Independent Degree Project - First Cycle

ET049G – Electrical Engineering BA (C), Thesis Project, 15 credits

PLC Lab Station
Solution for Automatic Unloading of Paper Reels

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Abstract

Automatic control of processes is a field that has evolved extensively over the years to reduce downtime, improve quality and increase the productivity of processes in manufacturing industries. ÅF Consult is a consult organization that provides industrial solutions worldwide. In order to test equipment and introduce employees and students to control systems, a PLC based lab station is necessary. The methodology used in the project is based on a literature study, followed by the solution approach and finally an evaluation. A Distributed Control System setup using a Siemens S7-300 and a Siemens S7-400 PLC has been developed. The PLCs communicate using PROFIBUS DP. The station is divided into two major parts: a conveyor belt with transportation functionality and a robotic arm with pick-and-place functionality. The station is provided with equipment similar to systems currently used in paper and pulp industries. Existing solutions for unloading of paper reels in the paper and pulp industries are non-universal due to extra equipment like pre-installed rails in trailers. An automated solution for unloading using a robotic arm is therefore presented, designed to reduce paper reel handling and to have the possibility to unload to any trailer. The lab station is implemented according to ÅF Consults demands of a portable, field related station. The low budget resulted in cheap equipment that lack accuracy, mainly resulting in issues relating to the ability to control the robotic arm properly. The unloading solution is emulated as a lab task on the station, showing that a control setup similar to the lab station would be a good approach for a real implementation solution.

Keywords: Automatic control, Lab station, PLC, PROFIBUS, Unloading solution, ÅF Consult.
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Terminology

Acronyms

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<th>Description</th>
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<tr>
<td>CCS</td>
<td>Centralized Control System</td>
</tr>
<tr>
<td>DCS</td>
<td>Distributed Control System</td>
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<tr>
<td>EEPROM</td>
<td>Electrically Erasable Programmable Read-Only Memory</td>
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<tr>
<td>FBD</td>
<td>Function Block Diagram</td>
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<td>LD</td>
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<td>PID</td>
<td>Proportional Integral Derivative</td>
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<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
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<td>PROFIBUS</td>
<td>Process Field Bus</td>
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<td>PWM</td>
<td>Pulse-Width Modulation</td>
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<tr>
<td>ROM</td>
<td>Read-Only Memory</td>
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<td>ST</td>
<td>Structured Text</td>
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<tr>
<td>TOF</td>
<td>Timer OFF</td>
</tr>
<tr>
<td>TON</td>
<td>Timer ON</td>
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1 Introduction

This thesis considers the development of a lab station for the consult organization ÅF Consult, located in Sundsvall, Sweden. In this thesis, the complete project is covered in *PLC Lab Station – Simulating an Automatic Quality Control of Loaf Products* [1] and *PLC Lab Station – An Implementation of External Monitoring and Control Using OPC* [2]. The lab station will be designed for educational purposes with task possibilities based on process controls in the paper and pulp industry. The hope of the project is to design a universal station with equipment and process chains common to existing system setups in manufacturing industries. Further on, a solution to automate unloading of paper reels in the paper and pulp industry will be presented. Subsection 1.1 presents the background and problem motivation to the project, followed by the overall aim and the scope of the project in subsection 1.2 and 1.3 respectively. A detailed problem statement is presented in subsection 1.4, before the outline of the report and contributions in subsection 1.5 and 1.6.

1.1 Background and problem motivation

Automatic control of processes is a field that started early for mankind and have evolved extensively over the years. In the mid-1970s, when the developing manufacturing processes demanded a more efficient way to be controlled, Distributed Control Systems (DCSs) became an important area to research. [3] The extent of optimization of the manufacturing controls became a main topic to consider for further development and evolution for industries worldwide. Nowadays, the Programmable Logic Controllers (PLCs) are the most common controllers in DCSs. The revolution of the PLCs began in the 1970s by replacing the early, simple logical control decision relays. [4]

ÅF Consult is a consult organization in Sundsvall, Sweden, with main areas in energy, infra-structure and industrial solutions. The organization provides industrial solutions worldwide, using PLC systems. [5] A PLC based lab station is necessary in order to test and introduce employees and students to industrial processes and the currently used systems in the company. Therefore, this thesis will consider the development of a PLC based lab station.

Automating industrial processes is a fundamental area in manufacturing processes in order to reduce downtime, improve quality and increase the productivity of the processes [6]. Present-day solutions for unloading of paper reels in the paper and pulp industries demands pre-installed equipment in pick up trailers, which results in non-universal solutions [7]. Therefore, a solution for an automatic unloading using a robotic arm will be researched and presented in this thesis, with the hope to provide a completely automated solution designed for unloading to any trailer.
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The solution should also minimize extra handling of the reels, which needs to be placed either standing up or lying down before the unloading stage [8]. In addition, a miniature process that provides this solution will be emulated at the lab station.

1.2 Overall aim

The overall aim of the project is to design a lab station for the employees at ÅF Consult. The station itself should be a small, portable station so that it can be used at ÅFs office as well as in the field. In order to design a field related lab station, solutions in paper and pulp industries will be researched and similar equipment and process chains will be implemented at the station. The possibilities of the station will be presented, mainly what lab tasks and functionality the station can provide. In addition, an automatic solution for unloading of paper reels in the pulp and paper industry will be presented and emulated at the station with a test program.

1.3 Scope

The scope of the project is limited to using two Siemens PLCs for the lab setup, namely a Siemens S7-300 [9] and a Siemens S7-400 [10]. The main reasons for using these PLCs are because they are currently used at ÅF Consult. The research is narrowed down to currently used solutions for automatic unloading of paper reels and general control systems in the paper and pulp industry, providing a motivation for the choice of equipment for the lab station.

1.4 Detailed problem statement

The main purpose is to design and implement a PLC based lab station. Designing a universal station is a main topic that covers common setups of PLC controlled processes in industries. The station will not only introduce students and employees to PLC based control systems [11], but also have the possibility to test software and hardware before field implementation. In addition, an automatic solution for unloading of paper reels in the pulp and paper industry will be considered.

