

**DEVELOPMENT OF PLC-BASED AUTOMATED PACKAGING CONTROL SYSTEM
VIA GRAFCET**

By

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13678

DISSERTATION

Submitted to the department of Electrical & Electronic Engineering

in partial fulfilment of the requirements for the

Bachelor of Engineering (Hons)

(Electrical & Electronic Engineering)

SEPTEMBER 2014

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

(Ap. Dr. Nordin bin Saad)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements.

Muhammad Azhar Bin Mohd Yunos

Abstract

The usage of packaging medium is a norm in the small and medium industries (SMI) in Malaysia, especially in the canned food industry. This is due to the fact that canned products are easier to transport and does not leak as easy as other medium used in the market. However, canned products are not free from problems. One of the common problems faced by companies with canned product is the slow packaging speed to fit the canned product in the cardboard box for transportation. In line with that, this project will be focusing on improvising the packaging system used in the manufacturing industry by designing a faster and more reliable automated packaging system. In detail, the project would be on improvising a system in packaging a batch of 24 canned food into a cardboard box for SMI production system. The system will be fully automatic and will be controlled using industrial controller, in this case a programmable logic controller (PLC). This project will be focusing on Grafcet programming method to develop the programming sequences for the actuators in the packaging system under study. At this phase of work, Grafcet method is shown to be a more simpler way to program a PLC as compared to other traditional programming method, namely flowchart.

Acknowledgement

First and foremost, the author would like to praise Allah for His endless blessing, without it, this dissertation would not have been possible. The author would also like to express his appreciation to his beloved family for their continuous support and motivation. The author would also like to take this opportunity to express deepest gratitude to all parties who have involved directly and indirectly in guaranteeing the success of this final year project.

Special acknowledgment goes to Electrical and Electronic Engineering Department Universiti Teknologi PETRONAS's (UTP) and their entire staffs who have given the author chance to conduct this final year project with ease. The author would like to thank AP. Dr. Nordin Bin Saad, author's supervisor, Mr. Azhar Bin Zainal Abidin, Technologist Plant Process Control Lab, and also Mr. Isnani Bin Alias, Technologies PLC Lab, for all the knowledge shared and for giving the maximum opportunity to obtain useful experience during the duration of this final year project.

Finally a token of gratitude to internal examiner, Dr Mohd Noh Bin Karsiti and external examiner, Ir. Halim Hafiz for their effort and time to attend author's final year project presentation.

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List of Abbreviations

PLC - Programmable logic controller

SMI - Small and medium industry

E&E - Electrical and electronic

Chapter 1: Introduction

1.1 Background

Small and medium industries (SMI) in Malaysia are growing and expanding like never before. To meet this new demand, the industries are emphasizing on monitoring and controlling the production systems to increase its efficiency and accuracy. Various automated machinery are used to reduce the manufacturing time of a product thus boosting its production volume. In the many process of manufacturing a product, packaging is the last but not least process as it plays quite a significant role to the manufacturing industries. A good and quality packaging ensures that the product arrived safely to the end user while at the same time easing the process of transporting the finish product.

However, packaging can be a complex and time consuming process as it involves wrapping, stacking, arranging, etc depending on the type of the finished product which require a good packaging system for the operation to run smoothly. Having a fast, efficient and reliable packaging system will definitely speed up the production time of a product and give a huge impact to the manufacturing industries.

1.2 Problem Statement

The trend of using can as a packaging medium for SMI production in Malaysia has long been in used by various companies. Canned food products are easier to transport and are less prone to leak upon impact. Although the can itself is design for high speed filling, the common problem faced by companies with canned product is the slow packaging speed to fit the canned product in the cardboard box for transportation. Other than that, some of the packaging is still being done manually by the operator in the plant. Not only it is a time consuming process, but it will cause fatigue to the operator by doing repetitive task. Thus, with the increasing demand from the market, it is crucial for the industry to have a more efficient packaging system needed to cope with the higher number of product. The packaging system also has to be reliable and accurate as the industry cannot afford to have a breakdown during production hours.

1.3 Objective and scope of study

The main objectives of this project are:

1. To design a reliable and accurate automated packaging system to control the packaging process.
2. To design and program a PLC-based control system via grafcet method.
3. To build a demonstration unit to prove the operability of the automated packaging system.

The scope of study of this project will be on programmable logic controller, Grafcet programming, and automation.

1.4 Relevancy and feasibility

In this project, a lot of Electrical and Electronic (E&E) engineering knowledge will be used such as designing a control system, programming and using a programmable logic controller. Due to this, this project is relevant to me as it involve a lot of E&E knowledge. Therefore, it is the right time for me to implement all the knowledge that I have learned in this project.

Other than that, the basic functions of the PLC have been taught in my undergraduate study which includes counters, timers, and relays. Thus, this project will further increase my knowledge on PLC which will benefit me in the future as an E&E engineer.

Last but not least, with the given time of 2 semesters, it is more than enough time to complete this project including testing and commissioning. Therefore, this project is feasible. The gantt chart and key milestone of this project are available in the appendix section.

Chapter 2: Literature Review

2.1 Automation

Automation is defined as “to make a process in a factory or office operate by machines or computers, in order to reduce the amount of work done by humans and the time taken to do the work”[1]. In automation, a variety of control systems are used to operate equipment and machinery automatically and are used in plant or factory where precision and accuracy is needed. Other than that, labor intensive task can also be replaced by automation to increase productivity and quality. Automation can be implemented using various mean such as pneumatic, hydraulic, and electric. However, complex automation might require the combination of all these method to perform the specific task.

Global competition is faced by many industries including the food industry. Other industries such as electronic and automotive industry have already developed new and fast system for their operation and control system to enhance productivity and reduce cost. Thus, process improvement and automation have become a norm in manufacturing industries in the struggle to gain manufacturing competitiveness [2].

Other than that, recent expansion and rapid growth of the food industry primarily from mergers and acquisitions force manufacturers to combine all of their human and material resource to be more flexible. Therefore, it has become necessary for manufacturer to improve the efficiencies of their operations through improvements in the processes [3].

Compare with other industry, the food industry has been slow to adapt new methods for their manufacturing processes due to the high initial cost required to install these new technologies. Figure 1 shows the sales of robot in each industry sector.

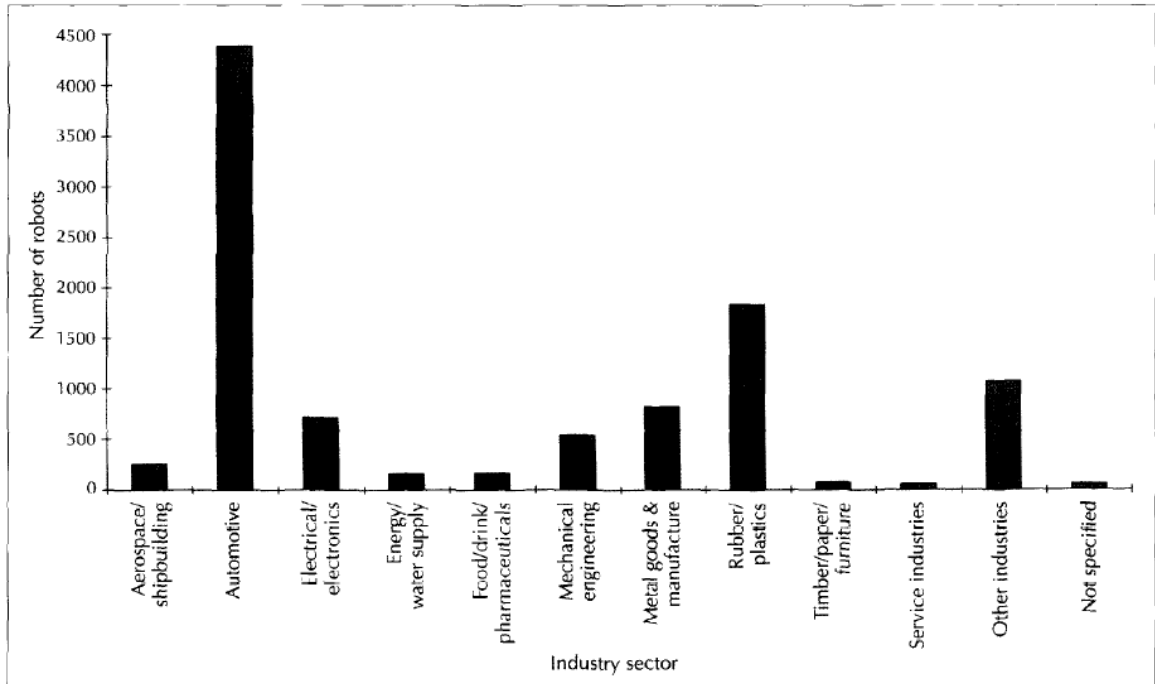


Figure 2: Sales of robot in each industry sector[4].

Clearly we can see that automation is not very popular in the food industry. Despite this, surveys show that companies are now started looking forward toward automation to improve their manufacturing flexibility and capabilities [3]. Automation is used mainly in material handling and packaging operation in the food industry.[4] With automation and good maintenance, manufacturers are expected to see less down time in their manufacturing plant.

2.2 Programmable logic controller

Manufacturing industries need a control system that is reliable, fast, cost-effective and can withstand the harsh environment in the manufacturing plant. Programmable logic controller or usually called PLC suite all of the above criteria and has gain popularity in the manufacturing industries. PLC is basically a digital computer used for automation. However, compare to general-purpose computers, the PLC is designed for multiple inputs and output arrangements.

Before PLC, most of the control system was based on relays. Not only is has limited function, but relays are also difficult to reprogram if there is any changes as the program is the hard wiring itself that it wired to perform task according to the users. Compare with PLC, the program can be change any time using laptop or any programming device. PLC is also immune to electrical noise, higher temperature ranges, and can tolerate more to vibration and impact. Therefore, it is really well suited to be used as a control system in this project. Other advantages of the PLC are high reliability, low power consumption and easy to expand [5].



Figure 2: A programmable logic controller

2.3 Grafcet

Grafcet is a graphical model representation of successive behaviors of a logical system, predefined by its inputs and outputs. Also, it is a graph, chart or functional standard that allows modeling of process to be automated, starting entries, actions performed, and intermediate processes that cause these actions. Initially it was proposed to document the sequential stage of process control systems discrete event. It was not intended as a PLC programming language, but a kind of Graph to build the model considering the direct implementation of the automation or PLC program.

Several manufacturers in their high-end controllers do this direct way, what has become a powerful graphical programming language for PLCs , adapted to the resolution of sequential systems. At present there is a wide spread as language, since most controllers cannot be programmed directly on this language, unlike the ladder diagram . However, it has been universalized as modeling tool that allows direct programming.

