Saimaa University of Applied Sciences
Mechanical Engineering and Production Technology
Automated Sorting System

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Implementing an Automated Sorting System

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Abstract

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The study was commissioned by Timo Eloranta, Faculty at Saimaa University of Applied Sciences. The thesis was approved by the programme manager Jukka Nisonen. The purpose of this project was to create a simulated and theoretical automated process to sort product coming out of the distribution centre. The process designed represented a realistic simulation of the manufacturing facility Nestle/Purina, located in Atlanta, Georgia, USA.

The original method of sorting the product consisted of manually driven forklifts that took the product from the distribution station to the storage location within the warehouse. The system that has been designed is connected to a programming logic controller. When implemented it is designed to work seamlessly with the distribution center, automatically transporting the different products to their designated location within the warehouse.

Based on the findings from this thesis, it is shown to be possible to eliminate most of the manual labor. Replacing the manual sorting method with this modernized system showed an increase in efficiency by 70%. The company that this has been designed for would also save money over the course of time. Although the initial investment of this project is quite high the overall effect on efficiency and monetary savings would be gigantic, projected to be around 63%.

Keywords: Programming logic controller, automated process, distribution center

Contents

1 Introduction

The thesis will concentrate on designing and implementing a realistic simulation for an automated method of sorting bags of product coming from the distribution side of manufacturing plant located in Atlanta, Georgia, USA. The goal is to develop a technique using mechatronics technologies, to automate the sorting.

1.1 Factory Description Currently

The factory discussed is known as Nestle/Purina located in Atlanta, Georgia, USA. It is one of the largest manufacturers of pet food in the South Eastern United States. It provides product for the majority of retail stores located within the South east. While they have other factories, nationwide in the USA and internationally in Europe this thesis will only be discussing the plant mentioned previously. The manufacturing plant employs over 600 people and is entirely self-contained. It bakes, bags, wraps, stores, and ships directly to retail locations.

1.2 Process Description Currently

The current system of production and distribution is automated. However; the sorting system uses a manual method. Forklift drivers use a database mounted to their vehicle which contains the selection of product for the driver to pick up. Once the driver has confirmed the product in the database is loaded onto their lift they then move it to its location within the warehouse. The product is usually stacked vertically, depending on the size and which product the forklift driver is relocating. After the product is released from the lift, it is then scanned manually via RFID readers similar that ones that are used in local grocery stores.

As seen from an older original blueprint (simplified for viewing) of the factory (Fig. 1), it remains unchanged.

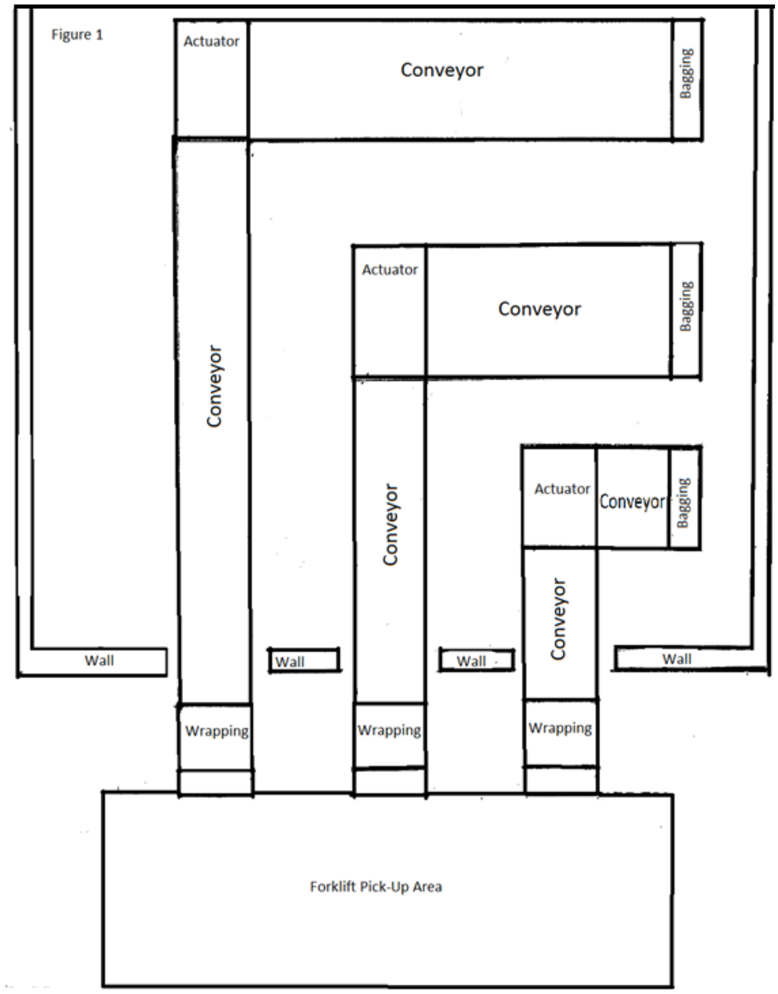


Figure 1 shows the enclosed space of distribution and how the distribution stations are brought to the fork lift area.

2 Limitations and Regulations

In this section the requirements, rules and regulations will be discussed.

2.1 Automation of the sorting System

It is required to be an automated system but have a manual start and emergency stop button. There is to be as little manual input as possible.

2.2 Handling Requirements

The handling requirements stem from the existing distribution methods and then the product is passed on to the automated system. There will be no external handling besides automated arms and conveyors.

2.2.1 Forces

The forces exerted on the conveyor belt are not to exceed 5,000 Newtons pounds per product. The forces on extorted horizontally by the lever arms are not to be over 5,000 Newtons.

2.2.2 Acceleration

The acceleration of the bags from non-movement to movement is not to exceed .5 meters per second squared. The deceleration maintains the same restrictions. Both of these values do not include the coefficient of friction μ_R (Rollers).

2.3 Storage Requirements

The products involved in the storage process are to be located in a space covered from outside environmental elements. They do not require a certain space. All of the different products must be wrapped by the plastic by the dispenser in the distribution before they can be moved to the storage location. They may be placed on the ground directly or stored on a shelving. They may also be put into bins with rollers. There must be a clear and distinct separation of each product. The storage location must be marked to indicate which product is to be placed in their respective locations. A similar example of a storage container can be seen below in Figure 3.

(Figure 2)

2.3.1 Package Requirements

The coloring of the cat and dog food bags are to be labeled so that the dog food bags are light colored and the cat food bags are dark colored. The limits of the colors are chosen according to the specifications of the sensors. This information can be found within the included documentation. The packaging must not be altered in anyway and distortion of the labels must be avoided. Any distortion, rips, tearing, or holes of the packaging must be avoided. There will be no external wrapping other than what is already provided by the plastic dispenser within the distribution area of the plant. Currently used barcodes can be swapped to RFID tags if deemed appropriate.

2.4 Costs

This section will cover the costs of the project. It will discuss the current costs and allocation of labor resources as well as the future estimated savings of the sorting system. The costs are to be reduced by 30% after the initial project price. The implementation cost of the project is estimated to be over $50,000. The initial budget is not to exceed $100,000.

2.4.1 Daily Use Cost

Currently calculating the number of employees and their hourly rates it shows that manual labor personnel alone is currently costing Nestle-Purina and estimated $10,560 each day from just the forklift drivers. The estimated costs for the managers and other essential staff is estimated to be $3,200 per day. This totals to be $13,760 a day in personnel costs. The requirements for this project are to reduce these costs daily by at least 30%.

2.4.2 Maintenance Cost

Maintenance costs are the primary budget resource currently for Nestle-Purina. According to a conservative estimate; it shows that the current cost for technicians and maintenance specialists is $3,520 per day. In addition to the cost of technicians; the cost to operate propane powered forklifts cost an estimated $8400 per day. The total cost for maintenance and to run the forklifts currently costs $11,920. The requirements for the project are to reduce these costs by at least 30%.

2.4.3 Investigation Cost

If a required regulatory investigation is needed then it is not to exceed $5,000 per visit. OSHA inspectors do not cost upon the initial inspection of the plant.

2.4.4 Insurance Requirements

There is an obligation required by state law to have insurance for the automated system. This insurance required covers risks that involve all environmental disasters and plant accidents that occur. There is also a security insurance required because of the automated nature of the system. The pricing of these services combined cannot exceed $10,000 a month.

2.5 Construction Requirements

The purpose of this thesis project is only simulate the proposed sorting system. The construction of conveyors, sensors, belts, motors and other assemblies are not within the scope of this project. Components that could be utilized for assembly will be mentioned if an upscale from simulation to a prototype were to take place for this specific application.

2.6 IT Implementation

The IT system and databases that belong to this system are not modified. They may only be connected to for the purpose of transmitting data. The services already installed by the company will be used and the data will be handled by the personnel responsible for it.

2.7 Environment Requirements

The temperature of the storage room is not to exceed 40 degrees Celsius. The sorting area is not to exceed 40 degrees Celsius. There are 8 fans required to be in the sorting area to prevent dust build-up.

2.8 Risk prevention requirements

There is a 1 meter gap between the conveyor systems and personnel maintained by a 1 meter tall metal fence. There are two doors with optical sensors that will shut off the operations if it crossed while in operation unless otherwise given an overwrite command. The Occupational Safety and Health Administration has issued regulations for conveyor safety, as OSHA 1926.555.

2.9 Area of Operation

The production and distribution areas are restricted and not interfered with in this project. The packing of the product is not included in the scope of the thesis.

2.10 Efficiency Increase

The requirement of this project is to increase the efficiency of sorting the product by 35%.

3 Theory

This section is for understanding the theory involved for all of the topics that will be used during the thesis. It will discuss the uses, types, costs, the innovations, and how it works.

3.1 Different Sorting Constructions

There are many different types of sorting systems in the world, large systems and small systems. Sorting can be manually done or automated, or it can be a mixture of both. Sorting systems that are automated can be done with hydraulics, pneumatics and/or RFID systems.

3.1.1 Large Systems

Conveyors are commonly implemented to assist in the transportation of products throughout its manufacturing and assembly process.

Seen below (Figure 3) is the Denver, Colorado airport baggage sorting system. This is an example of a large complex automated system with manual input for loading and unloading baggage, luggage, and other parcels.

Figure 3. A conveyor belt system of inclined, vertical, and L shaped are used in combination to transport luggage to the appropriate plane.

3.1.2 Small systems

Smaller scale sorting systems are commonly used in the food storage industry. Other applications include pharmaceuticals, libraries, and sports, such as bowling. The postal sorting system is another example however; it is not done with automation but by manual labor. It is done by cross checking a database and then manually placing the object in its defined position. The figure below describes a simple sorting system with almost no automation besides the conveyor belt.

