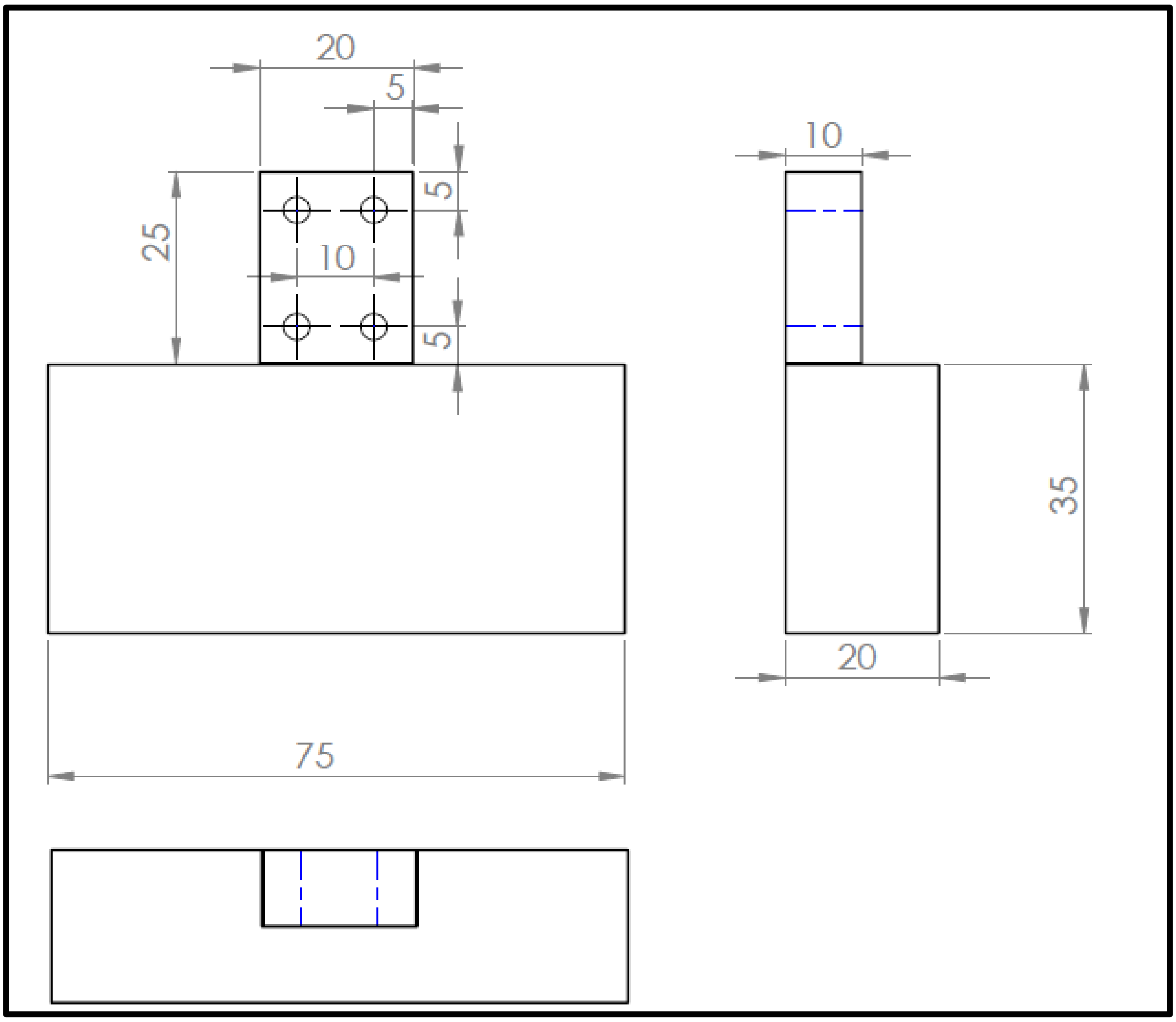


Figure 52 Robot Mandibles

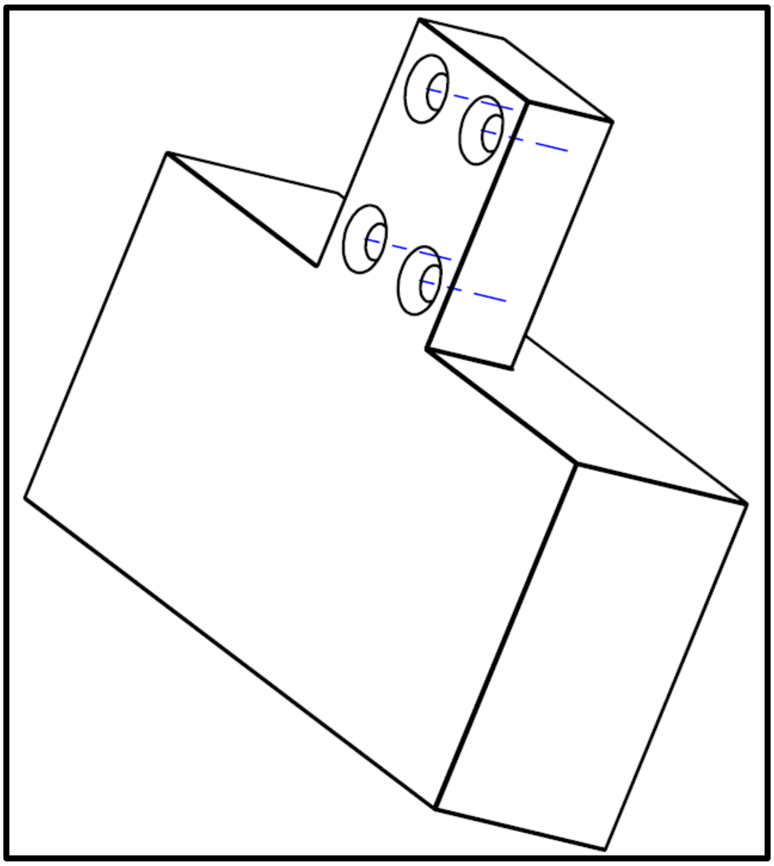


Figure 53 Robot mandibles isometric

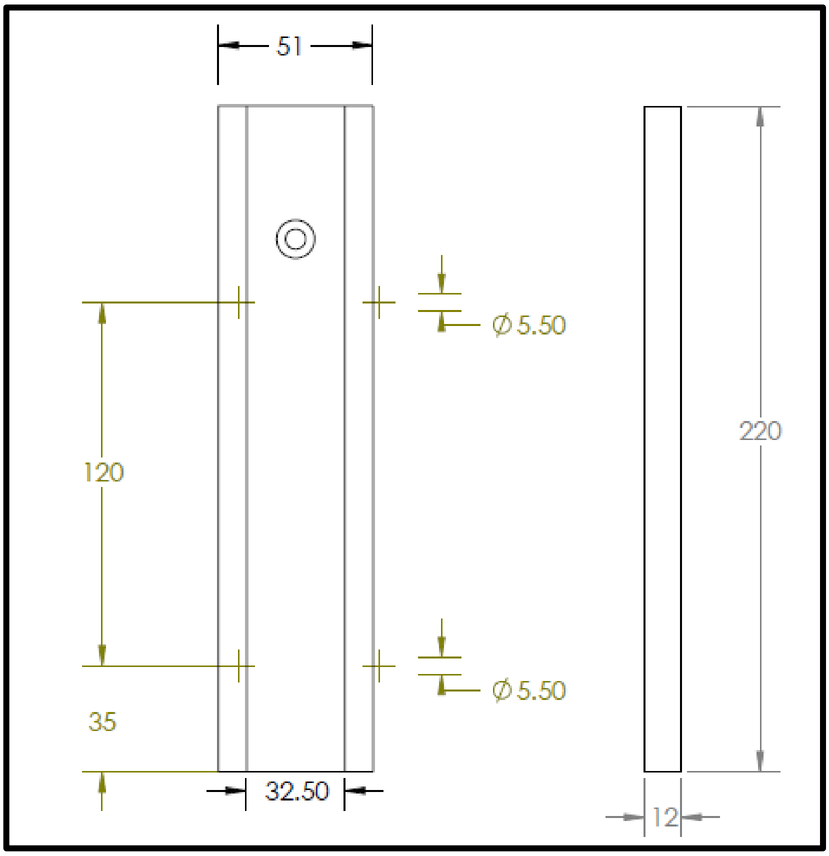