Grafcet is a mode of representation and analysis of automation that is particularly suitable to systems that can be broken down into steps. The Grafcet represents the operation of an automated assembly by:

- steps which are associated actions;
- transitions between stages with associated transition conditions (receptivity);
- Oriented links between steps and transitions.

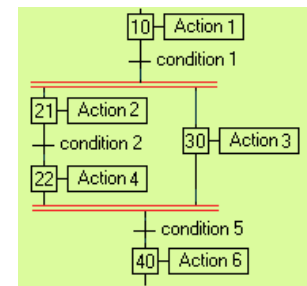


Figure 3: Grafcet Example[6]

The goal of the language:

- Grafcet is a programming language designed to be implanted on a controller, such as a programmable logic controller.
- Grafcet is a representation language that can be used to specify an expected behavior or to describe the behavior of existing automated systems.[6]

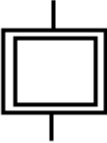
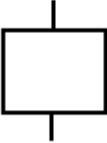


Chapter 3: Methodology/Project work

3.1 Grafcet Programming

Grafcet programming will be used to program the automated packaging system PLC in this project. Since Grafcet is quite a new method of programming, it is crucial to know the fundamentals and concept used to program in Grafcet before continuing this project. Below shows all the important fundamentals and concept:

3.1.1 Elements of Programming

To program in Grafcet it is necessary to understand each of the elements of which it consists. The following table shows the common Grafcet elements.

Symbol	Name	Description
	Initial Stage	Indicates the beginning of the Grafcet and is activated by placing the PLC in RUN. Usually there is only one initial stage.
	Stage	Stage will activate several processes or actions as program by the user.
	Joint	The joints are used to join together several stages.
	Transition	Condition for stopping the current step and activate the next stage is indicated by a line perpendicular to the joint.



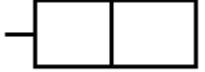
	<p>Addressing</p>	<p>Indicates activation of one and / or another step depending on the condition that is satisfied.</p>
	<p>Simultaneous process</p>	<p>Displays on or off several stages at once.</p>
	<p>Associated actions</p>	<p>Actions that are performed by activating the step to which they belong.</p>

Table 1 : Grafcet programming elements

3.1.2 Grafcet Basic

There are few basic principles used in Grafcet language program. Below shows the corresponding principles that should be taken into account when programming Grafcet:

- The process is broken down into stages that are activated one after another.
- Each stage is associated with one or more actions to be effective only when the step is active.
- A stage is activated when the transition condition is fulfilled and is on the previous stage.
- Fulfilling a transition condition involves activation of the next stage and the deactivation of the preceding stage.
- There can never be two consecutive stages or conditions, they should always be placed alternately.

The basic example of Grafcet is shown below:

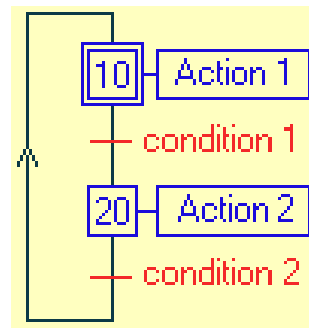


Figure 4: Grafcet Representation

1. A step is represented by a number square. Associated actions are listed in a literal or symbolic, in a rectangle connected to the right side. An initial step is represented by a square doubled. (In blue, Fig 4)
2. A directed link is represented by a line. Other than that, arrows can also be used. Crossings between the links are avoided. (In black, Fig 4)
3. A transition between two steps is represented by a bar perpendicular to the links that connect the steps. A transition indicates the possibility of change between steps with the given condition. (In red, Fig 4).

3.1.3 Classification of sequence

In Grafcet we can find three types of sequences:

- Linear
- With alternative routing
- Simultaneous

Linear

In a linear sequence, the sequence is composed of linear succession of stages as shown in the following example:

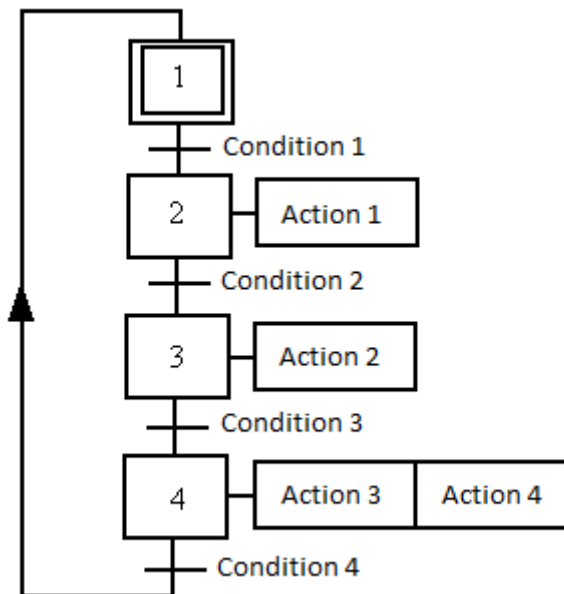


Figure 5: Linear Sequence

The program will activate each of the previous stages and off as they fulfill each of the conditions. The actions are performed based on the active stage at which they are associated. For example, stage 1 activated after starting the program, upon completion of the "Condition 1", step 2 is activated, it will disable the 1, and the "Action 1" will be held.

With routing

Grafcet can be addressed according to the conditions that are met. The following example shows that from the initial stage, it can follow three different cycles depending on which conditions that are met, however, usually only one of them may be met while stage 1 is active, although they can be several conditions met at once:

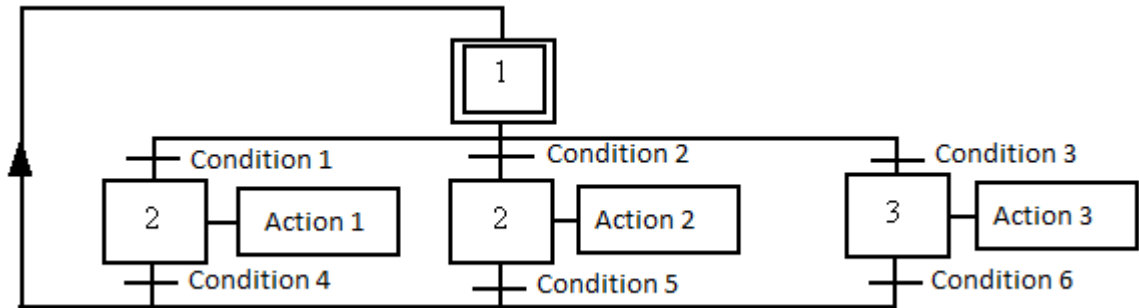


Figure 6: Grafcet with routing sequence

Concurrent

In concurrent sequence, multiple cycles can be running at once for simultaneous activation stages. In the following example, when condition 1 is met stages 2, 3 and 4 are activated simultaneously:

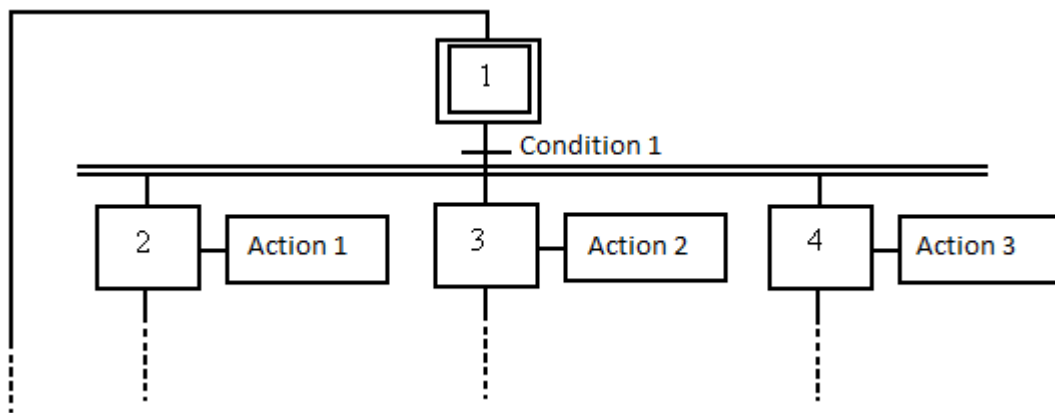


Figure 7: Concurrent Sequence

Note that the concurrent sequences have double horizontal line after the initial stage. Another important feature in concurrent sequence is that the next stage may start to close only when all of the parallel steps are completed.

3.1.4 Classification of actions

In Grafset we can find one or more of the actions associated with a stage :

Actions associated with various stages

The same action can be performed at different stages. In this example the action to be performed when stage 21 or 23 is active:

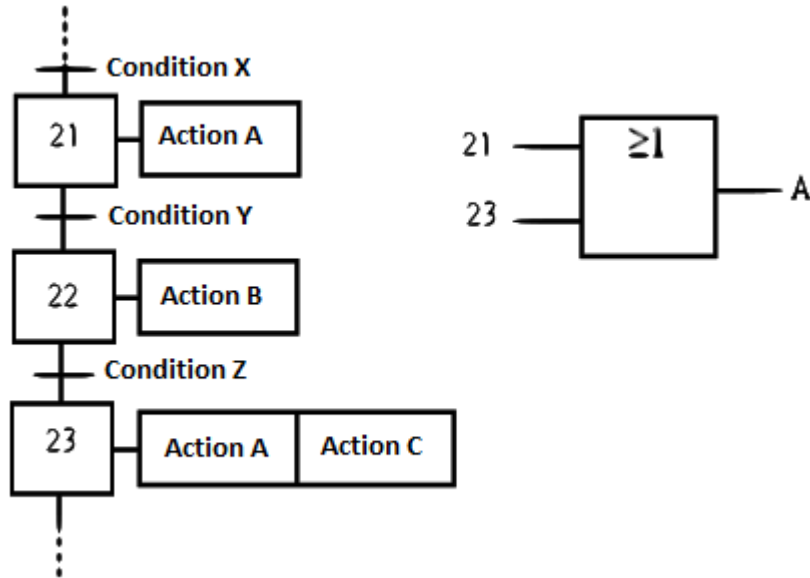


Figure 8: Actions associated with various stages

Conditional Actions

The implementation of the action occurs when in addition to being active stage at which it is associated, it also verify additional logical condition.