The following statements present problem formulations for the complete project:

1. Lab station
   a. Can a small, portable and universal lab station be designed in order to reach a field related station for industrial solutions?
   b. Can the station be implemented according to currently used setups for DCSs?
   c. What equipment is necessary for the setup?
   d. What communication methods should be included?
   e. Can the station be accurate and reliable enough to simulate industrial solutions?
   f. What appropriate lab tasks can be provided at the station?
2. Automatic unloading using a robotic arm
   
   a. How does currently used solutions for automatic unloading work?
   b. Is an automatic unloading solution using DCS setup with a PLC controlled robotic arm possible?
   c. What equipment is necessary?
   d. Will this solution result in a more efficient way of unloading in terms of:
      i. Functionality?
      ii. Universality?
      iii. Unloading time?
      iv. Heavy reel weight handling?
   e. Can the solution be emulated accurately at the lab station with a test program?

1.5 Outline

Chapter 1 introduces the project and describes goals and problem formulations. Chapter 2 presents all theory necessary for the understanding of the thesis and chapter 3 describes the methodology used in the project, where the solution approach and related evaluations are presented. Chapter 4 covers the design and setup of the lab station and the unloading solution. Chapter 5 presents the results to the solution and finally, in chapter 6, a discussion is presented and conclusions for the project as a whole are drawn. The last part of the report presents all provided references and appendices.

1.6 Contributions

The project presented in this bachelor thesis consists of three separate parts in three thesis projects by students from Mid Sweden University, Sundsvall. The setup of the lab station is a group work where the group members have different tasks and research different areas of interest. In addition to this thesis, the theses PLC Lab Station – Simulating an Automatic Quality Control of Loaf Products [1] and PLC Lab Station – An Implementation of External Monitoring and Control Using OPC [2] concerns the project presented.
2 Theory
This chapter presents facts and the research provided for the completion and understanding of the project covered in the thesis. First, in subsection 2.1, general information of PLCs and their purposes in control systems are presented, where main topics to research are hardware, software and industrial implementation. Subsection 2.2 presents industrial network standards, and general information regarding automation of systems is covered in subsection 2.3. Further on, a description of control systems in manufacturing processes are presented in subsection 2.4, where currently used solutions for automatic unloading of paper reels is the main topic to consider.

2.1 PLC fundamentals
Subsection 2.1 describes the fundamentals of PLCs as applications in control systems. This will include standards provided for the PLC architecture, the hardware of the PLCs and the most common programming languages [12]. In conclusion, useful and common programming blocks are described.

The main advantages of a PLC are:

- Cheap cost for complex control systems
- Flexibility of control systems or devices is quick and efficient
- Easy to troubleshoot
- Reliable components
- Robustness

Due to these properties, PLCs are essential devices for control systems, especially in industries. [12]

2.1.1 IEC 61131-3
The IEC 6131 [13] standard was developed by the International Electrotechnical Commission [14] to provide standards for PLC architecture. Each manufacturer of PLC related components and software will be able to configure their own systems in terms of functionality and layout, but a standard for core data representation is established. In the IEC 61131-3 [13] there are five main models provided for programming of PLCs. These are Instruction List (IL), Structured Text (ST), Ladder Diagram (LD), Function Block Diagram (FBD) and Sequential Function Charts (SFC). All these languages should comply with the standard for core data representation. [15]

Three of these languages will be explained in subsection 2.1.3.
2.1.2 **Hardware**

PLCs are microcontroller systems with hardware adapted to fit industrial environments. PLCs are designed to be user-friendly so that easy transition from all-relay control to electronic systems is possible. [16] This subsection describes the main hardware parts in a complete PLC setup:

**CPU**
The central processing unit is the central component of the PLC, where ladder logic is stored and executed. The instruction set for the CPU is a high-level program, installed in Read-Only Memory (ROM). The ladder logic programs are most commonly stored in Electrically Erasable Permanent Read-Only Memories (EEPROMs) or in flash memory. [16]

**Memory**
The most common implementation of the system memory is flash technology. External memory storage can be added in addition to the internal memory in the CPU. User memory is divided into blocks for different storage purposes such as I/Os, variables, timers or counters. [16]

**Communication-board**
Each brand of PLC uses different programming board hardware, but the most common way is to use an external communication board and a PC with an appropriate software program. This results in the possibility to create programs offline and load onto the CPU when required, instead of programming directly to the CPU. [16]

**I/Os**
Input and output units are available as analog or digital devices. The most frequent analog signal consists of a current signal of 0-20 mA or 4-20 mA, generated by sensors, which is the most common type of input. Common voltage levels are 12–24 VDC, 100–120 VAC and 5 VDC. The outputs are often devices like motors, solenoids and relays that either work as a digital switch (1 or 0), or as an analog continuous output. [16]

**Power supply**
Available as an external module or built into the PLC. Common voltage levels are 24 VDC, 120VAC or 220 VAC. [17]

2.1.3 **Programming**

This section presents required understanding in order to efficiently program PLCs according to standards provided. The subsection will consider three of the languages stated in the IEC 61131-3 standard [13] for PLC programming, where descriptions including the advantages and disadvantages of each language will be presented. In conclusion, useful and common programming blocks will be described.
2.1.3.1 Languages

This section describes three of the five stated programming languages in the IEC-61131-3 standard [13]. The most commonly used will be presented, namely Ladder Diagram, Function Block Diagram and Instruction List.