Figure 54 Bearing slide

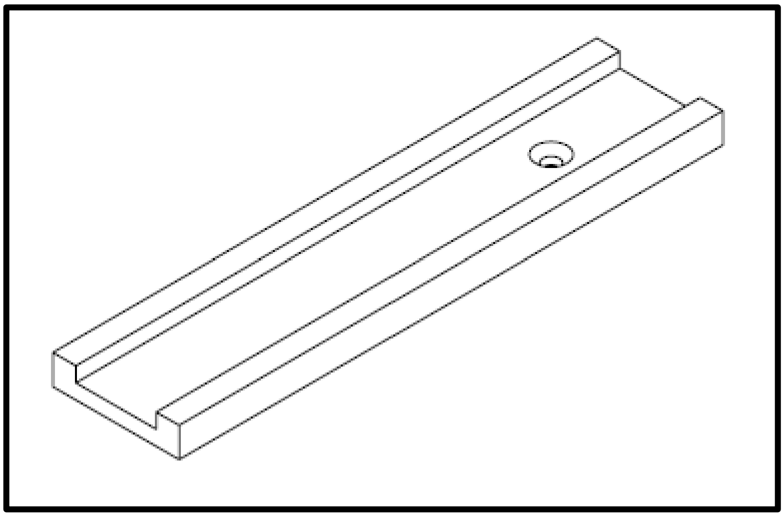


Figure 55 Bearing Slide Isometric

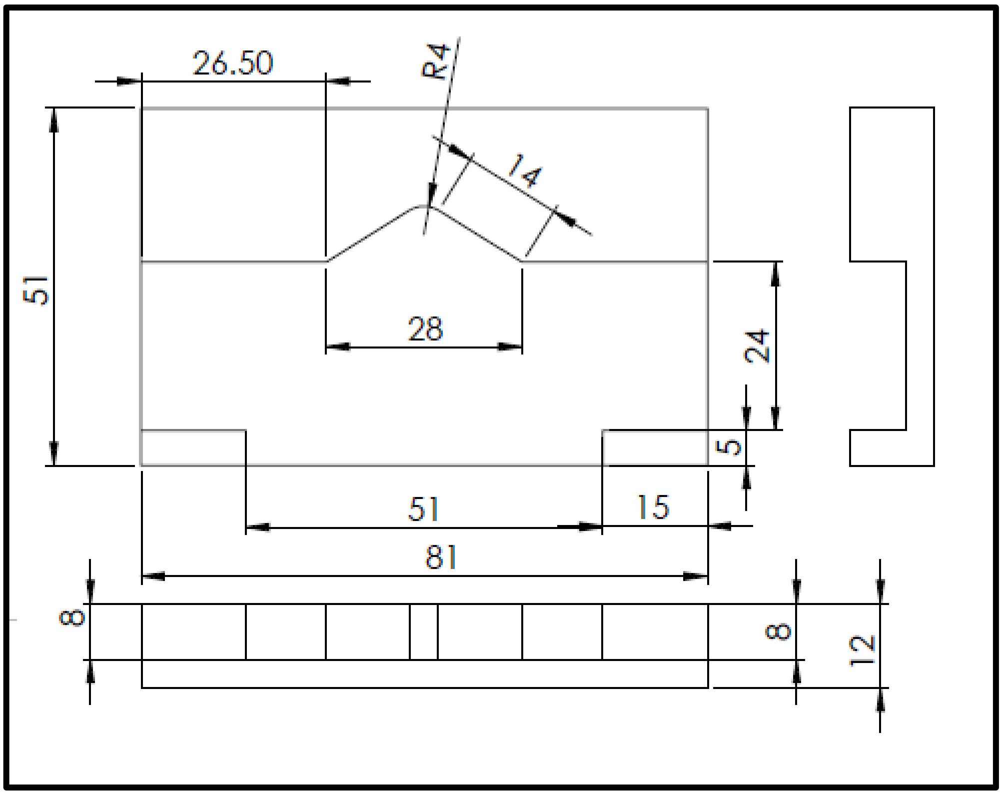