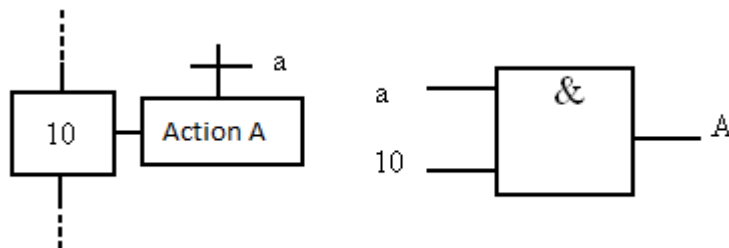


Figure 9: Conditional Actions

Timed Actions or delayed

It is a particular case of conditional actions found in many applications. In this case, the time involved act more as a logical condition. In the following example, the action to be performed for 10 seconds:

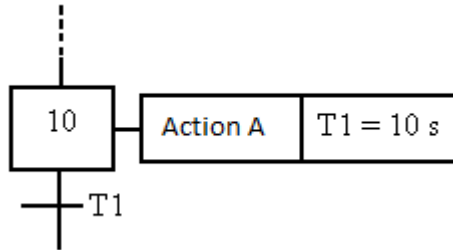


Figure 10: Timed Actions

3.2 Hardware

3.2.1 Hardware design

Figure 11a) and b) shows the planned hardware layout that will be used in this project. Figure 11a) shows the hardware layout for the packaging process while figure 11b) shows the stacking hardware design. Considering the benefit of PLC-controlled systems, the packaging system to be developed should be flexible and adjustable to the different quantity of cans and the number of stacking required.

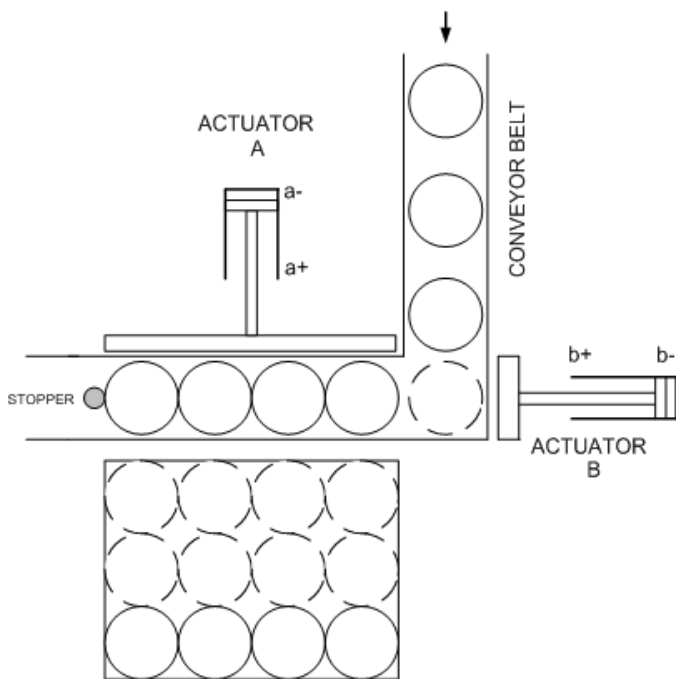


Figure 11a): Packaging hardware layout

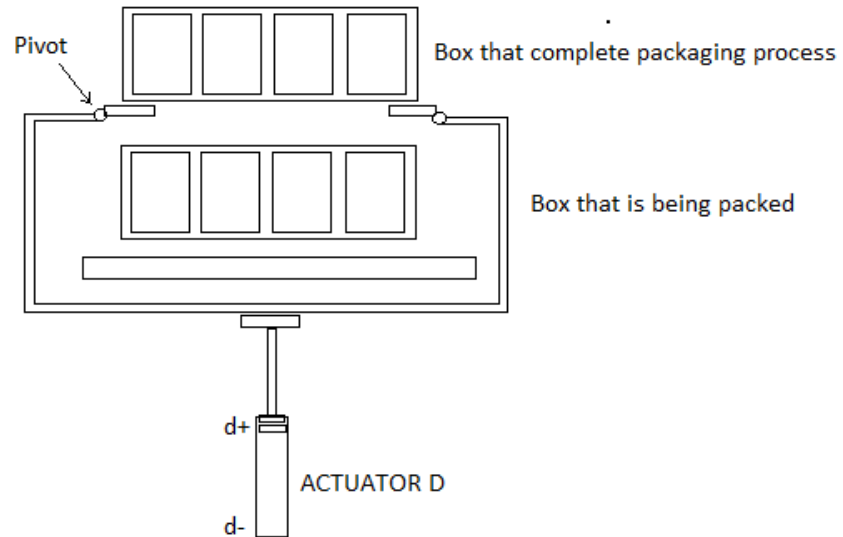


Figure 11b): Stacking hardware layout

3.2.2 List of hardware for control system

Item	Description
<p data-bbox="186 304 435 331">Pneumatic actuator</p> 	<p data-bbox="824 359 1425 552">The pneumatic actuator will create a linear movement either extend or retract according to the program. It is the final element of the control system.</p>
<p data-bbox="186 718 386 745">Solenoid Valve</p> 	<p data-bbox="824 758 1409 1062">The solenoid valve act as a converter from an electrical signal coming from the PLC to air signal that will be supply to the pneumatic actuator. There are many type of solenoid valve such as 5/2 way, 3/2 way, and many more.</p>
<p data-bbox="186 1087 407 1115">Proximity sensor</p> 	<p data-bbox="824 1127 1430 1325">Proximity sensor will sense and detect object if an object pass through the sensor face. This type of sensors are normally used to detect an object without contacting the object.</p>
<p data-bbox="186 1463 354 1491">Limit switch</p> 	<p data-bbox="824 1503 1425 1696">Limit switch is just a heavy duty switch normally used to send input to the PLC. It is normally placed where processes occur such as actuators.</p>

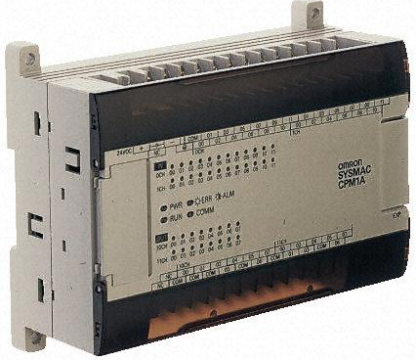
<p>Programmable logic controller (PLC)</p> 	<p>PLC acts as the brain of the control system where command and program are stored. PLC is known to be a very reliable and rugged component that suited harsh environment such as in a plant.</p>
<p>Air Compressor</p> 	<p>The air compressor is needed to supply the pneumatic actuator with compressed air.</p>

Table 2 : List of hardware for control system

3.3 Software

3.1.1 Automation studio

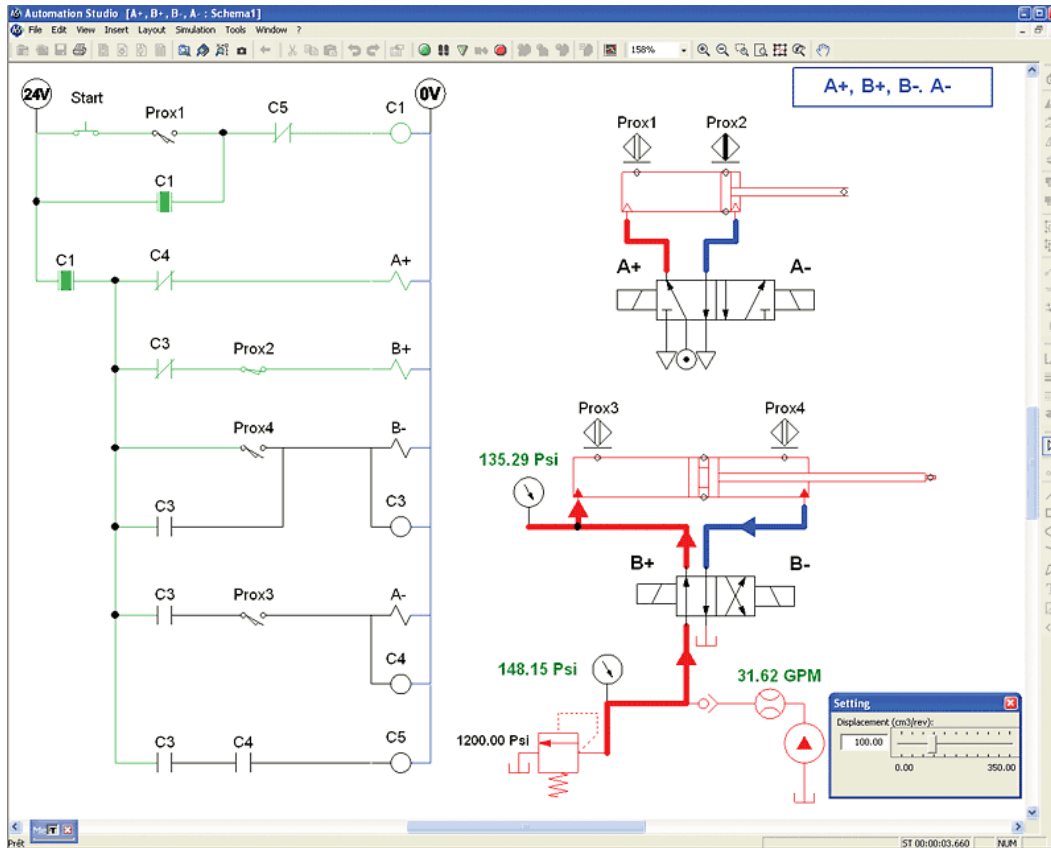


Figure 12: Automation Studio

Automation studio is a simulation software used to test the function ability of a program before implementing it to actual hardware. It is a crucial step in developing a control system as any error in actual hardware system could cause costly damage, accident and injury. Other than that, by using simulation software, programmers can tweak and try different approach of programming that will lead to simplification of the program that will reduce the number of component and hence reduce the development cost of the control system. Other than that, overall efficiency of the system can be increase as lesser component is used.