3.2 Conveyor Systems

In general conveyor systems are used in many different industries because of all of the advantages they provide. Conveyors can transport items from place to another easily and quickly. They can move all different sizes shapes and of products. Conveyor systems can be installed almost anywhere with many different layouts and operation modes available. Some examples include mechanical, hydraulic, and fully automated systems. When compared to manual labor that would be stressful and strenuous conveyor belts are an obvious advantage.

3.2.1 Conveyor Types

There are different types of conveyor belts that can be used to transport products. These can include, inclined conveyor belts, conveyors with a directly flanged motor, center drive conveyors, L shaped conveyors and vertical conveyors. Incline conveyors are usually the standard conveyor used in transporting objects from level to another. Typically a rubber surface is used to maintain the highest amount of friction. There are varying conveyor surfaces to fit the different needs of the product being transported. Conveyors with a directly flanged motor are the most common in the industry - typically a flat conveyor with a motor attached next to it. These can be used with inverters to vary the speed of the conveyor. Centre drive conveyors can be used in conjunction with other workstations. It can attach to machines / robots already functioning and the conveyor is treated as an attachment, or tool rather than an independent workstation. Another commonly seen conveyor in industry is the L shaped conveyor. It serves as a way to change the direction of motion for the product. It uses a 90° deflection angle an arm. It can also use an actuator to assist in guiding the product onto another workstation. Vertical conveyors are known as freight lifts. They are used to raise or lower materials or products to different levels during the handling process. These are usually not designed to carry large loads. They are constructed vertically and have horizontal forks perpendicular to it which enable other conveyors to slide materials or products onto it.

3.2.2 Belt Types and Material

When applying a conveyor system there are different belt types for different purposes. However; once a belt type is selected, there are other specifications that need to be considered, such as how it is cleaned, maintained, replaced.

3.2.2.1 General Purpose

This is a wide group made that is generally made with rubber materials. Other materials that the conveyors are made out of are Urethane, Neoprene, Nylon, Polyester, PVC, and Nitrile. These are common in bulk handling operations because of their high friction surfaces. Their surface friction is generally high but material can slide when being accumulated on the belt. They are able to move material on inclines and declines. They are cut resistant, and can withstand high temperatures. (Bastian Solutions, 2013)

3.2.2.2 Plastic Belting Chain

This is often referred to as MatTop belt or Microspan belting. The benefits of this belt type include wear resistance, and lightweight because of the small gaps. Common applications include food production, pharmaceuticals, and packaging. (Bastian Solutions, 2013)

3.2.2.3 Hinge Metal Belting

Hinge Metal Belting is the most durable of the different belt types. It is often used for materials with edges. It is often used in removing chips and metals scraps. Common applications for the belt type include, die cast operations, high temperature operations, as well as in wet and dry conditions. (Bastian Solutions, 2013)

3.2.2.4 Woven Wire Belting

This belt type is specifically for high and low temperature operations. Some manufacturing processes that qualify for the use of this belt would be – Heat treatment of parts and moving those parts throughout the plant. If there is freezing involved in the food industry then this belt would be applicable there as well. (Bastian Solutions, 2013)

3.2.3 Belt Surfaces and Material

Depending upon the needs of the manufacturer and the properties of the environment and the product being transported itself, different conveyor surfaces are needed. There are surfaces that have a higher tolerance to temperature variation and surfaces that have a higher friction coefficient. There are also surfaces with a lower coefficient of friction so that if needed when the parts are being allocated onto the conveyor they can be grouped easily by sliding along the conveyor surface. Seen below in Figure 4 there are a few examples of different surface types.

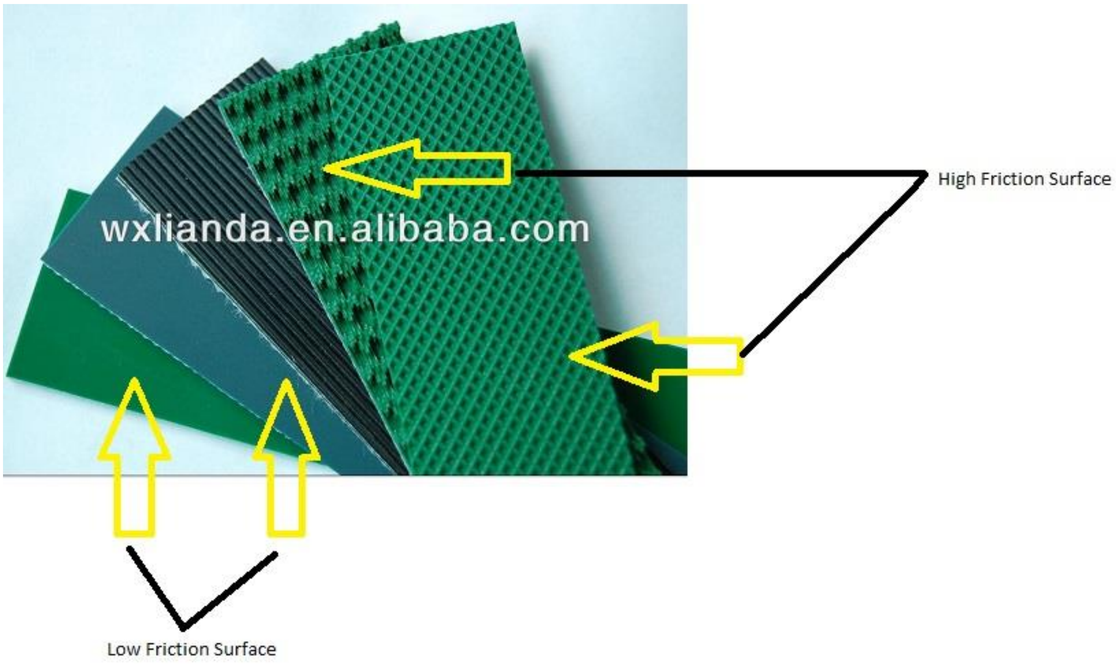


Figure 4. These conveyor surfaces shown all have different applications depending on the types of products that will be transported

3.2.4 Conveyor Forces

When choosing a conveyor, the material, forces, motor, rollers, and product mass must all be considered. On top of the specific components there must be considerations taken for the environment, and temperature.

3.2.5 Conveyor Variables

There are many different conveyor belt types but the most common type uses rollers along with a rubber material covering them. These calculations will exclude any other conveyor types. The variables needed to be considered depending on the conveyor construction can be seen below in Figure 6.

Force on each belt strand	F	N
Maximum belt pull (at drive drum)	F_1	N
Minimum belt pull (at drive drum)	F_2	N
Effective belt pull	F_U	N
Shaft load at drive drum	F_{WA}	N
Shaft load at end drum	F_{WU}	N
Motor power	P_M	kW
Calculated power at drive drum	P_A	kW
Belt pull at 1% elongation per unit of width	SD	N/mm
Drum/roller width	b	mm
Belt width	b_0	mm
Geometric belt length	Lg	mm
Calculation constants	c..	–
Drum/roller diameter	d	mm
Drive drum diameter	d_A	mm
Rolling resistance of support rollers	f	–
Difference in drum radii	h	mm
Coefficient of friction with support rollers	μ_R	–
Coefficient of friction with accumulated goods	μ_{ST}	–
Coefficient of friction with skid plate	μ_T	–
Acceleration due to gravity	g	$9{,}81 m/s^2$
Production tolerance	Tol	%
Upper support roller pitch	l_o	mm
Lower support roller pitch	l_u	mm
Transition length	l_s	mm
Mass of material conveyed over whole conveying length (total load)	m	kg
Mass of belt	m_B	kg
Mass of all rotating drum/rollers, except drive drum	m_R	kg
Mass of conveyed goods on upper side (total load)	m_1	kg
Mass of conveyed goods on return side (total load)	m_2	kg
Mass of conveyed goods per m of conveying length on upper side Line load	m'_o	kg/m

Tension take-up range	Z	mm
Total tension take-up range	X	mm
Height of lift	h_T	m
Conveyor length	l_T	β
Belt speed	v	m/s
Belt sag	y_B	mm
Drum deflection	y_{Tr}	mm
Arc of contact at drive drum and idler	β	°
Opening angle at drive drum	γ	°
Incline (+) or decline (–) angle of conveyor	α, δ	°
Elongation at fitting	ε	%
Drive efficiency	η	–
Density of material conveyed	ρ_S	kg/m^3

Figure 6. This shows a table of the different possible variables that needs to be taken into consideration

3.2.6 Load and Friction Calculations

Total load of the conveyor belt can be calculated from formula 1:

$$m = l_T \cdot \text{mass of conveyed material per m} \quad (1)$$

Effective belt pull can be calculated from formula 2:

$$F_U = \mu_T \cdot g \cdot (m + \frac{m_B}{2}) + \mu_R \cdot g\,(\frac{m_B}{2} + m_R) \quad (2)$$

3.2.7 Force Calculations for Rollers

Effective pull on rollers with or without an inclined plane can be calculated from formula 3:

$$F_U = \mu_R \cdot g\,(m + m_B + m_R) \overset{(-)}{+} g \cdot m \cdot \sin\alpha \quad (3)$$

3.2.8 Inclined and Decline Force Calculations for Conveyors with a Skid Plate and Rollers

Effective pull on an inclined plane with rollers and a skid plate is calculated by formula 4:

$$F_U = \mu_T \cdot g\,(m + \frac{m_B}{2}) + \mu_R \cdot g\,(\frac{m_B}{2} + m_R) \overset{(-)}{+} g \cdot m \cdot \sin\alpha \quad (4)$$

3.2.9 Coefficient of Friction Guidelines

The usual coefficient of friction for skid plates and rollers are found from:

µT (skid plate)	0.33
µR (rollers)	0.033

3.2.10 Max Belt Pull

Max belt pull can be calculated from formula 5:

$$F_1 = F_U \cdot c_1 \quad (5)$$

C_1 is a constant used for the drive drum

C_1 can be chosen from the table according to incline and physical property:

Arc of contact β	180°	210°	240°
smooth steel drum			
dry	1.5	1.4	1.3
wet	3.7	3.2	2.9

3.2.11 Minimum Drive Diameter

Minimum Drive Drum Diameter can be calculated from formula 6:

$$d_A = \frac{F_U \cdot c_3 \cdot 180}{b_0 \cdot \beta} \quad (6)$$

C_3 is a constant that can be chosen from the table below:

smooth steel drum	
dry	25
wet	50

3.2.12 Power at Drive Drum

Power can be calculated from formula 7:

$$P_A = F_U \cdot v \quad (7)$$

3.2.13 Motor Power

Motor power needed can be calculated from formula 8:

$$P_M = \frac{P_A}{\eta} \text{ [kW] = next largest standard motor is chosen} \quad (8)$$

3.3 Sensors

A sensor is a transducer that detects characteristics of its surrounding environment and then relays the information to be interpreted. Sensors are used in everyday devices. An elevator contains a tactile sensor that must sense a compressive force in order to activate. In manufacturing sensors are used to monitor temperature, pressure, or flow. The qualities of a well-balanced sensor usually follow:

- The sensor is sensitive to the measured property only.
- The sensor does not affect the measured property

Automated sorting systems use some sort of sensor type to command and direct the handling process. It could be controlled by optical sensors or an inductive sensor. Or a mixture of any of the other types of sensors.