- **Ladder Diagram (LD)** is a graphic based language and the most widely used for PLC programming. It can visually be described as series of control circuits; see Figure 1 for example code. Due to the extent of the use of this language, almost any programmer in any industry can read and write this language, making it a universal choice. However, as the complexity of PLC controls has grown, using the Ladder Diagram results in some disadvantages like the difficulty to read and interpret large sized programs. Functions like PID-controlling and data analysis are also more difficult to implement with this language. [18]

![Figure 1: Example code written in Ladder Diagram.](image1)

- **Function Block Diagram (FBD)** is a graphical programming language and the second most widely used for PLC implementations. The layout itself is similar to circuit diagrams, using blocks connected in sequence, making the code easy to read and understand; see Figure 2 for example code. FBD is an ideal choice for small, simple programs only consisting of digital outputs, but could also be beneficial where the LD is used. However, this language is not appropriate for large programs due to the required screen space for the complete setup of blocks. [18]

![Figure 2: Example code written in Function Block Diagram.](image2)
Instruction List (IL) is a programming language that uses simple instructions similar to assembly programming [19]; see Figure 3 for example code. Ladder logic like LD and FBD can be converted to IL, but IL programs cannot always be converted to LD. The language itself consists of many lines of code where each line represents one instruction. An advantage of this language is that, if the program is written according to the IEC version, it can easily be moved between hardware platforms. Furthermore, due to the fact that IL is a low-level language, it will execute faster in the PLC than graphical languages. Another advantage is it uses less memory space in the PLC, since it is a more compact language. However, despite these advantages, this language is not always preferred by programmers since it is not as visual as other languages provided, which results in maintenance being more problematic. Another aspect to look at is the fact that nowadays, modern PLCs have higher processing speed and larger memory available, resulting in less efficiency using IL. [18]

<table>
<thead>
<tr>
<th>Ladder</th>
<th>Instruction List (IL)</th>
</tr>
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</table>
| ![Diagram](image) | LD A  
LDN A  
LD B  
ANB  
ST X |
| ![Diagram](image) | ST X  
ST X  
ST X  |

Figure 3: Example code written in Instruction List [20].

2.1.3.2 Blocks

This section presents commonly used blocks for the programming of PLCs.

Latches are switches designed to stay in the position of their last action, i.e. a pushed in latch will stay in place until it is pulled out. Each change of position (latching or unlatching) demands a new instruction. Latches are not universal among the different PLC vendors, for example, Siemens use so-called flip-flops instead. Siemens’ flip-flops, also called SR-latches (Set-Reset-latch), have the same functionality but a slightly different notation. [21]
Timers are available in four different types: Timer ON (TON); Timer OFF (TOF); Retentive Timer ON (RTO); Retentive Timer OFF (RTF). Each timer can be set to be ON-delay, OFF-delay, retentive or non-retentive. An ON-delay timer waits for a specified time after the preceding ladder logic is true, before turning on. The OFF-delay timer turns on immediately when the preceding ladder logic is true, but a specific waiting time is elapsed before the timer is turned off. A retentive timer sums all of the ON or OFF times of a timer, even if it never finishes. A non-retentive timer counts the delay from zero each time. Common applications for retentive timers are time tracking before maintenance and the non-retentive timer is often used as a short delay between a start button and a process start. [21]

Counters are provided in two basic types, namely count-UP and count-DOWN. However, combinations of the two basic types are also a possibility. The counters can be configured to count during the period the input of the counter is true, but the possibility to count on rising or falling edge are also common options. [21]

2.2 Industrial networks

There are many communication protocols for industrial automation available, most are designed to be reliable and efficient, fulfill the requirements of large DCSs and support precision operations for real-time processes [22]. For control systems using PLCs, two of the most common networking standards are Multi-Point Interface (MPI) and Process Field Bus (PROFIBUS), which will be described shortly in subsections 2.2.1 and 2.2.2.

2.2.1 MPI

Multi-Point Interface (MPI) is a communication standard designed for programming and data services on devices in PLC systems. There must be at least one master unit in the network, with the main purpose to manage data flow in the complete network. The network speed of MPI is optional with a range from 9 kbit/s to 12 Mbit/s. The transmission technology is addressed according to the RS485 communication standard. [23]

2.2.2 PROFIBUS

Process field bus (PROFIBUS) is a networking standard developed 1989 by BMFT (German Federal Ministry of Research and Technology) in cooperation with automation manufacturers who demanded a more efficient and reliable communication standard. The PROFIBUS standard is available in the versions DP/PA/FMS. PROFIBUS Fieldbus Message Specification is an old, not so common version and therefore PROFIBUS Distributed Peripheral or PROFIBUS Process Automation is most commonly seen in control systems nowadays. [24]
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Devices connected to the PROFIBUS are divided into:

- **Master devices**, which control the bus and transfer messages without any remote request. The masters are mainly referred to *active stations* on the bus. [24]

- **Slave devices**, which mainly consist of peripherals, are devices that only can acknowledge received messages or transmit to a requesting master. The slaves are mainly referred to *passive stations*. [24]

The physical transmission technology used in PROFIBUS is provided in different versions of the OSI-model. Asynchronous RS485 transmission is a simple and cost-effective technology used for high transmission rates. A shielded, twisted pair of copper cable is used as transmission media. RS485 provide transmission rates of 9.6-12,000 kbit/s configured in a line topology setup with termination. Without repeater, a maximum of 32 stations are possible. Up to 9 repeaters can be used, with a total of 127 stations in the setup. [24]

### 2.2.2.1 DP

PROFIBUS Distributed Peripheral (PROFIBUS DP) is a master-slave configured standard that allows multiple masters on the bus. The efficiency of this is that multiple masters can read a device, but only one master at a time can write to it. PROFIBUS DP is developed for high-speed data transfer with a maximum rate of 12 Mbps, where the master reads or writes to the slave with a bus cycle time of less than 10 milliseconds. [24]

Up to 127 devices can be assigned to the bus, divided into the following types:

- DP-master class 1 (DPM1), usually a connected PLC
- DP-master class 2 (DPM2), mainly devices used for programming or diagnostics
- DP-slave (DPS), which are peripherals like sensors with a limited amount of 246 byte I/O data. [25]

Communication between active and passive stations is controlled by the master device, where the following states can occur:

- **Stop**: This state prevents the data transfer between the DPM1 and the DPSs
- **Clear**: The outputs are set to a fail-safe mode by the DPM1 and the input data from the DPSs are read
- **Operate**: The DPM1 is in data transfer state with a cyclic sequence where input data is read and output data is written to DPSs [25]
2.3 Automation systems

In order to efficiently manage, regulate or monitor the behavior of devices and processes, a control system needs to be provided. Automation of industrial systems has been a main topic to consider over the past few decades in order to produce qualitative, consistent and cost-effective products or services for markets worldwide [26]. An automatic process system is a setup for automatic control, i.e. a setup for monitoring and controlling systems without any manual intervention [27]. An automated system executes sequentially and cyclically in three steps, which can be seen in Figure 4.