3.1.2 CX programmer

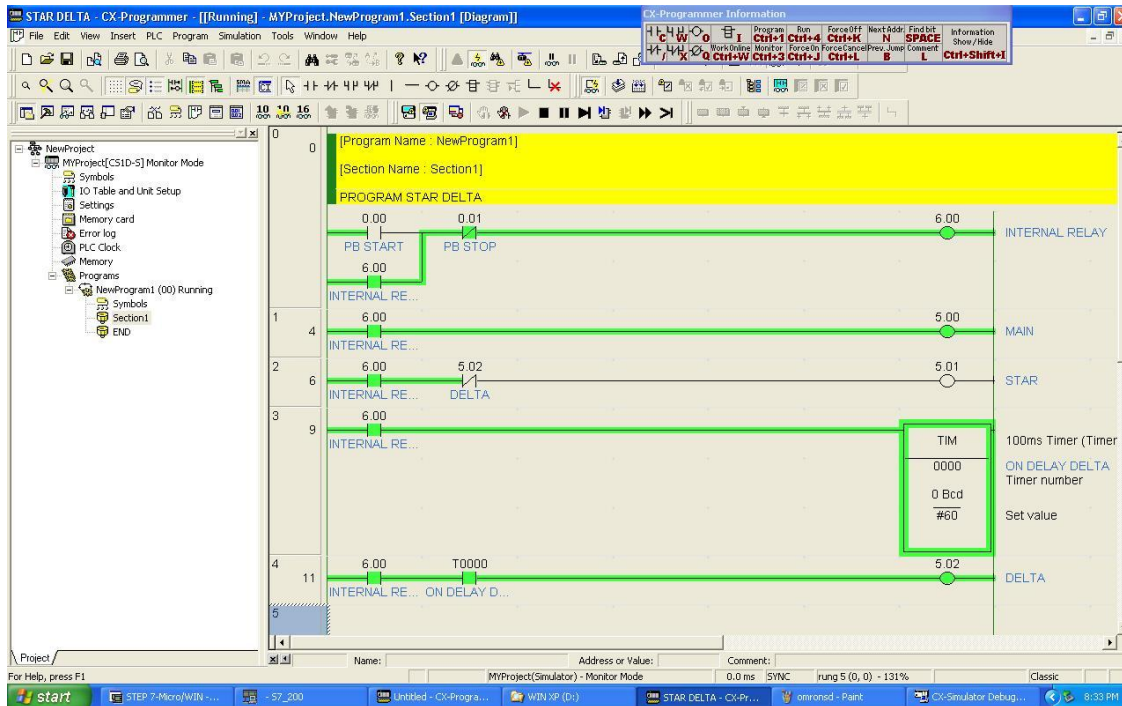


Figure 13: CX Programmer

Since the PLC that author will be using in this project is from OMRON, CX programmer is needed to download the program into the PLC. CX programmer allow users to build, configure, and program for all OMRON's PLC series. This greatly reduces the hassle of software maintenance and management at both the End-User and OEM level.

Chapter 4: Results and discussion

4.1 Simulation design

The full sequence of this project is : $[([B+B-] \times 4) + [A+A-] \times 3] \times 2$

As we can see, there are 3 parts in the sequence. The first part is cylinder B need to extend and retract 4 times, second part is cylinder A need to extend and retract after the first part process has completed for 3 times, and the last part is the 2 cycle combination of the first and second part.

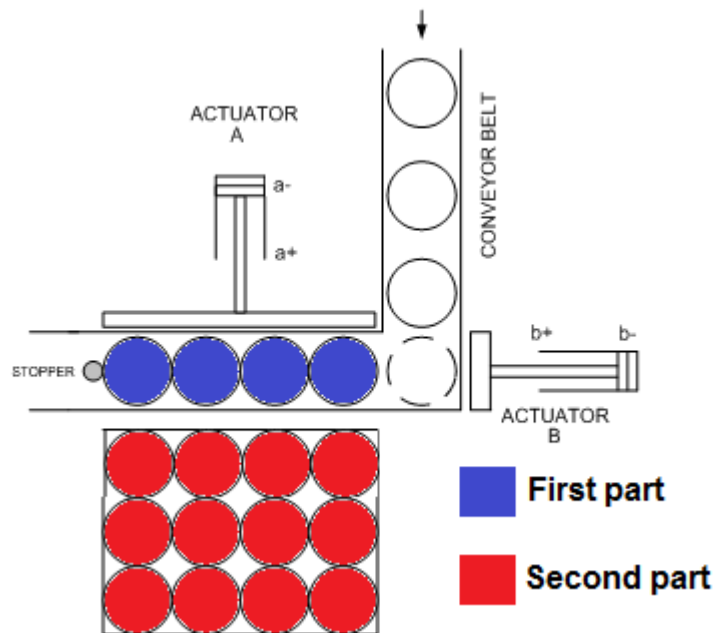


Figure 14: Hardware layout with colored sequence

From the diagram we can see that the first part of the sequence will create the 4 column of the canned food arrangement, the second part will create the 3 row arrangement and the last part is the stacking process of the canned food to create a 24 can arrangement.

Due to the many part of this project, the Grafset program will be broken down into 3 parts accordingly and will be combined after finishing all 3 parts to ease the programming process and to avoid any error in the program.

4.1.1 First part of the project

[([B+B-] x 4) + [A+A-] x 3) x 2]

The first part of the project is the sequence that creates the 4 column of the canned food product. Cylinder B needs to extend and retract for 4 times. Thus a simple counter system is used to implement the sequence. A double acting cylinder will be used as the actuator which will be controlled by a 5/2 way solenoid valve. A proximity sensor will also be placed at both end of the double acting cylinder to be used as a signal for the program. Below shows the Grafcet diagram and hardware simulation:

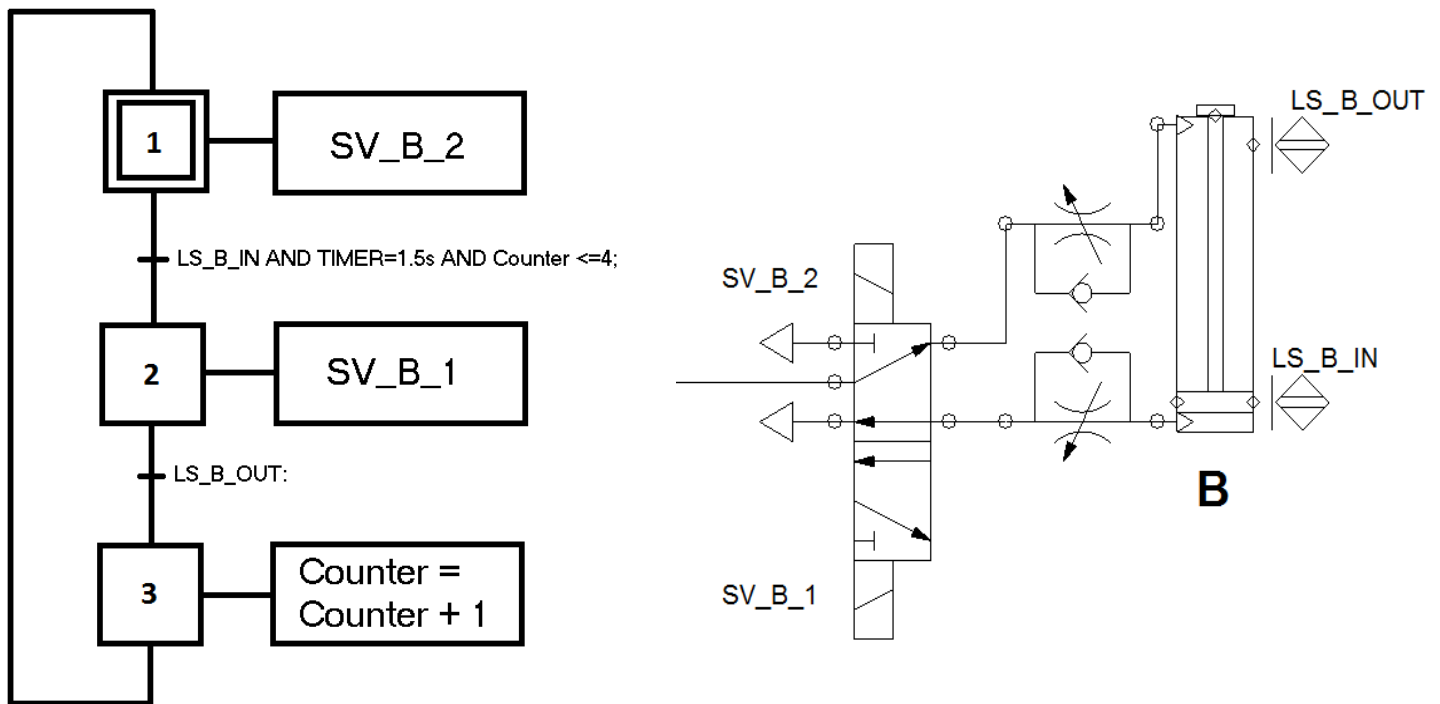


Figure 15: First part Grafcet diagram and hardware simulation

4.1.2 Second part of the project

$[(\{[B+B-] \times 4\} + [A+A-] \times 3) \times 2]$

For the second part, cylinder A needs to extend and retract for 3 times after the completion of each part one sequence. This is to create the 3 row of the 12 can arrangement. Thus, the program is implemented by using simultaneous exclusive action of Grafset which is to allow only one step to be active at a time by using transition condition. Also a second counter system is added to the system. The same hardware configuration from part 1 is used for actuator A. Below shows the program and hardware simulation:

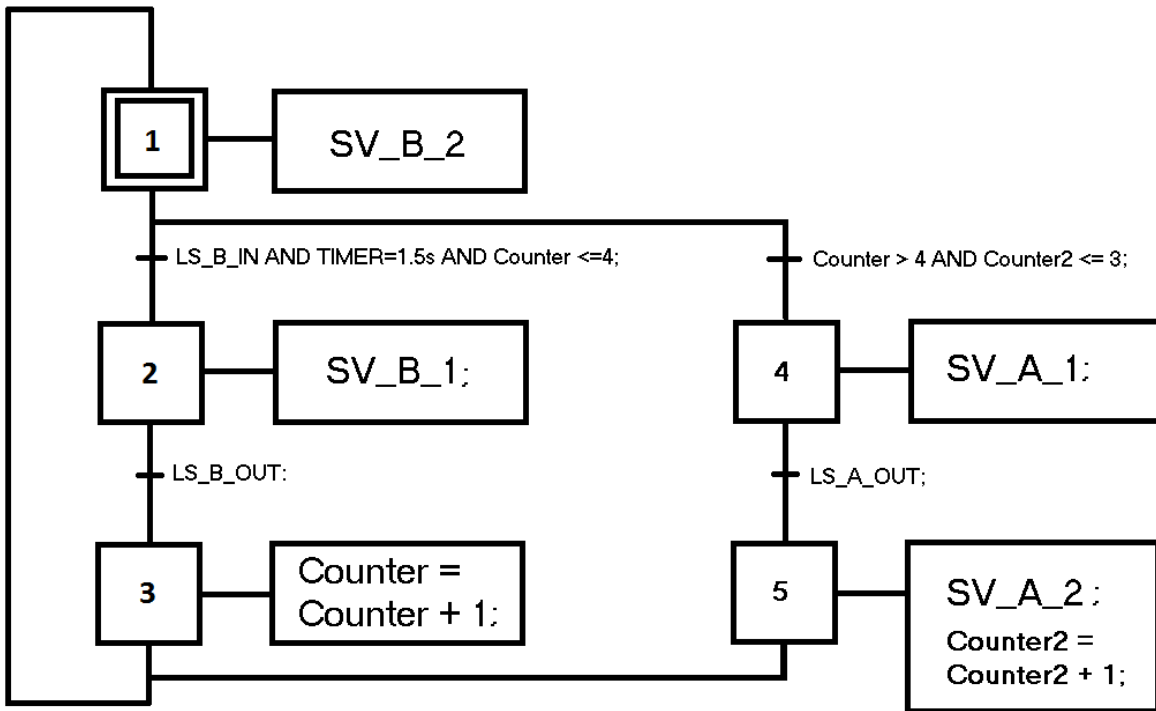


Figure 16: Second part Grafset diagram

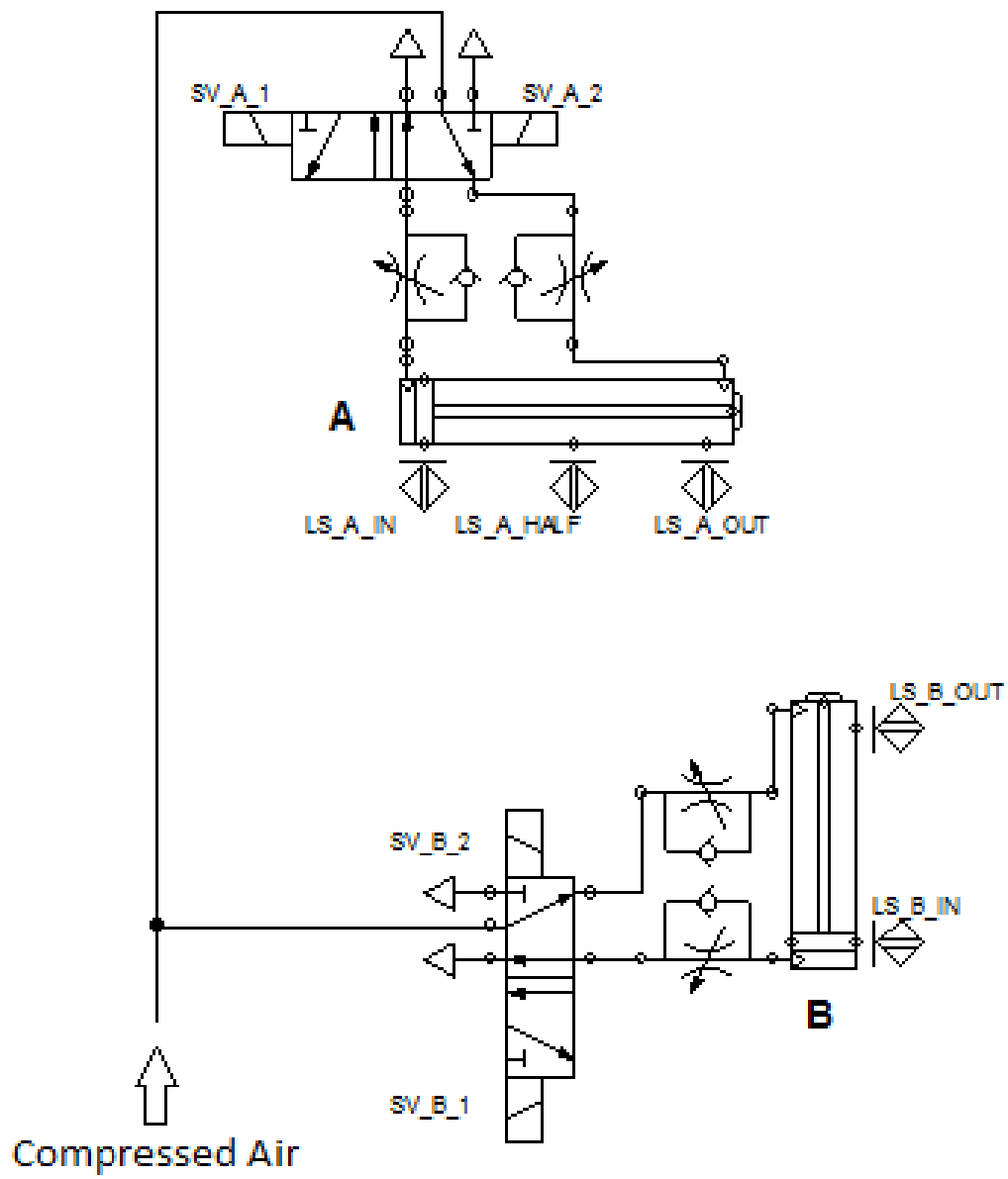
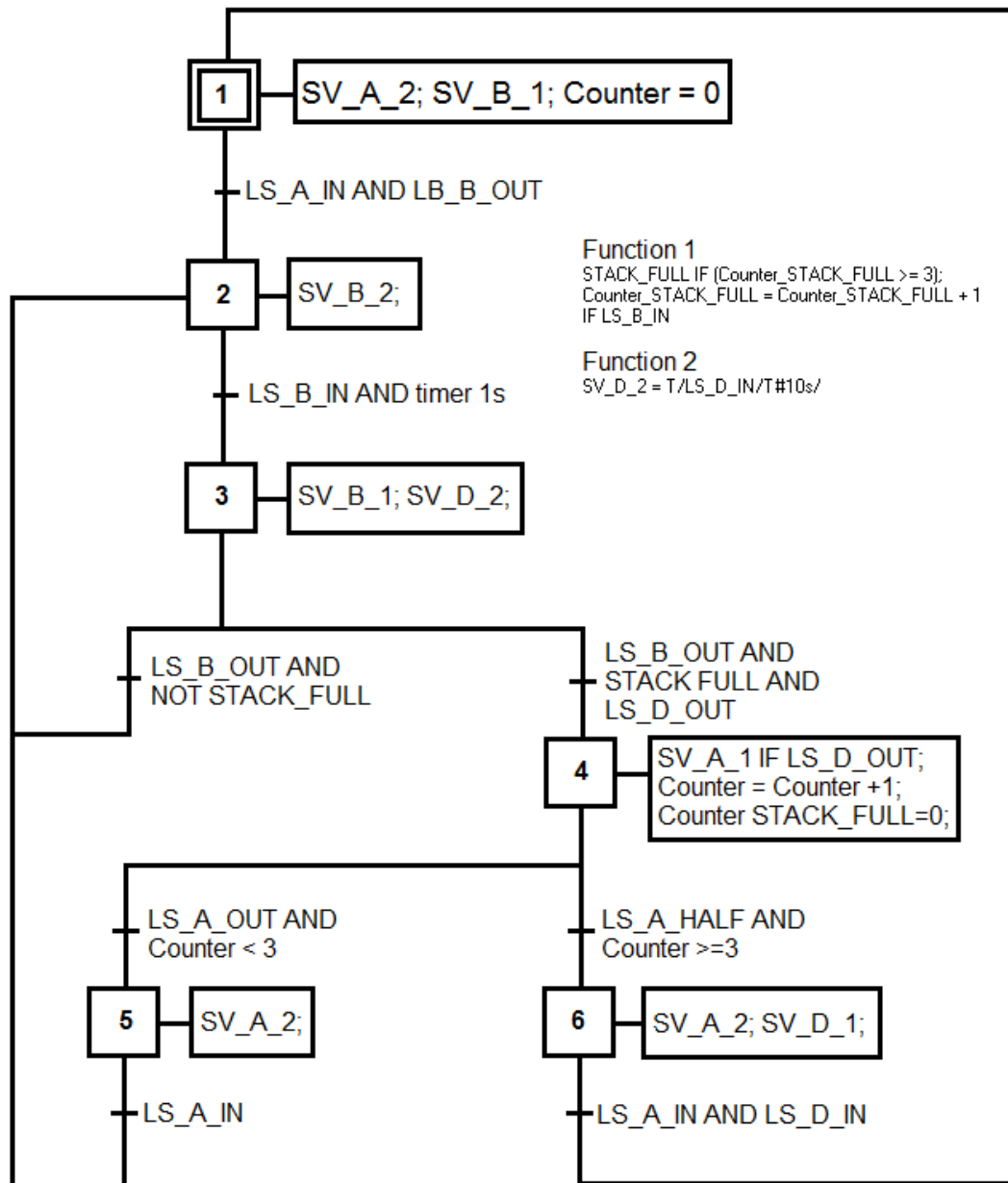


Figure 17: Second part hardware simulation

4.1.3 Third part of the project

[[{[B+B-] x 4} + [A+A-] x 3] x 2]

For the third and final part, the full sequence of the project will be implemented. Since actuator D only need to extend and retract once of the completion of both first and second part, no counter is needed. Instead Actuator D will be triggered by using similar method in second part which is using simultaneous exclusive action of Grafcet using transition condition. Also two function is defined in the program to simplify the Grafcet diagram. Similarly, the hardware configuration for actuator D will be the same as in first part and second part.