3.3.1 Sensor Types

This section will go over the different sensor types and switches. The different types that are applicable for this situation are:

- Pressure Switch
- Analogue Pressure Sensors
- Analogue Flow Meter
- Displacement Encoder
- Capacitive Proximity Switch
- Magnetic Proximity Switch
- Optical Switch

A pressure switch relays an electrical signal when the preset switching pressure at the pneumatic pressure switch is exceeded. Analogue pressure sensors relay the information from the adjacent pressure and transform it into a proportional electrical voltage signal. The voltage ranges from 0-10V. The analogue flow meter measures the volumetric flow and transforms it into a proportional electrical voltage signal. The voltage ranges from 0-10V.

A displacement encoder measures the displacement of a piston and encodes that to a voltage. The voltage ranges from -10V to 10V this component requires its own power supply of at least 13V. The capacitive proximity switch is a sensor that closes a switch when its electrostatic field is changed. A magnetic proximity switch is a sensor that closes a switch when a solenoid is brought near to it. And lastly an optical switch is a sensor that closes when the light barrier it produces is interrupted. These can be used to sense light and dark colors.

3.3.2 Sensor Faults and Failures

Due to the nature of sensors, they have the possibly of failing. When sensors fail they have the possibility to interrupt manufacturing, cause a loss of efficiency, monetary cost, or even harm to operators. It is important to know the possible sensor failure modes within each type.

3.3.2.1 Optical Sensor Failure

This sensor can fail when there is a dusty environment so that the light barrier cannot penetrate properly and it will in turn trigger the switch giving a false positive. There is also a failure if the property to be measured is too far away from the sensor. Reflective surfaces can also pose a problem although rare, possible.

3.3.2.2 Magnetic Sensor Failure

This sensor can fail when there are magnetic surfaces near it. Caution must be taken when deciding to use this, products passing by must not contain any magnetic material.

3.3.2.3 Capacitive Sensor Failure

This sensor is sensitive to object that can disrupt its electro static field. It should not be used in conjunction with devices or products that have their own electrostatic fields.

3.4 Actuators

An actuator is a type of motor that controls a mechanism or a system. These are commonly utilized to control the arms or levels that attach to conveyor systems. They can be used to introduce motion and they are responsible for moving or guiding the material, within the handling phase. The movement can be linear or non-linear. The different types and their benefits are discussed below.

3.4.1.1 Pneumatic

A pneumatic actuator is provided energy by compressed air, which then converts that into a linear or rotational motion. Pneumatic actuators have a high velocity as well as acceleration and deceleration. There is no required storage of the power source. Valves are responsible for converting the compressed air to force.

3.4.1.2 Electric

An electric actuator is powered by a motor that converts electricity to mechanical torque. Electricity is more readily available than other options.

3.4.1.3 Thermal and Magnetic

A compact alternative to larger actuators these are powered by energy from magnets.

3.4.1.4 Mechanical

This is the most dependable type of actuator. It can supply high forces but the energy use is high. It can also be a very dirty process because of oils and lubrications needed to keep high efficiency.

3.5 PLC

PLCs programs are used to control the hardware inside of a mechatronic system. It is commonly used in assembly lines and light fixtures. If a PLC is programmed incorrectly it can result in lost productivity and dangerous conditions. The advantages of using PLC simulation are the ability to save time and increase the level of safety around machinery and equipment because different scenarios can be simulated beforehand. Programming logic controllers can be an expensive investment when compared to manual labor. PLC devices can optimize efficiency and save money when used over a long duration (Song Lin, 2011)

3.5.1 PLC Software

3.5.1.1 Siemens

Step 7 Software is a popular PLC programming software that enables the use of different hardware with programming. Step 7 allows digital information to be transformed into analogue input and then into mechanical motion.

3.5.1.2 Rockwell

Rockwell is a control software that is popular in enabling batch motion systems. Along with the ability to control the machine system, Rockwell is popular for providing feedback on actions.

3.5.2 PLC Hardware

The most basic setup involving a PLC system uses a rack to hold the CPU, Ethernet chords, and usually a digital, to analogue converter. Siemens produces, hardware for their own software. Festo also manufactures and produces hardware. Allen-Bradly produces the components for connecting the hardware. PROFIBUS AND PROFINET will also be essential in connecting multiple devices to the PLC CPU. An example of this can be seen below in figure 11.

3.5.2.1 Profibus

PROFIBUS (Process Field Bus) is a commonly utilized method of communication with automation. PROFIBUS DP (Decentralized Peripherals) is the variant of PROFIBUS used to control sensor and actuators.

3.5.2.2 Profinet

PROFIT net is an industrial Ethernet used to handle the data that is being transferred from master control devices and slave functional devices. PROFINET has been designed to be more easily accessible because of the Ethernet connectivity.

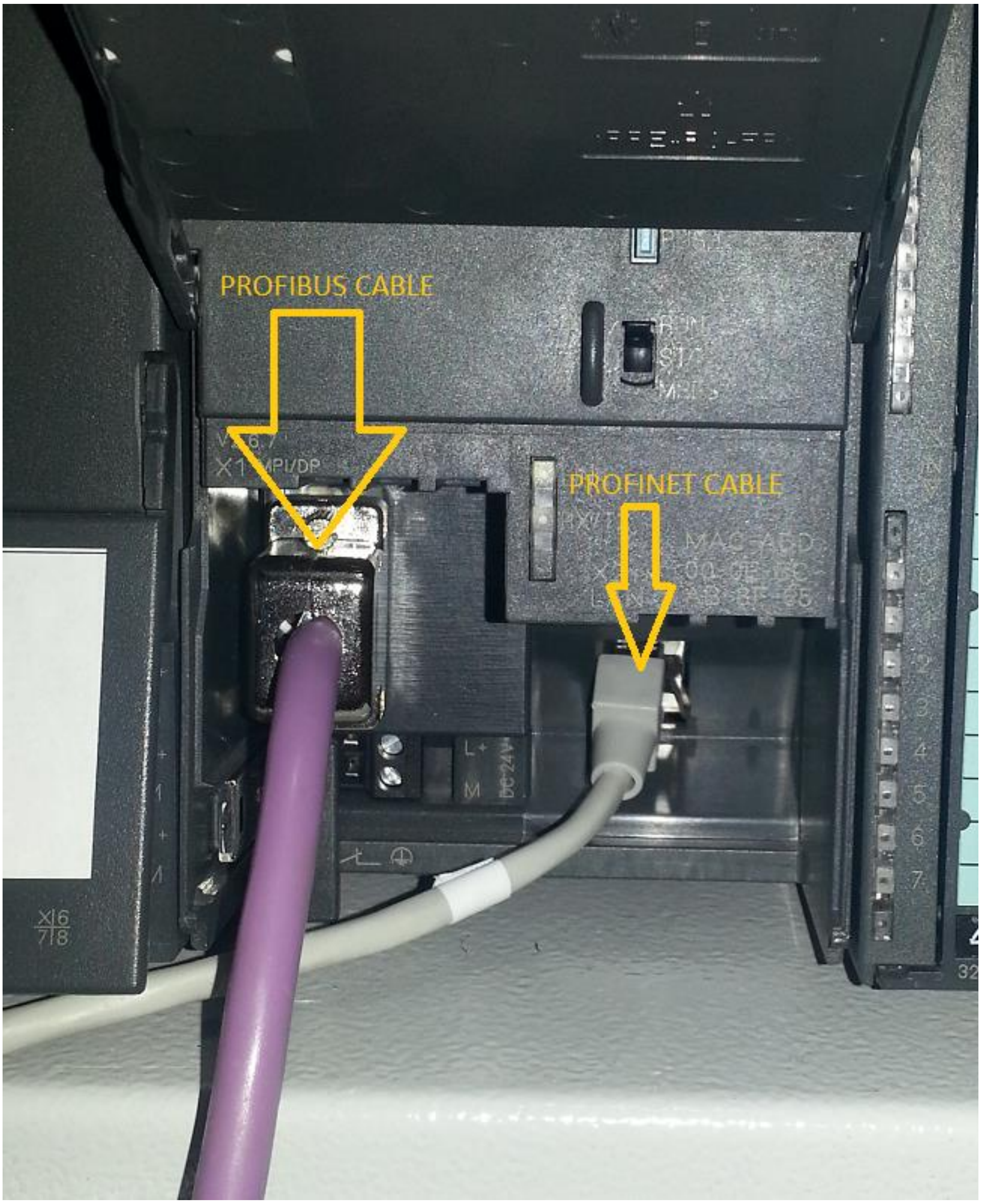


Figure 5. These cables are used to transfer information either by directly connecting or by using an Ethernet connection.

3.5.3 PLC programming language

There are many different syntaxes for programming a PLC but they all share a similar logic. This is most commonly shown in the form of Ladder logic. Ladder logic was designed for relay tracks used to control manufacturing and other machine processes. Usually ladder logic is programmed with an additional human computer interface. Although ladder logic is similar, there will not be complete compatibility between the systems that are from different companies. Shown below in Figure 6 is an example of ladder logic notation for a distribution station.

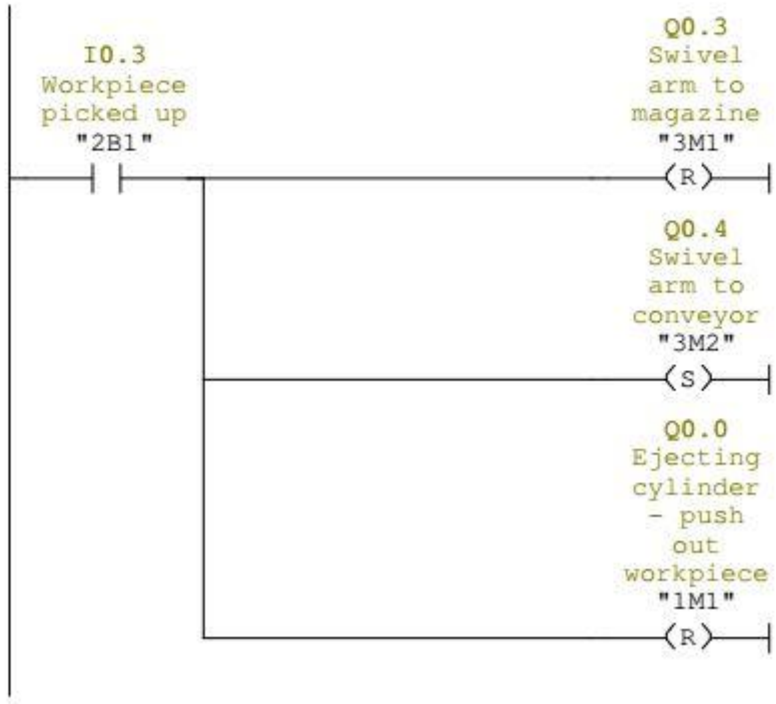


Figure 6.This figure shows ladder logic for basic “If then” commands.