![Figure 4: The three main steps in an automation cycle.](image)

- **Step 1** involves the gathering of information, i.e. the observations of the controlled process, with parameters referred as process inputs.

- **Step 2** compares the analyzed behavior of the process with the desired result, followed by a decision whether to correct any parameters or not.

- **Step 3** involves the control execution of the process, where actions leading to new decisions (if corrections are necessary), are directives referred to as process outputs.

[28]

The automation cycle is a basic execution description for automatic control systems in general. Control systems are divided into so-called Centralized Control Systems (CSSs) and Distributed Control Systems (DCSs) when designed for industrial environments. [29]

Centralized Control Systems are in general small configured systems with a control center placed close to the process itself. A CCS always uses one communicable controller, but can contain either a single operator or multiple operators connected directly to the controller. CCSs are ideal for small processes with advantages like technical simplicity, less cabling and a lower cost. A clear disadvantage of this type of system is the risk of making a complete automated process unavailable due to a controller failure. [29]
In order to efficiently control a large process, a network of many communicable controllers is formed to a DCS. Subsection 2.3.1 describes these types of systems.

2.3.1 Distributed Control Systems

Distributed Control Systems, or Decentralized Control Systems, are the most common setups in manufacturing industries. In general, a DCS is a way of setting up a control system without having a central point for the whole system. The purpose of this is to separate the whole system into so-called subprocesses, which makes it possible to remote-control and monitor processes from different locations in an easy way. A DCS can consist of several control systems, devices and subprocesses. Figure 5 shows how a central process can be divided into subprocesses. [30]

![Figure 5: The central process (a) can be divided into subprocesses (b), which is the main concept of Distributed Control Systems. [30]](image)

The process control in the manufacturing industry is often set up with many subprocesses and in order to make controlling efficient when using DCSs, the data exchange between the subprocesses and other devices is crucial. The complete system must have a fast and reliable data flow throughout the whole DCS. A distributed process can be spread out over a relatively large area with the option to have the control center physically separated from the sub systems of the DCS. The controllers are remotely connected to the operator stations through a communication interface, often using serial communication. [31]
2.4 **Current solutions for automatic unloading of paper reels**

This section presents general information on systems currently used for automatic unloading of paper reels in paper and pulp industries. Two different systems will be considered, where the main focus is to evaluate these systems based on the following criteria:

1. Functionality
2. Universality
3. Unloading time and reel weight
4. Control system

Subsection 2.4.1 presents a solution from Trancel Systems and a solution provided by Joloda International is described in subsection 2.4.2.

2.4.1 **Trancel Systems**

The LOADMATE® [32] is an unloading solution provided by Trancel Systems, designed for manufacturing and distribution industries. The main concept is based on using a conveyor belt and steel channels in the trailer to push the paper reels onto a docked loading truck, which can be seen in Figure 6. [32]

![Figure 6: Trancel Systems automatic unloading. Standing reels are pushed onto the trailer with conveyor belts. [32]](image)

The paper and pulp industry SCA Ortviken [33] in Sundsvall, Sweden, have recently installed an unloading solution from Trancel Systems. An interview with an employee at SCA Ortviken has, based on the criteria in subsection 2.4, given the following information regarding the system setup:
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1. The functionality of the solution is to unload standing paper reels to the trailers, using rails placed in steel channels. The reels must be placed in line on the rails before they are all simultaneously pushed into the trailer. The standing reels are mostly not stacked when loaded even though multiple stacking is a possibility, depending on the sizes of the reels. Lying reels are transported to the unloading station using conveyer belts and due to the fact that the reels are loaded standing up, a cradle is designed to lift the reels to a standing position. [8]

2. Each trailer being loaded with the Trancel System needs to be provided with steel channels and rails in the floor. In order to have a safe loading and no movement of the trailer, a docking station is also necessary. [8]

3. The unloading time depends on factors like trailer length, maximum speed on motors and the weight of the reels. A 13.6 meter semi-trailer can load in less than three minutes. This only includes the loading itself and therefore excludes the extra time spent redirecting the reels for the unloading phase. The system is designed for smaller paper reels with a weight of up to 1 000 kg. [8]

4. The control system setup is a Distributed Control System designed by Siemens. The system has a total of three SIMATIC S7 PLCs, including subprocesses for redirection, transportation and unloading. All PLCs are programmed using SIMATIC STEP 7 Engineering Software and the communication between the devices is established using PROFINET, a networking standard based on TCP/IP and Ethernet. [8]

2.4.2 Joloda International

Joloda International is a market leading company for loading systems, mainly in the UK, Europe and America. The company provides solutions for both manual and automated loading systems. Joloda Internationals automated solution for unloading of lying paper reels can be seen in Figure 7. [34]
The main concept of this system is using a conveyor belt and steel channels in the trailer to push the paper reels into a docked loading truck. The solution was developed to transport large paper reels with a length and weight up to 1 873 mm and 2 200 kg respectively. [34]

1. The functionality of the solutions is to use four lanes of skates that move in four channels placed in the trailer floor. When loading and unloading, the lanes are raised using an airbag. This system is mainly designed for the unloading of large lying paper reels. [34]

2. Each trailer being loaded with Joloda International system needs to be provided with steel channels and rails in the floor. In order to have a safe loading and no movement of the trailer, a docking station is also provided. The solution requires manual involvement using fork lifts. [34]

3. The unloading time depends on factors like trailer length and maximum speed of motors. This solution loads 12 reels per trailer with a reel weight of 2 200 kg. [34]

4. Further information regarding the control system setup could not be presented since contact could not be established with the company.
3 Methodology

Chapter 3 presents the methodology used for the completion of the project. A description of the literature study of the project is presented in subsection 3.1, followed by the solution approach in subsection 3.2. Finally, in subsection 3.3, an evaluation of the project as a whole is presented.