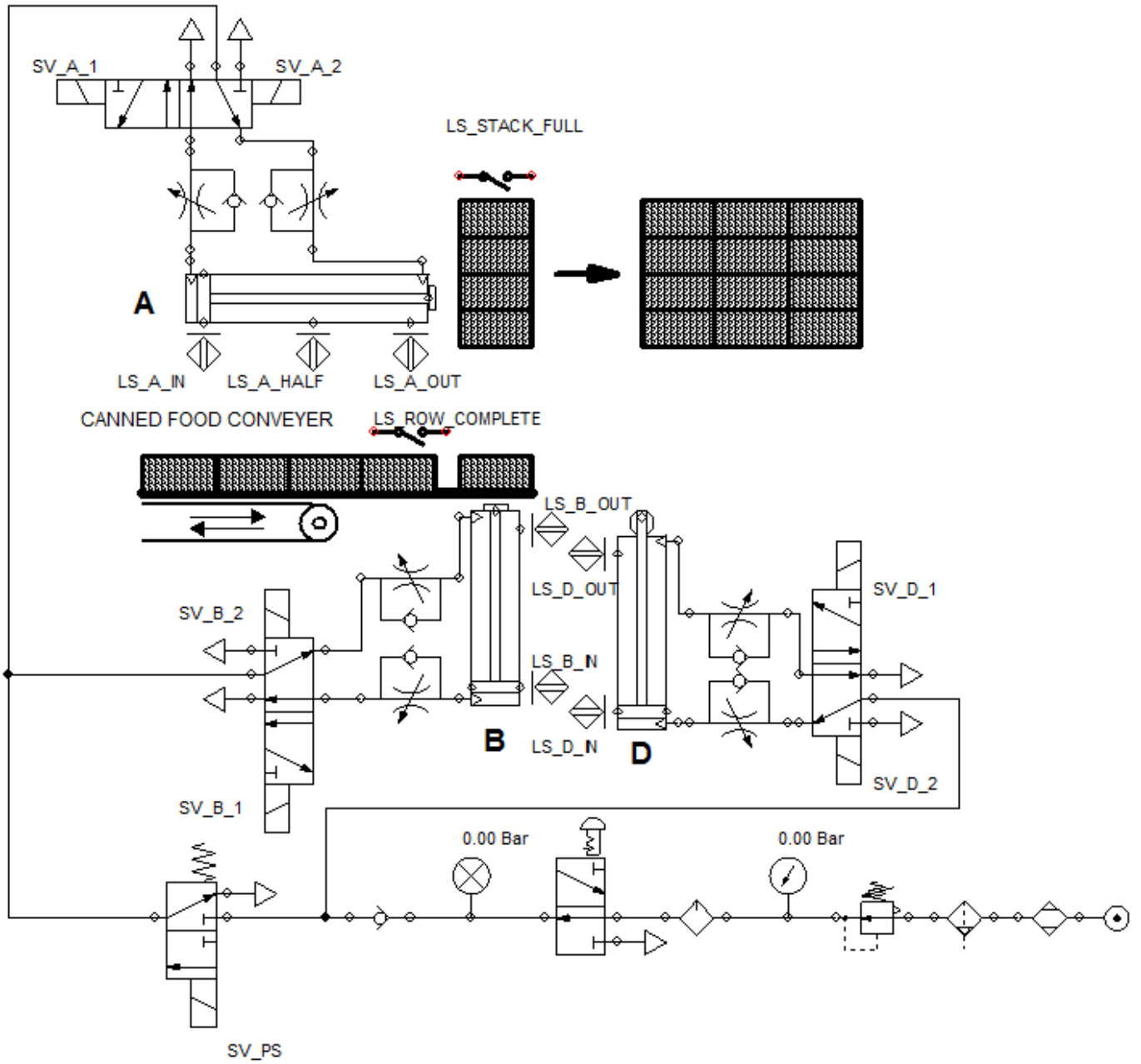


Figure 18: Third part Grafcet diagram and hardware simulation

4.2 Simulation testing

Simulation testing is needed before hardware implementation to verify that the program and hardware simulation is working accordingly. Any small errors that need minor modification and tweak can be done at this final stage before implementing it to the hardware. Thus the Grafcet program is tested and observed. We can see the Grafcet programming in action at this point and it is very different from normal ladder diagram sequence. Steps will not proceed until the transition condition is met.

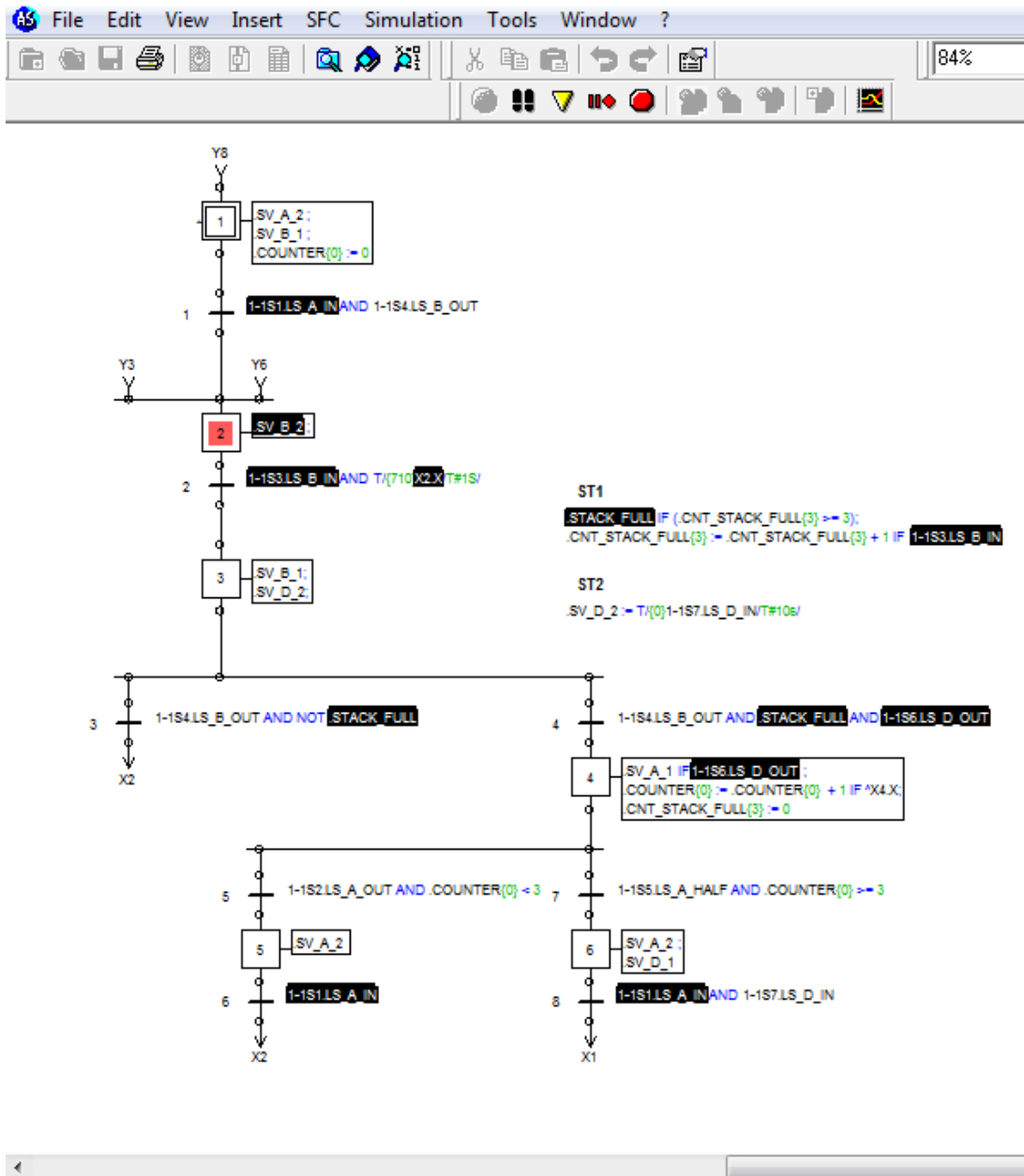


Figure 19: Grafcet simulation testing

For the hardware simulation, the actuator, solenoid valves and proximity switch is tested to make sure that it is following the right sequence tally with the Grafcet program. However, in this simulation, the conveyer motor output is not included. This will be tested later at hardware implementation part.

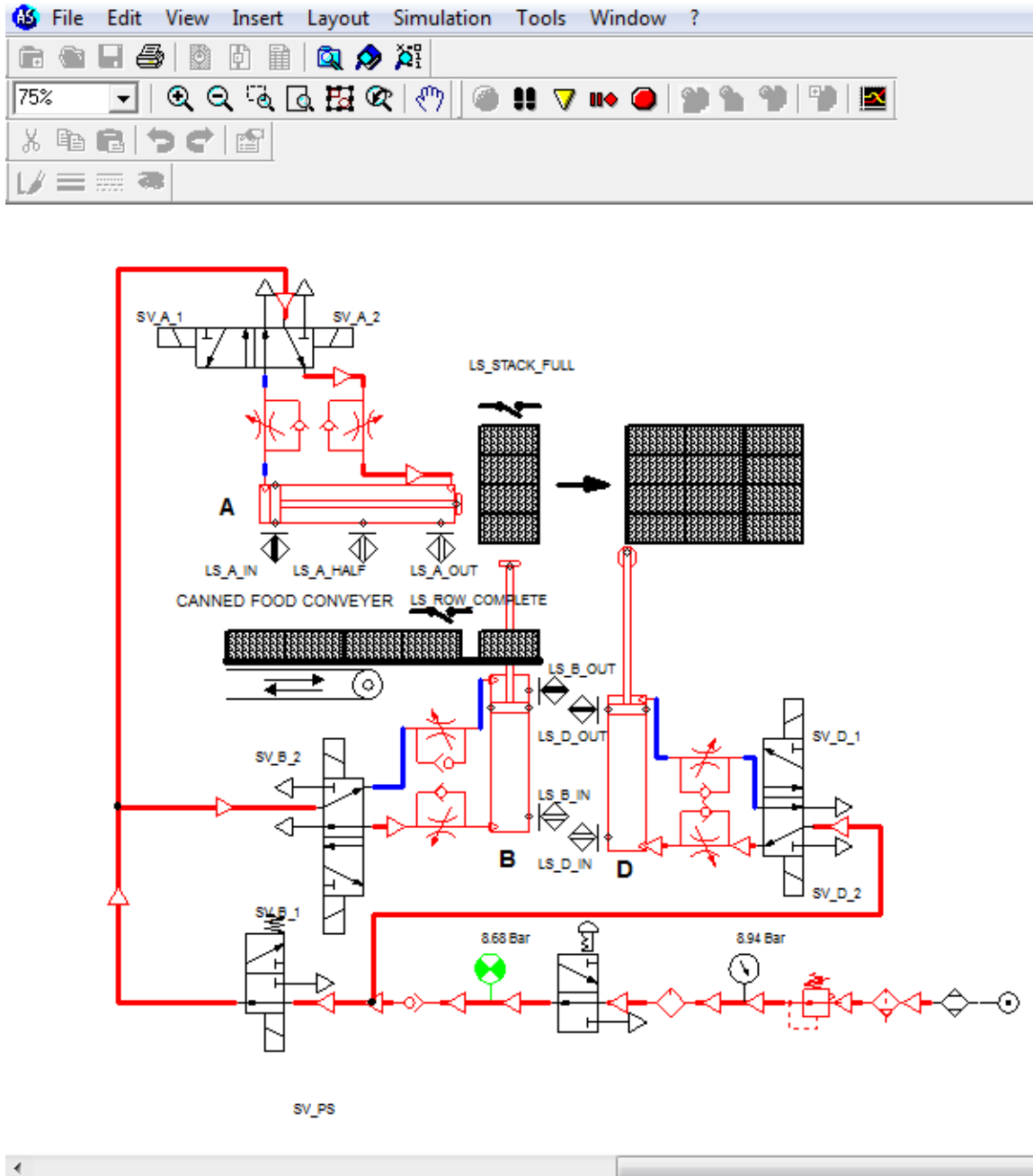


Figure 20: Hardware simulation testing

Overall, the simulation runs according to design. Although the program did hang and lag a little, after a minor modification and fine tuning ,the simulation run smoothly. The simulation is now ready for the next step of this project which is hardware implementation.

4.3 Hardware implementation

4.3.1 Conversion to Ladder Diagram

For testing and demonstration purpose, the program will be run using the PLC available at Universiti Teknologi Petronas lab. However, due to the incapability of the programmable logic controller to run direct Grafcet program, the program need to be converted to ladder diagram before downloading it into the PLC.