3.5.3.1 Step Counter

A step counter is a way to separate a sequence of commands using PLC logic. Normally when a PLC runs that logic that it is given, it will run the program thousands of times per second. Therefore; there needs to be a way to separate the steps. This is done by moving a bit from step to step and so that the next step can only be completed when the former is.

3.6 Package Recognition

Package recognition is a newer technology used in logistics and manufacturing in order to increase efficiency, whether it is for sorting, packing, or the manufacturing of the product itself.

3.6.1 Bar Codes

Basic barcodes represent data by varying the spacing of parallel lines and can be referred to as 1 dimensional. More advanced barcodes known as QR codes represent data in the form of blocks or hexagons. State of the art barcodes are a mix of data represented by shapes in the form of a barcode and a RFID "tape". An example of this can be seen below in figure 10. As systems become more advanced the type seen below, known as EAS is being used more widely because they are cheap and can be mass produced. They store more information than barcodes with RFID. Figure 7 shows and example of disposable RFID barcodes.

Figure 7. The RFID strip is on the adhesive side of the sticker, the barcode being normally shown can be read by a barcode reader, but also by a RFID reader.

3.6.1.1 Drawbacks

Barcodes require a direct line of site and need to be positioned relative to the scanner so that it can be read probably. Damaged bar codes become useless.

3.6.2 RFID

RFID stands for radio-frequency identification, which uses electromagnetic fields to wirelessly transfer data. The amount of data stored is limited to the size of the chip, and is generally used for identification or tracking.

3.6.2.1 Tags

There are three types of RFID tags. They can be active, passive, or battery assisted passive. A passive tag is the cheapest because it does not contain a battery. It works by using the energy transmitted by the reader. An active tag contains a battery and can transmit its ID autonomously. A Battery assisted passive tag is only activated when there is an RFID reader nearby.

3.6.2.2 Frequencies

In general the lower the frequency the lower the range that it can be read from, and the slower the data transmission speed.

Examples of the benefits and drawbacks can be seen below in Figure 8.

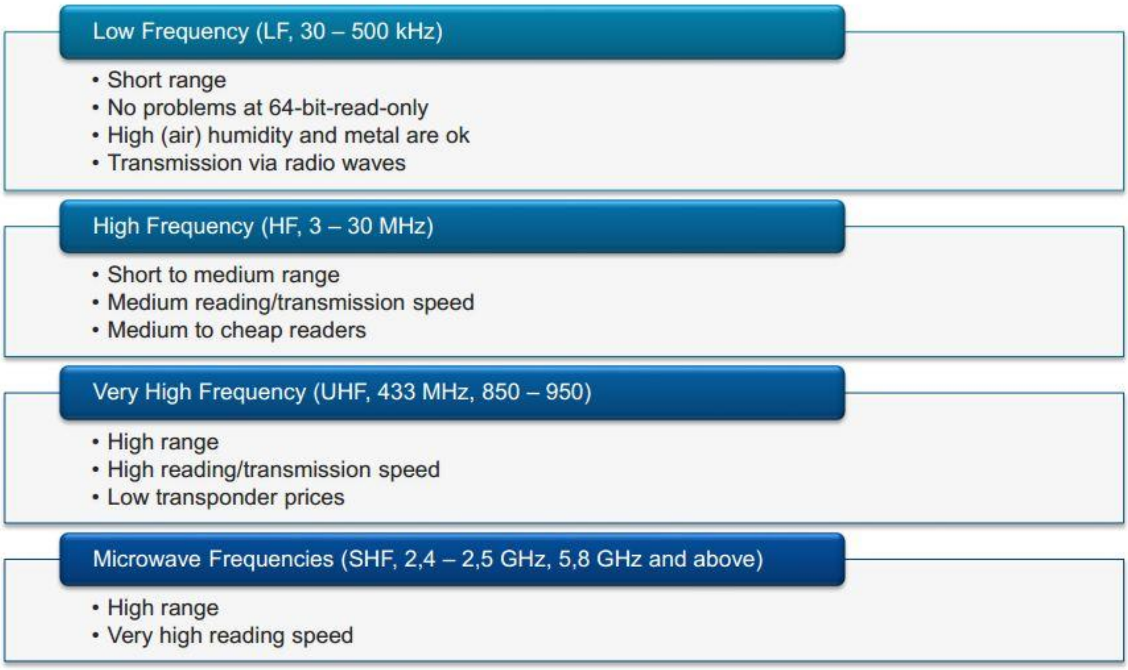


Figure 8. The table describes the different limits of RFID. (Slavinec, 2014)

3.6.2.3 Readers

There are 3 different types of readers in RFID. There are PRAT, ARPT, and ARAT tags.

A Passive Reader Active Tag (PRAT) uses a passive reader which can only receive signals from other tags that are battery operated. The range of Passive Reader Active Tags can be adjusted so that it can allow different types of applications. An Active Reader Passive Tag contains an active reader which can send interrogation signals and receive replies. Finally, the last tag, the Active Reader Active Tag commonly uses a battery and it is always looking for a signal to read.

3.6.2.4 Components

In order to design an RFID tag, a read-writing device is required. A middle ware connector (HMI) in conjunction with that can transmit the code to the read/write device.

3.6.2.5 Applications

Practical applications that use RFID can be seen in daily life. Retail stores use plastic attachments placed onto more valuable products that ring an alarm once it is passed through an electrical field. Retail stores also use EAS RFID tags to maintain an inventory database.

Other applications include limiting and controlling access to entries or exits, and also accessing protected information.

3.6.2.6 Drawbacks

RFID systems have a high implementation fee, and usually requires training for workers to get familiar with the technology. They can be easily disrupted by WiFi networks or cellular phones. Another common problem can is called RFID reader collision. This occurs when more than one RFID tag is activated at once.

3.6.3 Machine Vision

Machine visions refers to a computer vision based system that takes photographs and processes them. A camera is placed in a location so that certain parameters are able to be seen from the product. The camera will take a photograph and send it to a computer where it will be data mined according to the preprogramed logic. The data from that is then sent to the next station, and according to the rules at the second station it will be further processed.

3.6.3.1 Drawbacks

In order for machine vision to work, a steady environment is needed so that the camera is able to take a clear image.

3.7 IT Systems

Usually, large warehouses with distribution and storage centers utilize IT systems to help store and manage all of their data relating to the products being manufactured.

3.7.1 TCP/IP

TCP/IP is the basic communication language for networks. It can be used to communicate with the internet as well as communicate with private networks within companies. This is known as intranet.

3.7.2 XML

This is a markup language that is commonly used in encoding documents that can be read by humans as well as machines. It is normally used for data structures and to send sets of data.

4 Feature Comparison & Ranking

There are many different sorting methods and this section will describe the process used to establish the most efficient method. These properties are in order from the most important to the least important. The properties were scored 1-10 points, 10 being the highest. After this, due to limited time, they were narrowed from the original ideas down to 10 best ones. This was done by going through all the ideas and briefly considering their rationality.

- Efficiency 10p
- Economics 9p
- Lifetime 8p
- Safety according to OSHA standards 7p
- Maintainability 6p
- Ease of Use 5p
- Environmental 4p
- Availability of system (Backorders) 3p
- Size of the system 2p
- Time to build 1p

4.1 Different possibilities

After eliminating 7 other possibilities. The top three remaining possibilities have been selected according to the table below.

	PLC & RFID	Automated Crane	Line Sorter
Efficiency 10p	X	X	
Economics 9p			X
Lifetime 8p	X	X	X
Safety according to OSHA stand-ards 7p	X		
Maintainability 6p			X
Ease of Use 5p	X		
Environmental 4p	X	X	X
Availability of sys-tem (Backorder) 3p			
Size of system 2p			X
Time to build 1p	X		
Total	35 Points	22 Points	29 Points

4.2 Final Selection

PLC+RFID Implementation

According to the table above it was determined that the optimal solution for sorting the product was to use a combination of PLC controls and an RFID device used in conjunction with an HMI (Human Machine Interface).

5 Model

Since the optimal choice has been made the simulation model must be put together. The thesis will only attempt to simulate the combination of RFID and PLC to track and automate a sorting system.

5.1 Components

The components needed to simulate the project are mostly available through Simatic Manager.

5.2 PLC Hardware

In order to implement the project an S7-300 Series CPU 313C can be used.

5.3 PLC Software

Simatic Manager was used to program and create the ladder logic for the entire sorting design. Ciros mechatronics was also used to simulate it.

5.4 RFID Software

RF Manager Basic Software 2010 acts as the HMI allowing for the settings of the reader to be set. The country settings must be selected so that it follows the regulations and standards. The IP of the reader must also be set, as seen below in figure 9.