3.1 Literature study

Initially, a literature study will be mandatory in order to find the facts necessary for the project. The study will be divided into two main areas of interest, namely:

- General understanding of PLCs and control systems
- Currently used solutions for automatic unloading of paper reels

The main sources of the literature study are books and articles from the library of Mid Sweden University [35]. Additional information regarding control systems and current solutions for automatic unloading are gathered from producers and an interview with an employee at the paper and pulp factory SCA Ortviken in Sundsvall, Sweden.

3.2 Solution approach

The information gathered from the literature study will, together with the demands from ÅF Consult, constitute the basis for the completion of the project. The solution of the project is structured and executed as follows:

1. Design lab station
2. Develop station
3. Provide ÅF Consult with a test program
4. Simulate the emulation of the automatic solution for unloading of paper reels.

Schematics are drawn and tests for the equipment are provided before the development of the station. In order to test the equipment and present the possibilities of the station to ÅF Consult, test programs will be written with SIMATIC STEP 7 Engineering Software.

3.3 Evaluation

The project as a whole will be evaluated at the final stage of the project and it will be based on the problem formulations and goals described in subsection 1.4. The lab station is evaluated in regards to functionality and possibilities. The unloading solution will mostly be discussed but also simulated as an emulation at the lab station.
4 Design

This chapter presents the design and implementation of the lab station based on the specified problem formulations in chapter 1. This chapter will cover the: development of the lab station; PLC and communication setup; solution for automatic unloading of paper reels.

4.1 Lab station

The design of the lab station is established based on the research on industrial control systems and the demands from ÅF Consult. The station is implemented to be small and portable but still have as much equipment and possibilities as possible. The ÅF Consult budget was 6 500 SEK and in order to get as much equipment at the station as possible, most parts of the station were constructed by the project group members. The hope of this design is to implement the station with components and processes similar to common control systems in manufacturing processes, giving a field related station with tasks that are similar to those in industrial DCSs.

The station is divided into two major parts, namely a conveyor belt and a robotic arm. For simulation of tasks, iron and wood cubes will be directed throughout the whole station, constituting a process chain. The complete setup can be seen in Figure 8.

Figure 8: Complete setup of the station, which consists of the main parts: 1) Conveyor belt; 2) Robotic arm; 3) S7-300; 4) S7-400.
4.1.1 Conveyor belt

The conveyor belt is one of the main parts of the station, designed for transportation and sorting. The belt is designed to run in one direction and consists of two sub parts, namely the storage and the belt. The complete setup of the conveyor belt can be seen in Figure 9.

![Figure 9: Complete setup of the conveyor belt, which consists of the main parts: 1) Stockpile; 2) Load Cell; 3) Speed sensor; 4) Ramp 1; 5) Ramp 2; 6) Stockpile motor; 7) Stockpile sensor; 8) Inductive sensor; 9) Photo diode; 10) Actuator 1; 11) Actuator 2. 12) Emergency limit switch.](image)

The storage is designed to contain multiple cubes (a maximum of four cubes). A 6 VDC motor pushes the cubes onto the belt via a ramp. A photo diode, placed to sense the arm from the motor, works as a switch to see when a cube is pushed onto the belt. An inductive sensor is placed in the ramp to detect metal cubes.

The conveyor belt was constructed by the project’s group members due to the expenses of ready-made belts. Two 3D-printed rolls in plastic combined with three fan belts and a motor, constitute the conveyor belt (see design of the rolls in Figure 10). The functionality of the belt is to transport the cubes to the robotic arm station and should be able to sort metal and wood cubes. Two ramps are placed at the long side of the belt, directing cubes to the robotic arm station. Each ramp has a limit switch, detecting if a cube is sliding down the ramp. Two actuators are constructed with two 12 VDC solenoids, pushing out metal walls to redirect the cubes as the conveyor belt is running. A photo cell is placed at the start of the conveyor belt in order to detect both types of cubes. A limit switch is placed at the end of the belt which serves as an emergency stop. In addition, the conveyor belt is designed with speed regulation using a PWM module. In order to read the current speed of the belt, a photo resistive sensor is placed under one of the 3D-printed rolls. Pieces of metal, placed at the center of the roll, are designed to break the contact of the sensor resulting in an impulse each time a metal piece passes. For further accuracy, four metal pieces are used, resulting in a total of four impulses per revolution.
4.1.2 Robotic arm

A 5-axis robotic arm is the main station of the setup, implemented as a pick-and-place machine. Each axis movement of the arm is controlled by a 3 VDC motor. The arm itself is placed on a trolley at the center of the station, connected to a chain driven by a 6 VDC motor in order to move the arm between the substations. Figure 11 shows the parts of the robotic arm, including the motors.

Figure 11: The robotic arm consists of a rotational axis, bottom joint, middle joint, top joint and a grip claw. These are controlled by the: rotation motor (1); bottom motor (2); middle motor (3); top motor (4) and the grip claw motor (5). [38]
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The rotation of the arm is controlled by motor 1 and has, due to the wiring, a positioning range of 180 degrees. Motor 2 controls the bottom joint of the arm and is equipped with two limit switches for security reasons, giving a 90 degree movement range from a vertical position to a nearly horizontal position. The bottom joint is therefore mainly designed for two positions, i.e. at the extreme positions.

Motor 3 also has a 90 degree movement range, using a resistive flex sensor [39] to monitor the position. Motor 4 adjusts the top joint, with its position monitored with another resistive flex sensor [39]. The top joint is designed to move from a horizontal down to a nearly vertical position, due to the top placement of the sensor. Motor 5 controls the grip claw, equipped with a pressure sensor [40] in order to sense a gripped object as well as being able to adjust the pressure based on the type of object.

In order for the six motors to run in both directions, a total of 12 relays are connected between the S7-400 PLC and the robotic arm. Each motor is connected to two relays according to Figure 12.

Figure 12: Control schematic for the motors of the robotic arm.