There is a formula that can be used to convert the Grafcet diagram to ladder diagram, the formula will convert the Grafcet diagram to Boolean equation which in turn can be used to convert into ladder diagram. Below shows the formula:

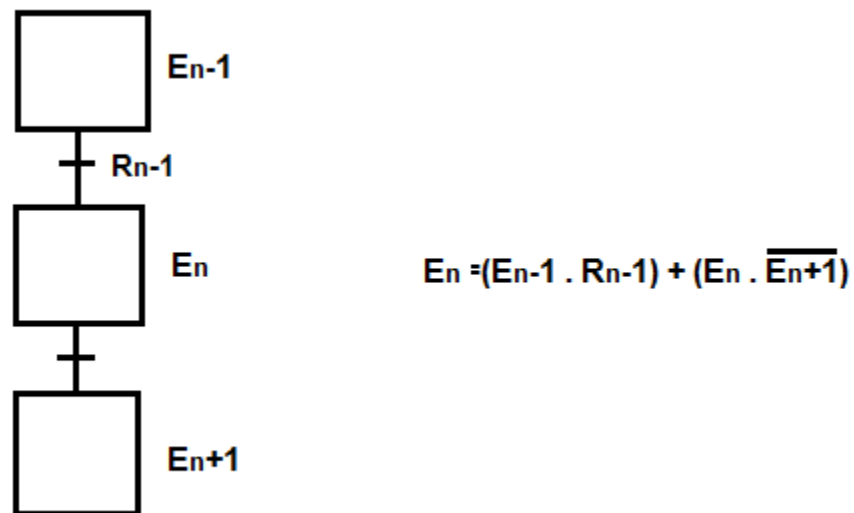


Figure 21: Boolean equation conversion formula

However, after further examining, it is realized that the solenoid valve available at the lab is a 5/2 way single solenoid spring return type valve compare to the designated 5/2 way double solenoid valve used in this project. Therefore, it is not possible to convert the Grafcet diagram to ladder diagram using the Boolean equation formula. Instead, flowchart method is used to create the ladder diagram for the PLC. Below shows the flowchart and ladder diagram.

Sequence: $[(\{[A+A-] \times 4\} + [B+B-]) \times 3] \times 2$

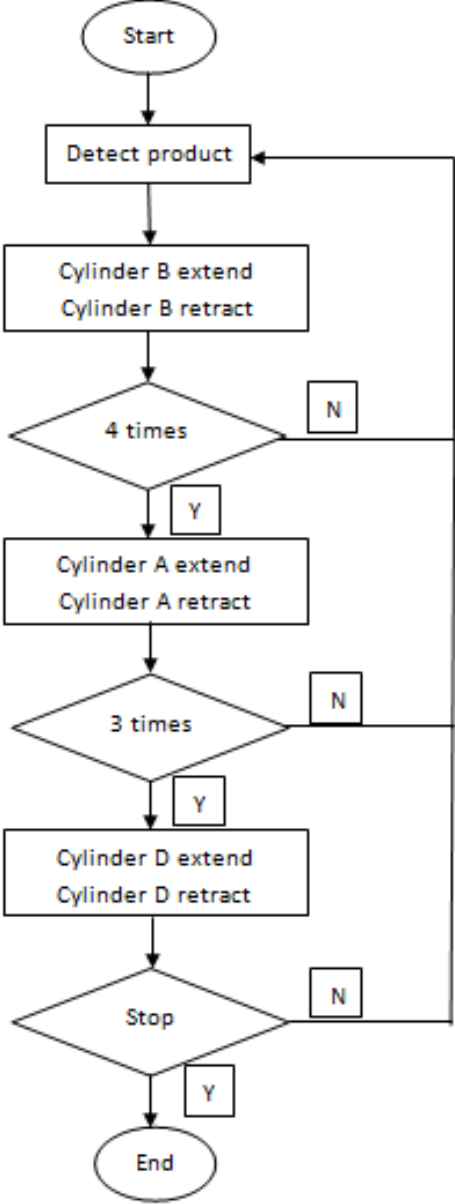
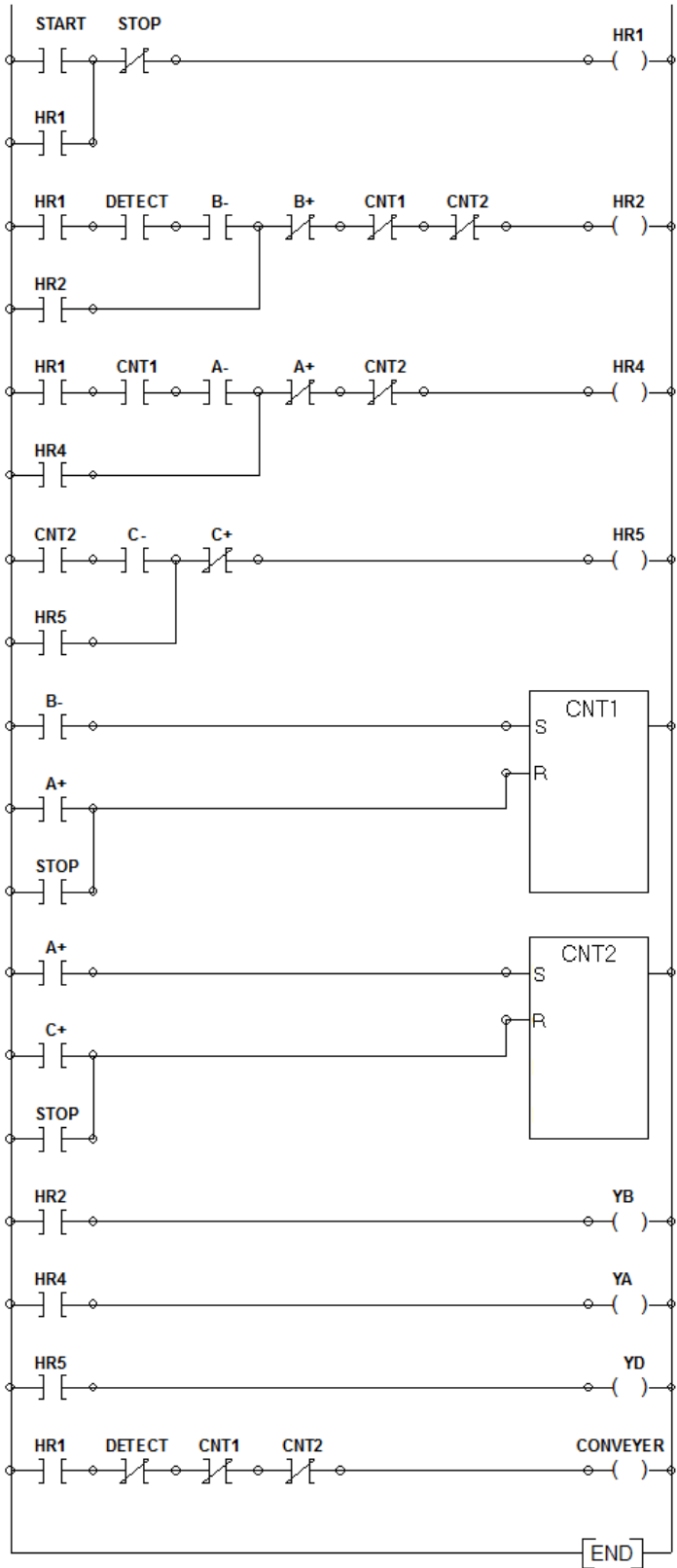


Figure 22: Flowchart diagram



Input	Address
-------	---------

Start	0.00
Stop	0.01
A-	0.02
A+	0.03
B-	0.04
B+	0.05
C-	0.06
C+	0.07

Table 3: Input addresses

Output	Address
YA	100.04
YB	100.05
YD	100.06

Table 4: Output addresses

Figure 23: Ladder diagram

4.3.2 Hardware final preparation

The converted Grafcet diagram is downloaded into the PLC using CX Programmer. The ladder diagram is rewritten and tested accordingly.

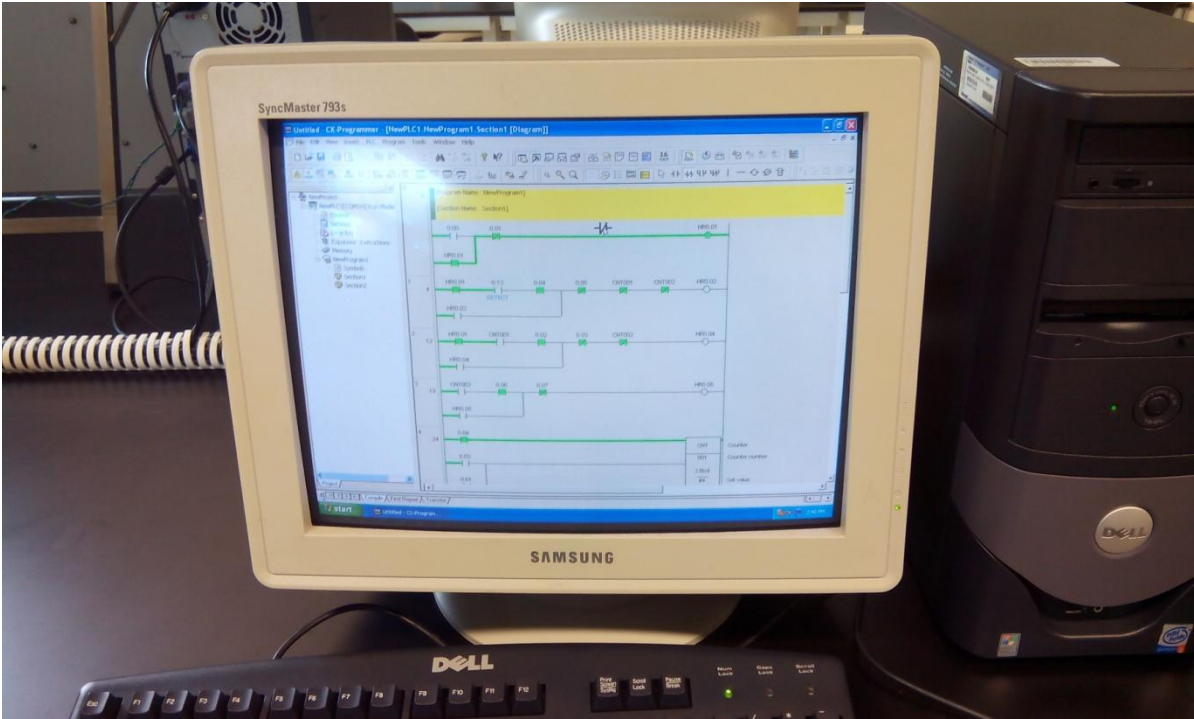


Figure 24: Downloading program

The PLC that will be used in this demonstration unit is an OMRON CQM1H PLC. This PLC support up to 16 input and 16 output assignments. Below shows the PLC unit.