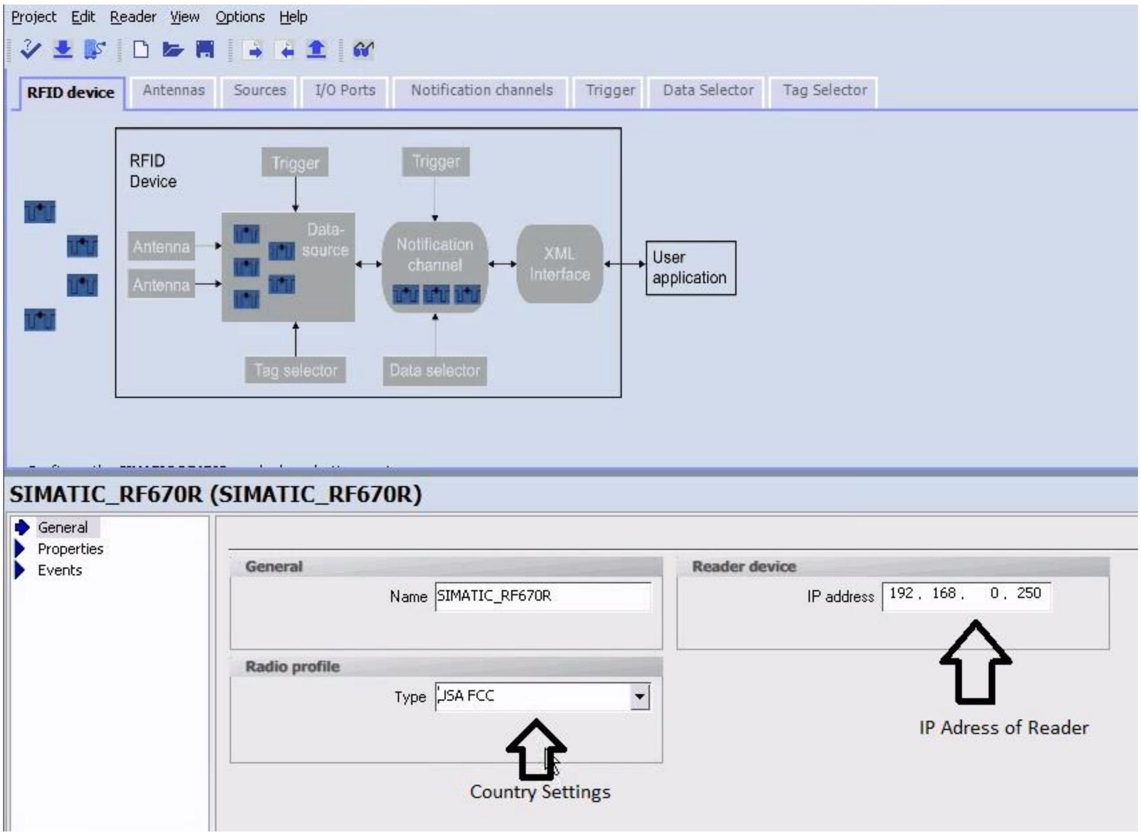


Figure 9 this shows how the hardware is connect to the devices and how they will read. The country profile can be selected here.

Since there is only one antenna in use it must be set. The power (W) level was set to 500mW and the gain (dBi) to 4 as recommended by the included documentation. This can be seen in Figure 10.

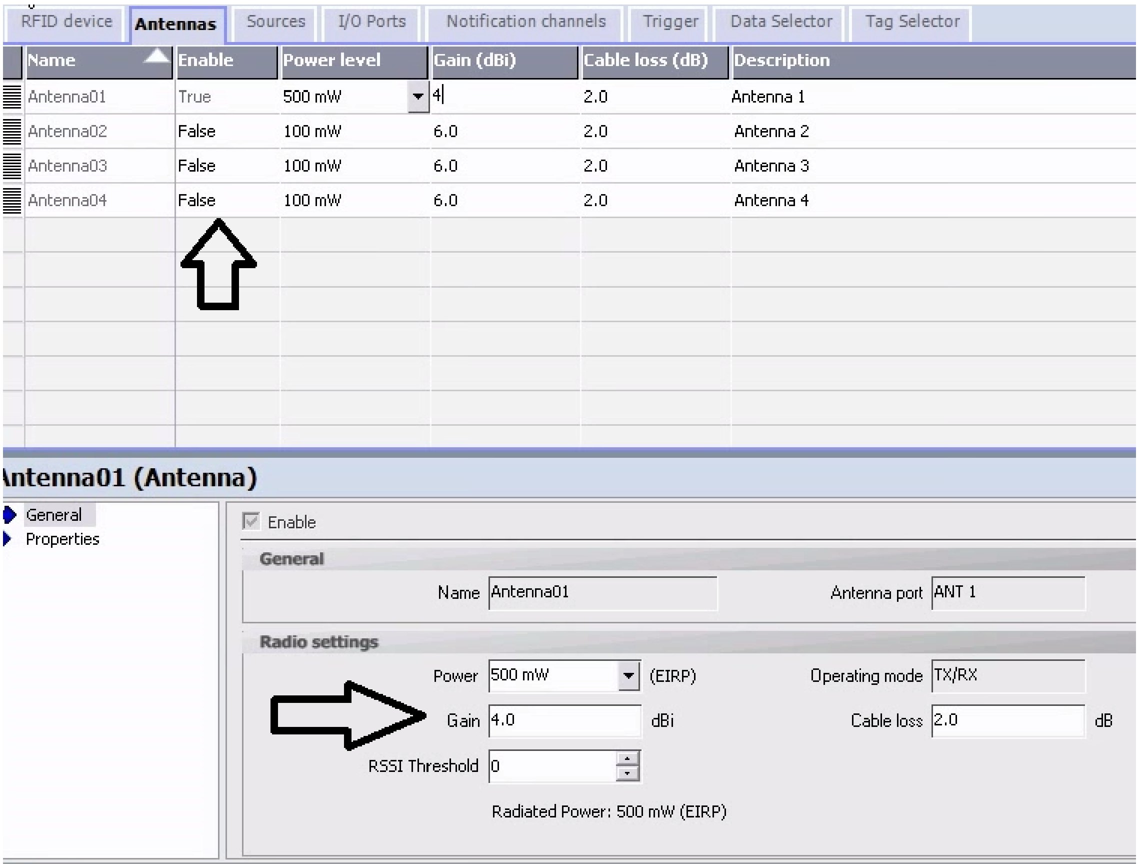


Figure 10. The correct power settings for this application are shown. Since there is only 1 antenna being used the rest are set to “false”.

5.4.1 RFID Hardware

In order to interpret the information from the RFID tags two pieces of hardware are used: a communication device and the actual reader. One antenna is needed in this specific setup. The antenna is attached to the RF670r. This is classified as an ultra-high frequency reader because it uses the frequencies of 865MHZ to 865MHZ. The reader is then connected by an Ethernet cable to a PC acting as an HMI. (Siemens)

5.4.1.1 Simatic RF670R RFID READER

This reader allows for a range of up to 8 meters. The reader will be spaced 2 meters away from the conveyor belt so that small movement can be allowed for the packages while moving along the conveyor belt. The RFID reader has a read time of 6.3 milliseconds so that flow of product will practically never be a problem. The SIMTATIC RF640A is a universal antenna utilized for many purposes. This antenna has a large range and high allowable operating temperatures. For this specific purpose OMNI-ID IQ UHF tags were used. The barcodes put on the packaging will need to be changed to instead use these tags.

The reader used is shown below in Figure 11.

Figure 11. With the SIMTATIC RF670R reader there are 4 slots available for antennas but this application will only need 1 connection.

5.5 Simulation

The simulation used the Ciros mechatronics MPS default standard sorting system layout and the sensor inputs used within that. The RFID system can be then theoretically attached to this system using the settings described in order to optimize distribution and the overall efficiency of the warehouse side of the plant.

5.5.1 Separating System Code

First a pneumatic diagram was made and then ladder logic for sorting was created in Simatic Manager. A two product line sorting machine was used for this since the basic premise can be expanded upon by changing the sensors to color. An optical sensor is used to check which product is on the conveyor belt. It does this by using color. All of the dog food bags are reflective colors and all of the cat food bags are dark - light absorbing colors. This can be seen below in Figure 12.

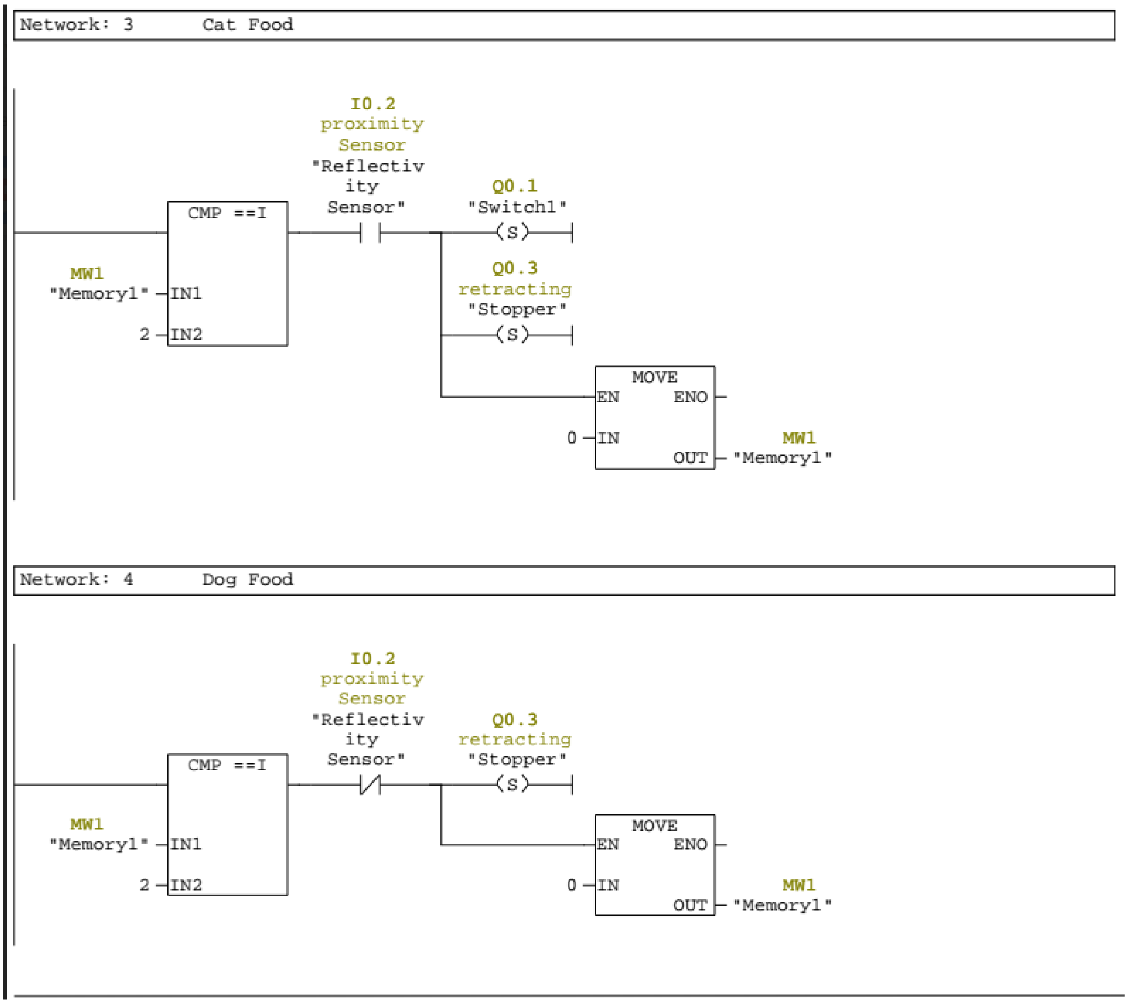
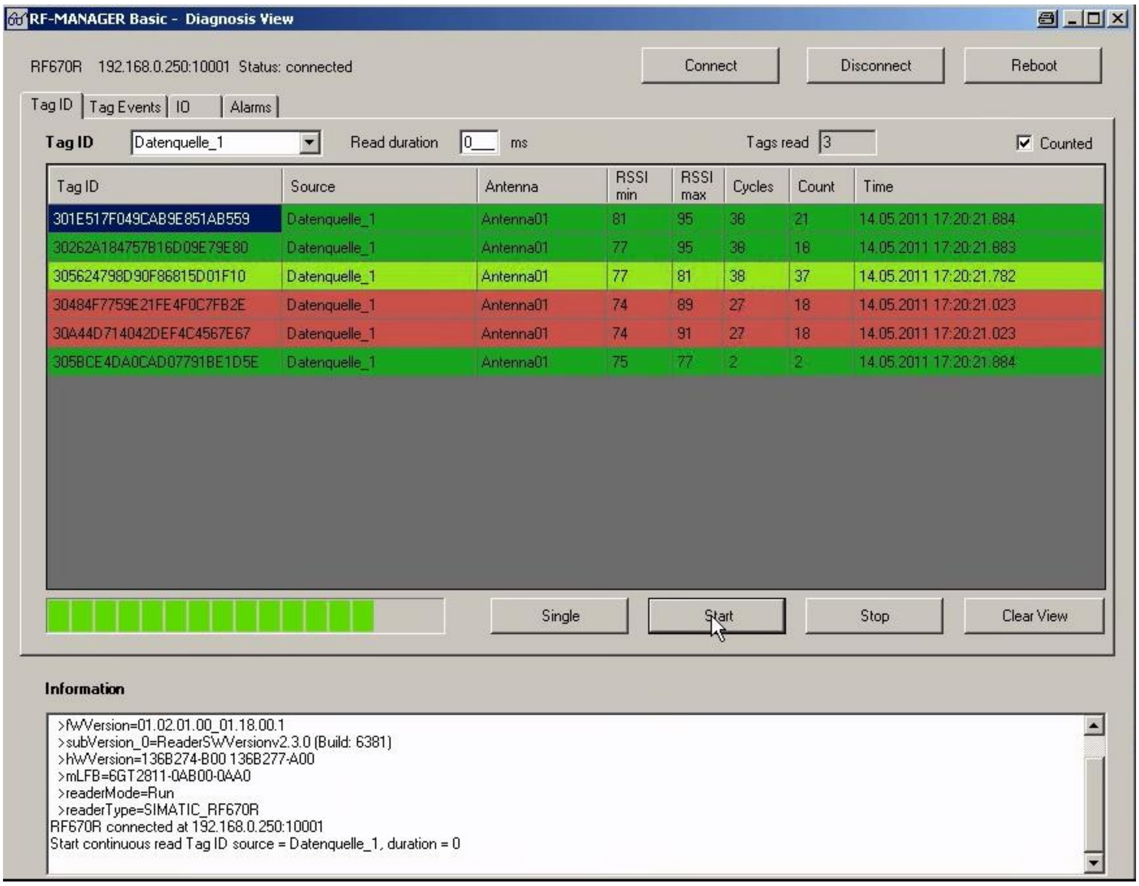