Figure 56 Bearing collection plate

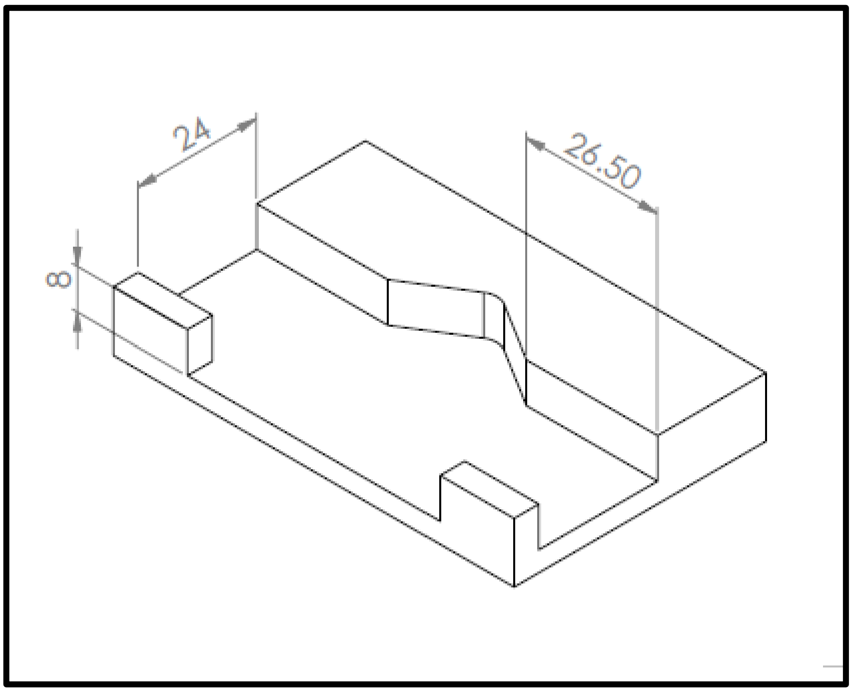


Figure 57 Bearing collection plate Isometric

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