Figure 25: PLC unit

For the hardwiring of the inputs and outputs (I/Os), the connection is done using digital input and output module available in the lab. This greatly reduces the time taken for me to connect all the I/Os and also it is much more organize way to build a demonstration unit.

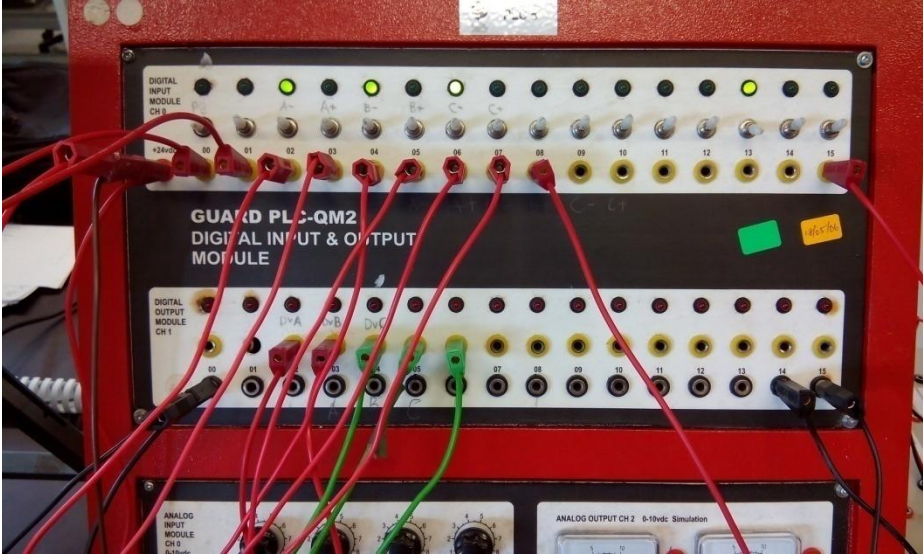


Figure 26: Digital input and output module

For the actuators, the demonstration unit will be using 3 double acting cylinders with 5/2 way spring returned solenoid valve. Also, due to the limited parts available, the proximity sensor will be replaced by a limit switch which will be triggered by the movement of the cylinder.

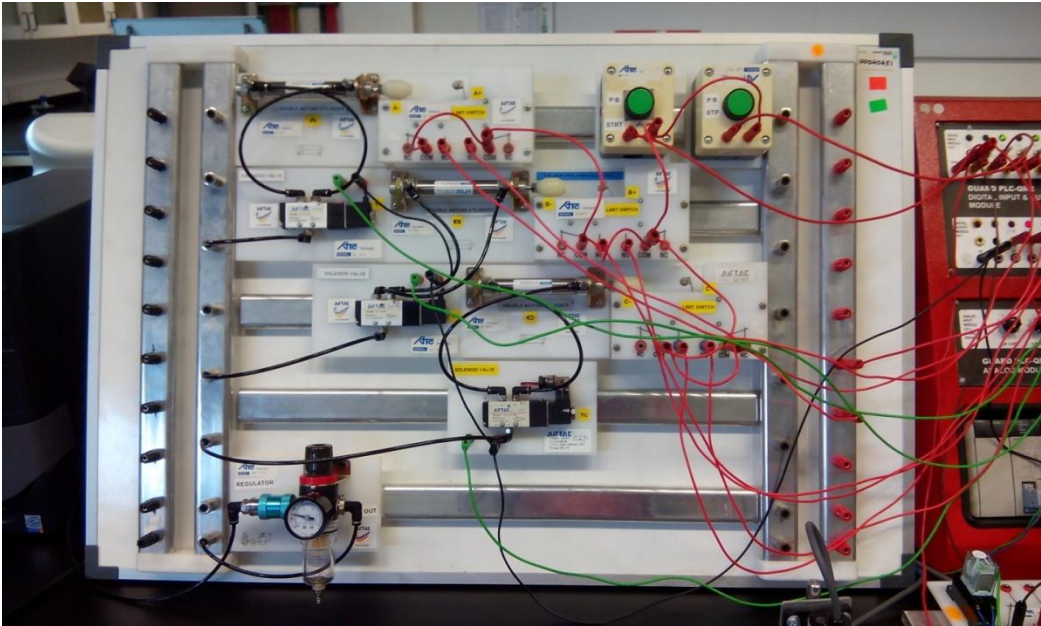


Figure 27: inputs and outputs

4.3.3 Testing and commissioning

After all the hardware and program is setup properly, the automated packaging system demo unit is run for the first time. Below shows the full setup.

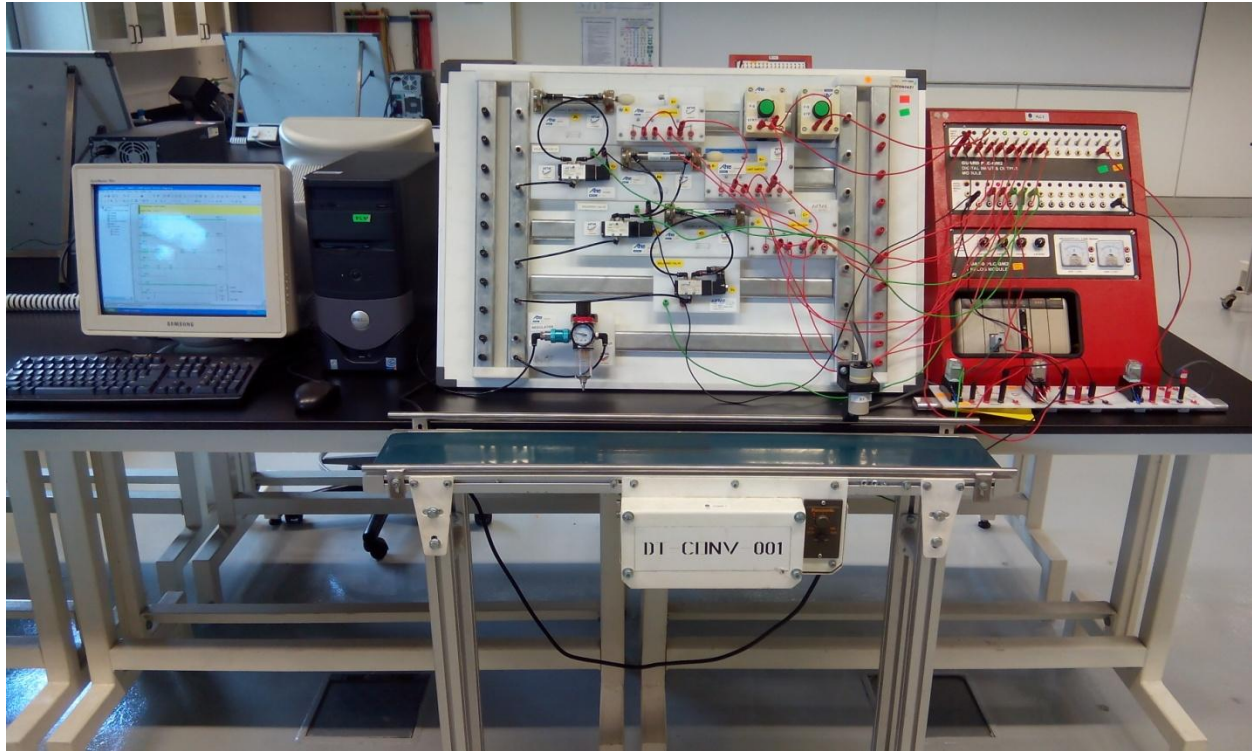


Figure 28: Full setup.

After the first run, it is realized that the first part of the counter system was not working properly. Thus a few minor modifications were done to the ladder diagram by changing the input from actuator B from B+ to B-. After the modification was done, the system run flawlessly. Also a conveyer system which was not previously available in the simulation was added to the system. The conveyer system is controlled by the proximity sensor, counter 1 and counter 2 of the system.

4.4 Discussion

From this project, we can clearly see the advantage of Grafcet in developing a control system. The benefits are numerous but some of the most important one are listed below:

- Grafcet program can be directly implemented to PLC that supports Grafcet program. This greatly reduces the time taken to develop a control system as ladder diagram conversion is not needed.
- It makes program troubleshooting easier as only one part of the program is active at a time.
- It reduces overall PLC program scan time by only scanning active program steps.
- Well suited method for systems that work in sequence.

Other than that, we can also see that the Grafcet diagram is basically a flowchart that has been converted. Actions are beside the sequences compare to the flowcharts which is below. Also addition of step condition is added in Grafcet.

Therefore, new users that are developing program in Grafcet do not need to have tare experience in Grafcet programming as knowledge from flowchart can be use to implement the new Grafcet diagram. This greatly reduces the training time of new staff for companies that deal with PLC programming and thus increasing the profit margin.

This project also emphasize on using PLC as the main controller for the control system. We can clearly see the benefit of using PLC as the control system in this project where program modification can be done easily without interrupting the hardware connection. In a real world, this translates into having a very flexible system that can be alter and tune according to the user needs.

Other than that, PLC is also a very efficient and space saving component. This is because, component such as timer, counter and relay is a built in feature in a PLC. Thus, fewer components are needed in developing the control system hence reducing the overall cost.

Chapter 5: Conclusion and recommendation

5.1 Summary of project

The Grafcet method have proved itself to be very helpful in doing the simulation for the project as sequences and outputs are much more organized and easier to troubleshoot. Other than that, using PLC as a controller in a control system has proved to be very helpful when program modification is needed. PLC also allows great flexibility to user and developer which translate into having a flexible control system. Overall, a reliable and accurate automated packaging system is develop successfully and all the objectives are achieved.

5.2 Future work

For future work, a full prototype should be built to test the workability of the program and hardware. This is because, the demonstration unit only shows the workability of the program not the hardware. Other than that, by building the prototype, the concept used for the stacker system can also be tested and verified.

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APPENDIX 1

Gantt chart

Timelines for FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■												
2	Preliminary Research Work		■	■	■	■									
3	Submission of Extended Proposal						●								
4	Proposal Defence								■	■					
5	Project work continues										■	■	■		
6	Submission of Interim Draft Report													●	
7	Submission of Interim Report														●

● Suggested milestone
 ■ Process

Timelines for FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■								
2	Submission of Progress Report							●								
3	Project Work Continues								■	■	■	■	■			
4	Pre-SEDEX										●					
5	Submission of Draft Final Report											●				
6	Submission of Dissertation (soft bound)												●			
7	Submission of Technical Paper												●			
8	Viva													●		
9	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone
 ■ Process

APPENDIX 2

Key Milestone