Figure 12. The sorting code for the different products is calculated by using “if then statements, following me an action and then moves to the next step to be repeated. The hardware used for this was a S7-300 Series 313C CPU.

5.6 Critical Innovation

The input that the RFID reader receives from scanning the product goes directly to the IT database. It can be seen by the workers manually driving forklifts when the product has been sorted. This reduces the time that the drivers need to manually check that the product is ready to be moved into the truck. Once the settings of the reader have been set, the RF Diagnosis tool is used to check the functionality of the system.

Figure 13 shows how the RFID tags can be read and tracked.



(Figure 13. The green indicates that it has been read, while the red indicates it is out of range. RSSI indicates the quality of the connection to the reader.)

This information is then sent to the IT database within the warehouse that the forklift drivers use to know when products are ready to be picked up and packed. To do that an xml file is created and then sent across TCPIP to the host application accepting the xml file. Figure 14 shows the .xml and connections used.

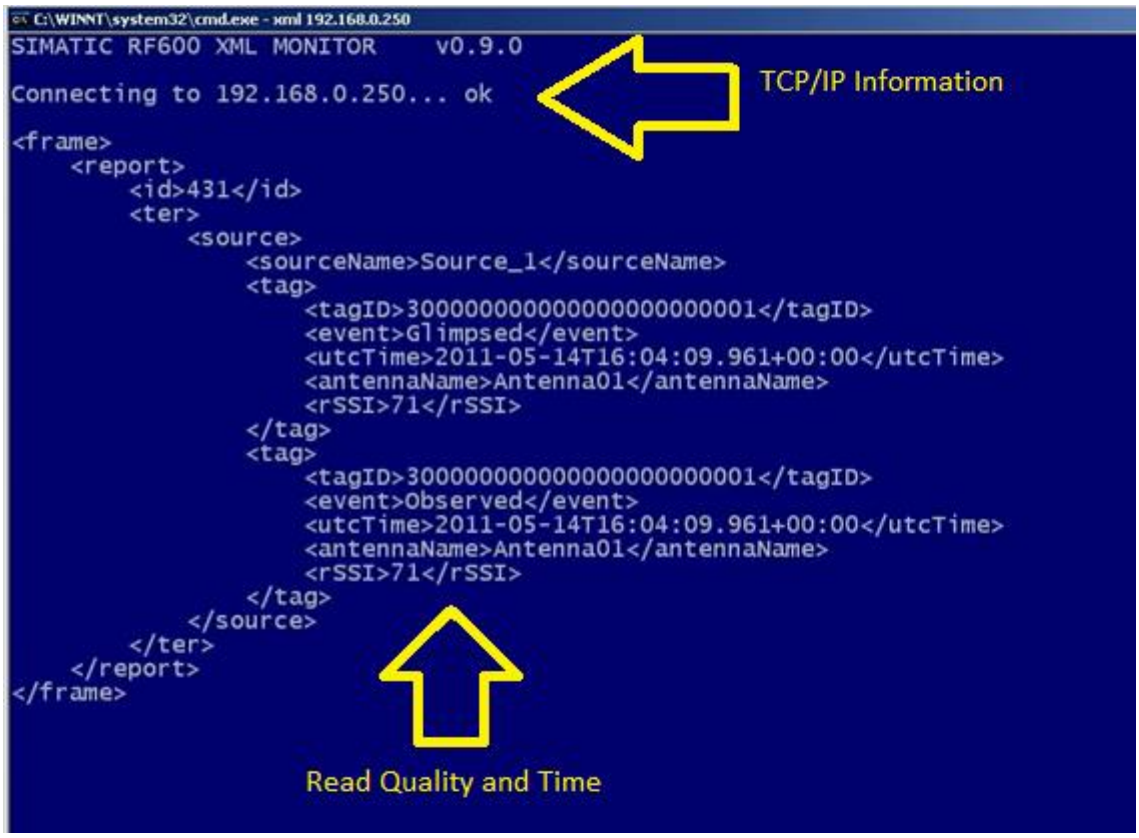


Figure 14. This figure shows the RFID tag ID, the time it was scanned, the quality of the scan and antenna involved.

5.7 Upscale Possibilities

The basic concept that was used in the simulation can be applied on a larger scale. The variation of weight from the products requires that a specific conveyor type be used. This was decided from the following calculations.

5.7.1 Conveyor Calculations

To choose the components for building a similarly designed sorting system there are many variables that must be calculated to find the motor power for the specific application. They are as follows

- Total Conveyor Mass – M
- Effect Roller Pull
- Max Belt Pull
- Power at drum
- Max Motor Power.

To account for all possibilities the maximum possible loads will be used because they are the most critical.

- The largest food bag has a mass of 23 kg
- The coefficient of friction using rollers on the conveyor system is .03
- The conveyor has a length of 18 meters.

The conveyor mass is calculated from using the length of the conveyor multiplied by the mass of the product per meter in length. This can be seen in the calculation below.

Total Conveyor Mass

As described by the formula discussed previously it is:

$$m = l_T \cdot \text{mass of conveyed material per m} \quad (1)$$

18m x (23 kg / .06 m) = 248.4 Newtons

Effective Roller Pull

Effective Pull on the rollers was calculated by:

$$F_U = \mu_R \cdot g\,(m + m_B + m_R) \overset{(-)}{+} g \cdot m \cdot \sin\alpha \quad (3)$$

.03 x 9.81 (248.4 kg +15 kg belt + 11kg roller mass) = **80 N**

Max Belt Pull

Max Belt pull is calculated by:

$$F_1 = F_U \,.\, C_1 \quad (5)$$

80 kg x 1.5 = **120 N**

Drum Power

Power at drum can be calculated from:

$$P_A = F_U \cdot v \quad (7)$$

(120 N x .2 m/s) = **20 watts**

Max Motor Power

Max Motor power is calculated from:

$$P_M = \frac{P_A}{\eta}\ [kW] = \text{next largest standard motor is chosen} \quad (8)$$

20 W / .8 = 25 **Watts**.

The previous calculations assumed that the conveyor system would only hold 1 bag that is the maximum load product. Assuming the conveyor holds 10 (the maximum allowed on the conveyor at once) bags of food that are the maximum load then the motor would need to generate 250 Watts. Adding in effects of dust and other possible increases of friction the Motor standard is chosen to be 300 Watts.

Deduced from these calculations the components best suited are:

- MEC Aluminum Shell and Solid Shaft for the roller
- EP 400/2 Belt
- 24V 300 Watt Motor

5.7.1.1 Conveyor Efficiency

The conveyor efficiency can then be calculated. The original time it took for 5 bags of product to be sorted was 300 seconds when picked up from distribution by a manually driven forklift. One bag transported on a conveyor belt take between 45 and 90 seconds depending on which sorting gate the product goes to.

The time on conveyor belt was calculated by:

Conveyor Length / Conveyor Velocity

18 meters / .2 meters per second = 90 seconds

The efficiency increase of the product sorting can be seen as follows:

Improved sorting time / Original Sorting Time = % of original Sorting Time.

100% - % of Original Sorting Time = Efficiency increase.

After the calculations a 70% increase of efficiency is achieved.

5.7.2 Actuator Calculations.

In order to know the sum of the forces on the bag. This includes the normal force on the bag and the force of friction. The coefficient of friction is defined by the belt type, which gives $F\mu$=.3

- The normal force was calculated to by 23 kg x 9.81 m/s
  23 kg x 9.81 m/s^2 = 225.63 N
- The force of friction was calculated by 23kg x 9.81 x .3
  23 kg x 9.81 m/s^2 x .3 = 67.68 N

These two forces add together and give the amount of force that needs to be moved. By choosing an actuator that has the length of 450 mm and thickness of 2 mm it gives a cross-sectional area of 900 mm^2.

Using the equation Pressure = Force / Area it is deduced that the pressure needed to move the maximum load of 293.31N will be .32 MPa or 3.2 Bars. This can be safely raised to 4 bars to incase of sudden increases in surface friction.