There are two implemented solutions for monitoring the position of the robotic arm along the connected chain. An ultrasonic range sensor [41] is placed in line with the arm to give the position of the trolley. The second solution is by using limit switches and a photo diode. The limit switches are placed at the extreme positions of the arm and the photo diode is placed in the middle of the chain. The limit switches are designed as placement sensors for five of the stations namely the: unloading station; the stockpile station; the weighing station; the metal cube ramp; and the measuring station. The photo diode has the function of a placement sensor for the second ramp. In order to monitor the placement of the rotational axis of the arm, an inductive sensor is used together with four metal pieces with 90 degree dislocation from each other. Using counters in the PLC program results in an efficient way of monitoring the rotational position.
4.1.3 Additional equipment

In addition to the equipment stated in subsections 4.1.1 and 4.1.2, the station is also provided with the following equipment and functionality:

- **Scale**: The station is provided with a load cell [43] in order to measure small objects, up to 0.6 kg. Due to the low change of output voltage from the load cell, a differential amplifier is designed to get the desired value of 1-5 V to the PLC input. Figure 13 shows the amplifier setup for the scale, using a MC3403PG [42] operational amplifier.

![Load cell setup](image)

*Figure 13: A load cell [43] used as a scale. An MC3403PG operational amplifier is used as a differential amplifier in order to amplify the small output voltage from the load cell.*

- **Measuring station**: The lab station is provided with a measuring station for height and temperature measurements. This is not covered in this thesis.

- **PC**: In order to monitor and remote control the station, communication to a PC is established via OPC with a server-client connection. This is not covered in this thesis.

4.2 PLC setup

This section presents the setup in order to control the equipment of the lab station. The control system is designed as a DCS using two PLCs in a master-slave configuration. Due to the fact that ÅF Consults mainly work with Siemens controllers, the station is limited to using a Siemens S7-400 series and a S7-300 series PLC. Subsections 4.2.1 and 4.2.2 present the setup for the Siemens S7-400 and the Siemens S7-300 respectively. In conclusion, subsection 4.2.3 presents the PROFIBUS configuration for the communication between the nodes.
4.2.1 **Siemens S7-400**

A Siemens S7 416-2 DP CPU [44] is used as the master device of the station, equipped with: a power supply; a communication module for Ethernet; a digital output card with 32 outputs. Included modules and the currently configured addresses can be seen in Figure 14. The electrical schematics for the DO card can be seen in Appendix B.

The S7-400 is mainly configured to control the six motors of the robotic arm and to send and receive data to and from the S7-300 and a PC respectively.

![Figure 14: Hardware configuration of the CPU 416-2 DP. In the rack the following is included: the power supply (PS 407 10A) in slot 1; the CPU in slot 3-4; a communication module for Ethernet connection in slot 5; a digital output card (32 outputs) in slot 6. The addresses currently used are also shown.](image)

4.2.2 **Siemens S7-300**

A Siemens S7 315-2 DP CPU [45] is used as a slave device to the S7 416-2 DP CPU. The CPU is equipped with: a power supply; a digital input card with 16 inputs; a digital output card with 8 outputs; an analog input card with 8 inputs; an analog output card with 4 outputs. The modules and current addresses included can be seen in Figure 15. The electrical schematics for the Siemens S7-300 PLC can be seen in: Appendix C for DO; Appendix D for DI; Appendix E for AO; Appendix F for AI.

The Siemens S7-300 PLC is mainly configured to control: the three actuators on the conveyor belt; the conveyor belt motor; the rest of the equipment, i.e. sensors and limit switches.
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4.2.3 PROFIBUS configuration

The communication between the devices is established with PROFIBUS where the Siemens S7-400 PLC is configured as an active DPM1 and the S7-300 as a passive DPS device. Since the lab station is also provided with the possibility to monitor and remote control the PLCs with a Programming PC, another node is added in the network. Both PLCs have the option to use MPI, which was also used for the initial programming of the PLCs before the establishing of the PROFIBUS configuration. The configured nodes can be seen in Figure 16.

Figure 15: Hardware configuration for the CPU 315-2 DP. In the rack the following is included: a power supply in slot 1 (not included in the picture); the CPU in slot 2-3; a digital input card (16 inputs); a digital output card (8 outputs); an analog input card (8 inputs); an analog output card (4 outputs). The addresses currently used can also be seen.

Figure 16: Network configuration of the PLCs. Currently configured addresses for MPI and PROFIBUS can be seen below each PLC.
The available I/O-addresses of the PLCs can be configured as inputs and outputs between the nodes in the PROFIBUS connection. In order to have a data flow between the master and the slave CPU, each PLC was configured with the addresses seen in Figure 17. These addresses are pre-allocated for the established communication. The PC used for monitoring and remote control is directly connected to the Siemens S7-400 Ethernet connection board.

<table>
<thead>
<tr>
<th>Row</th>
<th>Mode</th>
<th>Partner Addr</th>
<th>Partner Addr</th>
<th>Local Addr</th>
<th>Length</th>
<th>Consist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MS</td>
<td>O 260</td>
<td>O 20</td>
<td>16 Word</td>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>MS</td>
<td>2</td>
<td>1 200</td>
<td>2 Word</td>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>MS</td>
<td>2</td>
<td>1 100</td>
<td>2 Word</td>
<td>Unit</td>
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<tr>
<td>4</td>
<td>MS</td>
<td>2</td>
<td>1 100</td>
<td>2 Word</td>
<td>Unit</td>
<td></td>
</tr>
</tbody>
</table>

Figure 17: Address configuration between the PROFIBUS nodes, i.e. the S7-300 (slave) and S7-400 (master).

### 4.3 Automatic unloading using a robotic arm

This section presents the solution of using a robotic arm for an automated unloading of paper reels in the pulp and paper industry. The solution will only be presented theoretically, where the advantages of the solution are the main topic to consider. This solution will be further evaluated and discussed in chapter 6.

**Functionality**

The main concept of the solution is to unload the paper reels to trailers using a PLC controlled robotic arm. Loading will be carried out at the long side of curtain side trailers. The arm should move on reels along one side of the trailer, unless a system is installed on each side for faster unloading. Therefore, the arm needs to be long enough to reach the far side of the trailer along the whole trailer height for multiple stacking of reels. A standard semi-trailer has an inside width of 2.54 meters [46].