The appropriate hardware for this should be an up-scaled Festo's Didactic Sorting Gate.

6 Analyzation & Reflection

The initial purpose of this thesis was to create an automated system that would increase efficiency of the plant and reduce the costs. The sorting solution was decided upon using a list of best qualities that fit this plant's purpose. The problem of what way to sort the product was solved by using sensors and setting up a conveyor belt, followed by connecting the system that to a PLC. If the plant were to decide to build this project, calculations were needed to decide the size and power for the products being moved within the plant. Sorting gate forces were also calculated so that the pressure used to move the product would be sufficient. The components that would be suitable for use were also selected.

6.1 Completion Percentage

Now that there is a sorting system that puts the product into its proper location - there can be a reduction in the amount of forklift drivers and fork lifts, management, and fuel consumption. There will still need to be a few forklift workers remaining in order to pack the trucks. The simulation was completed without fault and will work successfully provided that they use the components listed above.

The completed layout for the sorting of one product can be seen below in Figure 15.

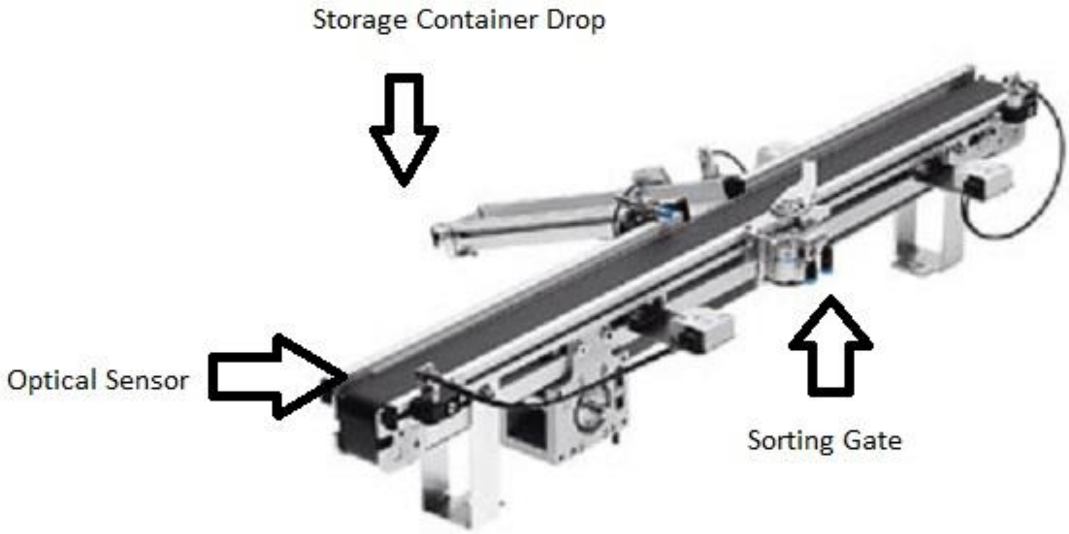


Figure 15. Shows how the sorting would be done for a product. Two of these in a line then can sort both products.

6.2 Reflection

As expected, the time management for this project was very strict. This thesis was done in conjunction with a full load of courses and during the testing times it was difficult to continue on this. Most of the time was spent learning how to implement the RFID, learning about how the components connect and the rules and regulations of differing circumstances, learning how to initialize the RFID and figuring out how to read and setup the .xml file so that it could be sent to their IT system which they then forward to their forklift drivers. There may be possible interference in the factory on the RFID readers but it is impossible to tell with by implementing only a simulation. The proper precautions were taken to avoid most possibilities, but nevertheless it is a simulation. The PLC programming was relatively straight forward.

6.3 Future development

For the future development of this project there needs to be a continued focus on applying different sensors that could widen the different product's color possibilities which would enable it to be marketed easier. Another aspect that could be expanded on is adding a mechatronics station that could also pack the product into the truck which would thereby eliminate the need for any fork lift drivers further decreasing the costs. This would also increase the productivity.

6.4 Requirements fulfilled

The design of the sorting system can be successfully implemented following the description in this thesis. The requirement for there to be an automated method after distribution was fulfilled. The increase of sorting product by 35% percentage was also fulfilled. The percentage increase was actually around 70%. Of course this is at optimal conditions without a delay in any other part of the factory. The acceleration and maximum force loads were also kept within the restrictions.

6.4.1 Cost Requirements Fulfilled

A major part of this thesis was done with regards to cost. This can bring the total amount of forklifts down to less than half of the original fleet.

After the sorting machine has been implemented it is estimated that 70% of the forklift labor can be eliminated. This brings down the initial total of forklifts of 30 down to 9. Because of this reduction in forklifts the operating costs can be drastically reduced. The daily cost of labor would be reduced from $13,760 to $4,752 per day. The requirement of cost reduction was to bring it down by 30% and the actual reduction after this implementation would be closer to 66%.

The maintenance costs were initially $11,920. After the implementation there can be a reduction needed in maintenance services and fuel provided which brings the cost down to $4,746. This gives a total savings of 60%.

Inspection costs cannot be calculated unless this is implemented. The initial budget was also not fulfilled because of the differing variables outside the scope of this project.

7 References

Anon., 2015. *Equinox.* [Online]
Available at:
http://www.equinoxmhe.com/site/index.php?option=com_content&task=view&id=89&Itemid=84

Anon., 2015. *Troughability.* [Online]
Available at: http://wbmttt.tudelft.nl/rapport/7695e.pdf

Anon., ei pvm *Problems with RFID.* [Online]
Available at: http://www.technovelgy.com/ct/Technology-Article.asp?ArtNum=20
[Haettu February 2015].

Anon., ei pvm *Technical / Equations.* [Online]
Available at: http://www.conveyorbeltguide.com/Equations.html
[Haettu 2015].

Bastian Solutions, 2013. *A Conveyor is Only as Good as the Belt That's on It.* [Online]
Available at:
http://www.bastiansolutions.com/blog/index.php/2013/12/12/conveyor-belt-types-and-applications/#.VSPLtvmUcm-

CEMA, ei pvm *BELT TENSIONING, POWER, AND DRIVE ENGINEERING.* s.l.:s.n.

Hounshell, D. A., 1984. *From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States.* Baltimore: John Hopkins University Press.

PHOENIX, 2013. *Textile Conveyor Belts.* [Online]
Available at: http://www.phoenix-conveyorbelts.com/pages/technical-information/textile-conveyorbelts/textile-conveyorbelts_en.html

Sandvik Mining and Construction, 2008. *Conveyor Components.* [Online]
Available at:
http://www.miningandconstruction.sandvik.com/sandvik/0120/Internet/global/S003713.nsf/Alldocs/Products*5CConveyors*and*conveyor*components*5CRollers*2AImperial*Medium*duty/$file/DataBrochureMEC_RollerV1.pdf

Sen, D., 2009. RFID For Energy and Utility Industries. Teoksessa: s.l.:Pennwell, pp. 1-48.

SIEGLING, ei pvm *Calculation methods - conveyor belts.* [Online]
Available at:
http://belt174.com/files/misc/konvejernyelentytransilon.metodyrascheta.%28304_e%29.pdf
[Haettu 2015].

Siemens, ei pvm [Online]
Available at:
https://cache.industry.siemens.com/dl/files/587/44474587/att_34842/v1/SIMATIC_RF-MANAGER_Basic_2010_Operating_Manual_en.pdf

Siemens, ei pvm *Siemens Industrial Mall.* [Online]
Available at:
https://mall.industry.siemens.com/mall/en/ca/Catalog/Products/10087172#Overview

Siemens, ei pvm *Siemens Industrial Mall.* [Online]
Available at:
https://mall.industry.siemens.com/mall/en/WW/Catalog/Product/6GT2811-0AB00-0AA0

Slavinec, S., 2014. *RFID For Process Optimizing in Automation Technology,* Graz: s.n.

Song Lin, S. L. X. H., 2011. *Advances in Computer Science, Environment, Ecoinformatics, and Education, Part III.* Wuhan, China: Springer.

Tables

X-Mind Original 10 Ideas

Sorting Machine
HMI (Human Machine Interface)
Voice Picking
Slide Tray Sorter
Oval Sorter
Hang Sorter
Cross Belt Sorter
Automated Crane
PLC + RFID
Machine Vision
Line Sorter

Top 3 Elimination

	PLC & RFID	Automated Crane	Line Sorter
Efficiency 10p	X	X	
Economics 9p			X
Lifetime 8p	X	X	X
Safety according to OSHA stand-ards 7p	X		
Maintainability 6p			X
Ease of Use 5p	X		
Environmental 4p	X	X	X
Availability of sys-tem (Backorder) 3p			
Size of system 2p			X
Time to build 1p	X		
Total	35 Points	22 Points	29 Points

Symbol Table

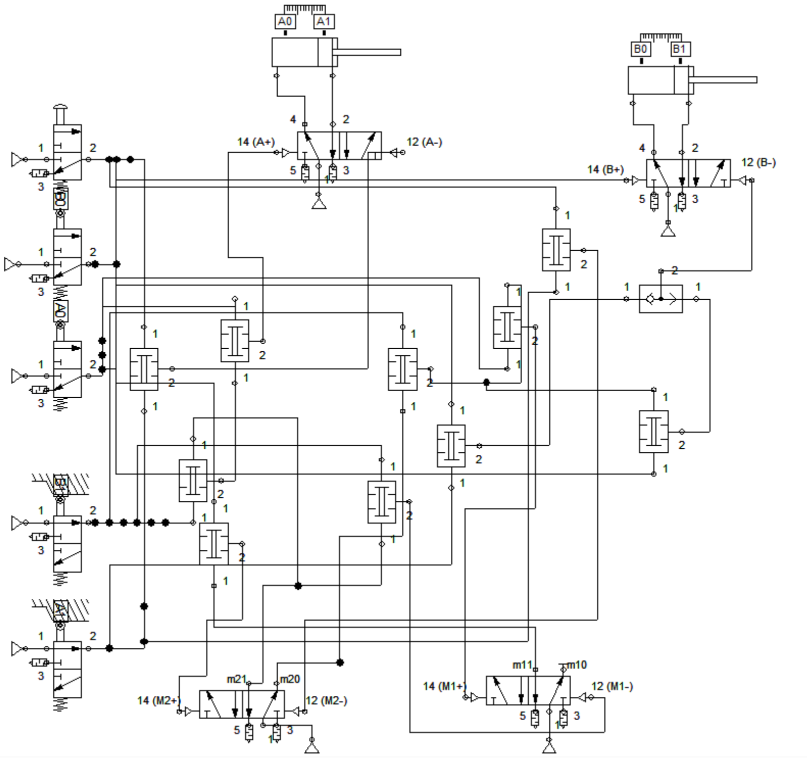
S7 Program(1) (Symbols) -- Task4_Sorting Station\SIMATIC 300 Station\CPU313 C(1)

	Statu	Symbol	Address	Data type	Comment
1		Belt_on	Q 0.0	BOOL	
2		Cycle Execution	OB 1	OB 1	
3		Memory1	MW 1	INT	
4		Part_AV	I 0.0	BOOL	
5		Reflectivity Sensor	I 0.2	BOOL	proximity Sensor
6		ResetLight	Q 1.1	BOOL	
7		Slide_full	I 0.3	BOOL	
8		Slide_full_Light	Q 1.2	BOOL	
9		Start	I 1.0	BOOL	
1		StartLight	Q 1.0	BOOL	
1		station_taken	Q 0.7	BOOL	
1		Stopper	Q 0.3	BOOL	retracting
1		Switch1	Q 0.1	BOOL	
1		Switch1_extend	I 0.5	BOOL	
1		Switch1_retract	I 0.4	BOOL	
1		Timer1	T 1	TIMER	
1					

PLC Sorting Program

Pneumatic Diagram

A+ = b1*m21*a0
A- = S*a1
B+ = b0
B- = S*a1 + b1*m20*a0
M1+ = b1*m20*a0
M1- = b1*m21
M2+ = b0*m11
M2- = s*a1



Ladder Logic

OB1 - <offline>

"Cycle Execution"

Name: **Family:**

Author: **Version:** 0.1

Block version: 2

Time stamp Code: 04/01/2015 12:00:35 PM

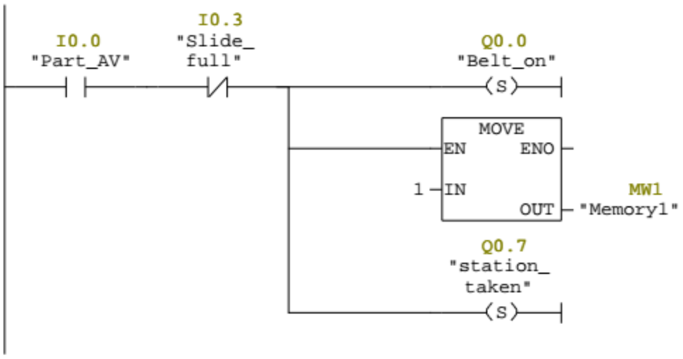
Interface: 02/15/1996 04:51:12 PM

Lengths (block/logic/data): 00320 00188 00022

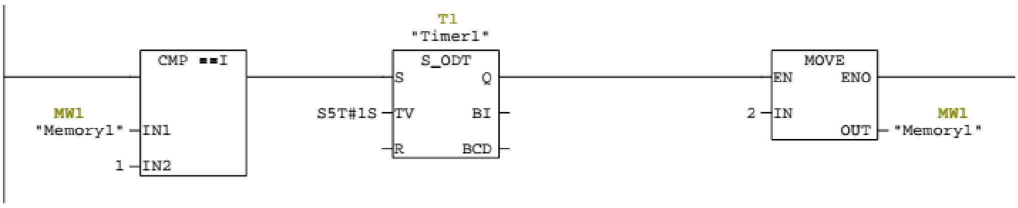
Name	Data Type	Address	Comment
TEMP		0.0	
OB1_EV_CLASS	Byte	0.0	Bits 0-3 = 1 (Coming event), Bits 4-7 = 1 (Event class 1)
OB1_SCAN_1	Byte	1.0	1 (Cold restart scan 1 of OB 1), 3 (Scan 2-n of OB 1)
OB1_PRIORITY	Byte	2.0	Priority of OB Execution
OB1_OB_NUMBR	Byte	3.0	1 (Organization block 1, OB1)
OB1_RESERVED_1	Byte	4.0	Reserved for system
OB1_RESERVED_2	Byte	5.0	Reserved for system
OB1_PREV_CYCLE	Int	6.0	Cycle time of previous OB1 scan (milliseconds)
OB1_MIN_CYCLE	Int	8.0	Minimum cycle time of OB1 (milliseconds)
OB1_MAX_CYCLE	Int	10.0	Maximum cycle time of OB1 (milliseconds)
OB1_DATE_TIME	Date_And_Time	12.0	Date and time OB1 started

Block: OB1 "Main Program Sweep (Cycle)"

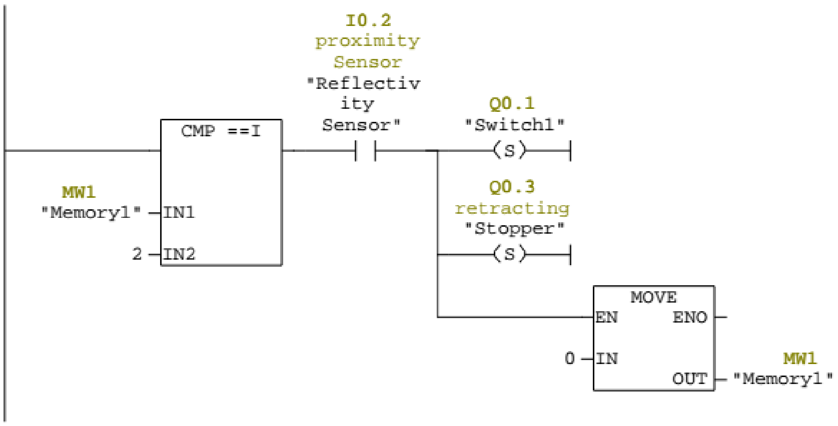
Network: 1 Power On



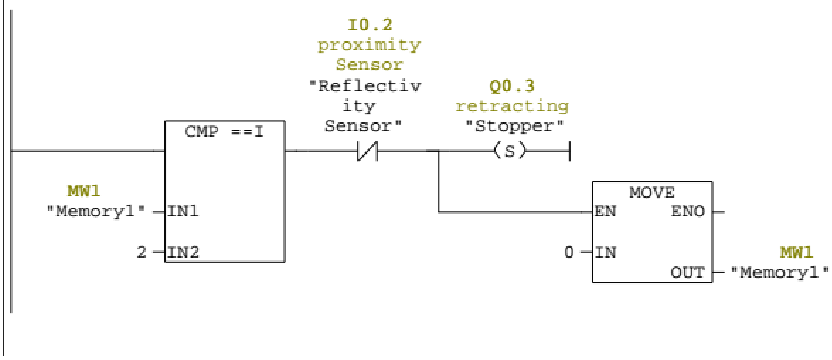
Network: 2 Memcheck



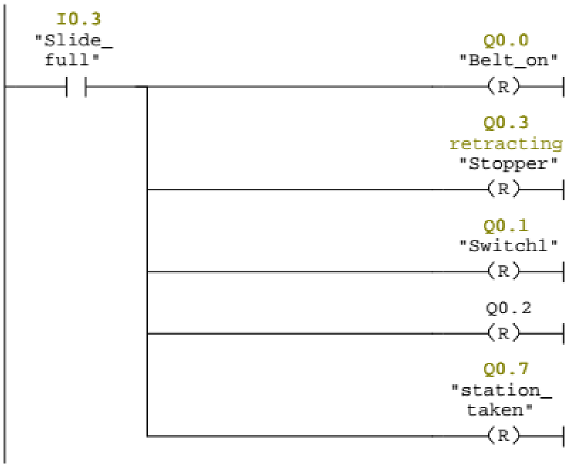
Network: 3 Cat Food



Network: 4 Dog Food



Network: 5 Full Slide



Formulas

7.1.1.1 Variables

Force on each belt strand	F	N
Maximum belt pull (at drive drum)	F_1	N
Minimum belt pull (at drive drum)	F_2	N
Effective belt pull	F_U	N
Shaft load at drive drum	F_{WA}	N
Shaft load at end drum	F_{WU}	N
Motor power	P_M	kW
Calculated power at drive drum	P_A	kW
Belt pull at 1% elongation per unit of width	SD	N/mm
Drum/roller width	b	mm
Belt width	b_0	mm
Geometric belt length	Lg	mm
Calculation constants	c..	–
Drum/roller diameter	d	mm
Drive drum diameter	d_A	mm
Rolling resistance of support rollers	f	–
Difference in drum radii	h	mm
Coefficient of friction with support rollers	μ_R	–
Coefficient of friction with accumulated goods	μ_{ST}	–
Coefficient of friction with skid plate	μ_T	–
Acceleration due to gravity	g	$9{,}81 m/s^2$
Production tolerance	Tol	%
Upper support roller pitch	l_o	mm
Lower support roller pitch	l_u	mm
Transition length	l_s	mm
Mass of material conveyed over whole conveying length (total load)	m	kg
Mass of belt	m_B	kg
Mass of all rotating drum/rollers, except drive drum	m_R	kg
Mass of conveyed goods on upper side (total load)	m_1	kg
Mass of conveyed goods on return side (total load)	m_2	kg
Mass of conveyed goods per m of conveying length on upper side Line load	m'_o	kg/m

Tension take-up range	Z	mm
Total tension take-up range	X	mm
Height of lift	h_T	m
Conveyor length	l_T	β
Belt speed	v	m/s
Belt sag	y_B	mm
Drum deflection	y_{Tr}	mm
Arc of contact at drive drum and idler	β	°
Opening angle at drive drum	γ	°
Incline (+) or decline (–) angle of conveyor	α, δ	°
Elongation at fitting	ε	%
Drive efficiency	η	–
Density of material conveyed	ρ_s	kg/m^3

7.1.1.2 Applied Formulas

$$m = l_T \cdot \text{mass of conveyed material per m} \quad (1)$$

$$F_U = \mu_T \cdot g \cdot (m + \frac{m_B}{2}) + \mu_R \cdot g\,(\frac{m_B}{2} + m_R) \quad (2)$$

$$F_U = \mu_R \cdot g\,(m + m_B + m_R) \overset{(-)}{+} g \cdot m \cdot \sin\alpha \quad (3)$$

$$F_U = \mu_T \cdot g\,(m + \frac{m_B}{2}) + \mu_R \cdot g\,(\frac{m_B}{2} + m_R) \overset{(-)}{+} g \cdot m \cdot \sin\alpha \quad (4)$$

μT (skid plate)	0.33
μR (rollers)	0.033

$$F_1 = F_U \cdot c_1 \quad (5)$$

Arc of contact β	180°	210°	240°
smooth steel drum			
dry	1.5	1.4	1.3
wet	3.7	3.2	2.9

$$d_A = \frac{F_U \cdot c_3 \cdot 180}{b_0 \cdot \beta} \quad (6)$$

smooth steel drum	
dry	25
wet	50

$$P_A = F_U \cdot v \quad (7)$$

$$P_M = \frac{P_A}{\eta}\ [\text{kW}] = \text{next largest standard motor is chosen} \quad (8)$$