In order to design a solution for different sizes of reels, a heavy duty robotic arm is necessary. KUKA Robotics KR 1000 1300 TITAN PA [47] is a 6-axis arm and is currently the strongest on the market, with a maximum payload of 1 300 kg. The maximum reach of the arm is 3 203 mm. The standard version of this arm does not provide the top module for handling of the cylindrical reels. Therefore, a top module with functionality as a grip claw is necessary. [47]

**Universality**

The main purpose of this solution is to design a universal unloading station, discarding extra processes like redirection of reels and pre-installed equipment in the trailers. The hope is to implement a solution that is completely automated and able to unload to any trailer. This solution will only consider unloading to and not from trailers, even though unloading from trailers would be based on the same concept.
Unloading time and reel weight

Due to the fact that this solution will not be implemented in real life, but instead emulated as accurate as possible on the lab station, it is difficult to present times for the unloading itself. This solution is expected to not have the capacity of unloading as fast as currently used systems, but focus more on a completely automated and reliable solution for different reel weights. The maximum capacity of payload for the robotic arm will limit the weight handling to reels under 1300 kg.

Control system

Instead of using the KUKA Robotics provided controller, the control system setup will be designed as a DCS using PLCs. The main concept of the setup is to, in accordance with the setup at the lab station, use two PLCs to control divided subprocesses. One PLC will mainly handle the movements of the arm along the trailer and monitor the position of the arm. The other PLC will be configured as master device and handle the motors of the robotic arm. Due to the fact that this solution will not be implemented, it is difficult to pinpoint what type of equipment the solution needs in terms of sensors, PLC modules and further equipment.

4.3.1 Emulation to automatic solution on lab station

The solution presented in subsection 4.3 will be emulated at the lab station using cubes instead of real paper reels. The hope is to test the DCS setup with a test program designed according to the flow chart seen in Appendix A. The following subprocesses are considered:

Stockpile station

Metal and wood cubes are stored in the stockpile until pushed out onto the conveyor belt. The cubes are then sorted on the belt and, depending on the type of cube, directed to either the weighing station (if metal) or the unloading station (if wood). In case of an error or missing cubes, the program will loop back to push out a new cube in the process chain.

Weighing station

The metal cubes from the conveyor belt are moved to the weighing station by the robotic arm. This function is implemented to make sure that the objects for unloading have the correct properties. If the weight is correct, the metal cube is transported to the unloading station, otherwise it is moved back to the stockpile again.

Unloading station

The unloading station is designed with the purpose to simulate unloading to a curtain side trailer. The cubes are first placed in a line with a space of 1 cm between each cube due to the width of the grip claw. Further on, as more cubes are transported to the unloading station, multiple cubes are stacked on each other.
4.3.1.1 Software approach

The test program is written in SIMATIC STEP 7 Engineering Software, where the complete setup is divided into one part for the S7-300 and one part for the S7-400 PLC. Ladder Diagram was the language used for the programming. Each PLC communicates with the operating system using an organization block (OB1 default). The program is designed with function blocks that are called from OB1 for execution. Each function block pertain a specific part of the lab station in order to control each substation efficiently and provide an easy readable program for further implementations and troubleshooting. The hope of the program design is to easily configure the station for different purposes and process flows. To divide the sub stations of the lab setup in function blocks results in easy management of the robotic arm between the stations of the lab setup. Implemented counters monitor how many cubes of each type the ramps contain, which makes deciding the correct function call easy, whether the arm should pick up a wood or metal cube. The count is calculated by using the limit switches placed in the ramps.

Data flow between the peripherals and the PLCs are either analog or digital values. The digital values are used as switches with the current state stored in memory bits. The analog values are configured with different voltage levels depending on type of sensor. The analog input values are configured as 1-10 V range in the PLCs, i.e. the range for the values from the flex sensors, range sensor, the grip claw pressure sensor and the load cell.

The analog values from the flex sensors are handled in the PLCs with compare blocks; see example code in Figure 18. Input values from the sensors are compared with pre-defined threshold values for required positions of the joints of the arm. The same applies to the range sensor and the grip claw.

Figure 18: Compare block example.

Figure 19 shows an example of a move block, which is used in order to copy the analog values from one memory area to another. This data exchange is established between peripherals and the PLCs according to the address configuration described in subsection 4.2.3.

Figure 19: Move block example.
5 Results

This chapter presents the evaluation of the solutions in the work. The evaluation is divided into main areas according to the stated problem formulations in subsection 1.4. Subsection 5.1 presents the result of the design and construction of the lab station, where the equipment and lab possibilities are covered. Subsection 5.2 describes a lab task for the station. Subsection 5.3 presents the results from the emulation of the automatic unloading. Finally, in subsection 5.4, existing solutions similar to the stated lab station will be presented.

5.1 Lab station

All equipment covered at the lab station is placed on a one square meter plywood board, resulting in a portable solution. The hope of designing a field related lab station is considered fulfilled since the equipment and the development of the station is based on researched industrial solutions. The proven usage of conveyor belts, sorting and pick-and-place functionality in paper and pulp factories results in similar solutions being implemented at the station. Together with the research provided from the other group members, the final lab setup is implemented with equipment for industrial solutions regarding transportation, measuring, monitoring and sorting processes.

The literature study showed that the extent of setups using DCSs are very common for industrial solutions. One of the main purposes of designing the station according to these types of systems resulted in configuring the PLCs to control one subprocess each. The communication is established with a master-slave configuration using PROFIBUS DP. The equipment of the lab station lack accuracy due to a low budget, resulting in cheap and unreliable equipment. This will be further discussed later on in this chapter.

5.1.1 Conveyor belt

The main functionalities of the conveyor belt are to sort and transport cubes. Each substation of the belt is described separately in regards to the formed problem statements.

The hope of designing a stockpile with the possibility to store multiple cubes appeared to be a problem and was therefore redesigned. The demands of ÅF Consults to have a small and portable station caused issues in regards to the dimensions of the complete lab station. The height of the stockpile became a problem and the solution was to place a ramp as a stockpile, making it possible to store four cubes. Due to mechanical issues, the stockpile motor only pushes correctly when only one cube is present in the stockpile; multiple cubes result in a failure.
The sorting on the conveyor belt has the possibility to sort two different types of cubes, directing them to separate ramps. The two ramps from the conveyor belt direct cubes correctly, but due to mechanical issues, the cubes are not always placed at the correct spot for the robotic arm. Manual intervention is necessary to remove cubes not correctly placed. The conveyor belt is designed for speed control with correct functionality despite a smaller control range than planned. This is because of the tension in the fan belts, resulting in a slower speed than expected.

### 5.1.2 Robotic arm

The robotic arm is designed as a pick-and-place machine to transport the cubes throughout the stations subparts. However, the arm is not considered as a reliable solution due to the lack of accuracy of the required sensors. The positioning along the board using the chain works correctly and the robotic arm reaches all stations in an easy manner. The positioning of the arm is monitored with either end position limit switches combined with a photo resistive diode or using the provided range sensor. The range sensor has a dead zone of 30 cm and its conical distribution result in a loss of focus as the arm moves towards the far end of the chain. The low accuracy of the range sensor resulted in using the other implemented solution as test programs and simulations were developed.

### Sensors

The robotic arm is provided with a total of seven sensors to monitor the position of its axes and rotations; see subsection 4.1.2 for implementation of these. The hope of being able to control the arm with enough accuracy on all stations of the lab setup is not fulfilled due to the low accuracy of the provided flex sensors. The high movement of the arm results in high operation of the flex sensors, which both tend to give different results each time they are used.

Measurements were done on each flex sensor twice before implementation. It can be seen in Figure 20 and Figure 21 respectively, that the sensors are not accurate due to differences between each trial. The output voltage is proportional to the resistance but the fact that an offset occurs each time a sensor is used results in a low accuracy of the arms position monitoring. The placement of the grip claw is highly exposed and the arm’s tends to miss cubes at stations, all depending on the behavior of the flex sensors.

The grip claw sensor has a steep resistance curve which results in difficulties gripping with different pressures due to the mechanics of the grip claw. However, the ability to grip with different pressures is available as the output voltage changes in proportion to the pressure. The remaining implemented sensors work as intended.
Figure 20: Top flex sensor output signal to the Siemens S7-300 PLC, depending on the flex angle. The angle range of the sensor is 0 to 45 degrees, starting from a horizontal position.

Figure 21: Middle flex sensor output signal to the Siemens S7-300 PLC, depending on the flex angle. The angle range of the sensor is 0 to 90 degrees, starting from a vertical position.
5.1.3 **Load cell**

The load cell is designed to weigh the cubes and has a maximum load of 600 g. The output from the load cell is a small voltage (microvolts) which required an implementation of a differential amplifier. The amplifier was designed with a gain of approximately 5,000 times. Since the resistance of the resistors are not exactly the same result in a common-mode gain that differ from zero. A small offset arise which can be seen in the equation in Figure 22. The input on the PLC is set to 1-10 V which results in a loss of measuring range for the load cell. As seen in Figure 22, the load cell can only measure objects with a weight of up to 300 g due to configuration of a maximum of 10 V.

![Load Cell Graph](image)

Figure 22: Output signal to the Siemens S7-300 PLC from the differential amplifier, depending on the load.

### 5.2 Lab task

In order to introduce the functionality and equipment of the station, lab tasks will be described. Lab tasks are covered in all three theses regarding this project, with the main purpose to introduce employees and students to the lab station designed. Tasks presented in this thesis can be seen in Appendix G.
5.3 **Emulation of unloading solution using robotic arm**

An automatic solution for unloading of paper reels in paper and pulp industries was presented in this thesis. The emulation showed that the cubes could be unloaded according to the presented solution in subsection 4.3. Cubes were unloaded to a station similar to how an unloading in a semi-trailer would work. The unloaded cubes could be placed in a line and multiple stacking was possible to a certain extent. The unreliability and accuracy of the equipment of the station resulted in an unreliable unloading where stacking of cubes and the distance between them varied depending on the behavior of the arm.

Using a DCS setup with two PLCs is a good approach for the solution designed. This is confirmed by the result of the emulation as well as the fact that the system currently used at SCA Ortviken is based on a similar setup using a Siemens DCS with three Siemens S7 PLCs.

5.4 **Similar lab station solutions**

This subsection presents already existing solutions similar to the implemented lab station considered in this thesis.

One of the main concepts of functionality for the station was to implement a conveyor belt for transportation and sorting. An already existing solution from Staudinger GMBH, namely the *Compact Transport and Sorting Line*, simulates a sorting functionality for objects that are redirected to substations of the setup. [48]

The station is equipped with the following components:

- **Sensors:**
  - 2 inductive proximity switches
  - 7 mechanical switches
  - 4 reed switches (magnetic switches)

- **Actuators:**
  - 1 motor with one direction
  - 2 motors with two directions
  - LED

- **Control System Requirements:**
  - 13 digital inputs
  - 8 digital outputs

The Compact Transport and Sorting Line station can be seen in Figure 23.
The robotic arm implemented at the station has the functionality of a pick-and-place machine. A similar existing solution to this is the Compact High Level Storage Warehouse from Staudinger GMBH, seen in Figure 24. The station simulates a storage system with the possibility to sort and replace object with a pick-and-place functionality. [49]

The station is equipped with the following components:

- **Sensors:**
  - 1 reed switch
  - 16 mechanical switches
- **Actuators:**
  - 3 motors with two directions
  - 2 LEDs
- **Control System Requirements:**
  - 15 digital inputs
  - 8 digital outputs

[49]
6 Discussion

This chapter presents the discussion of the solution and evaluation of the project covered in the thesis. Subsection 6.1 presents the solution evaluation of the lab station and the unloading solution. Subsection 6.2 presents ethical and social aspects of the project and finally, future work is presented in subsection 6.3.

6.1 Evaluation of solution

The overall goals to design a lab station and emulate the automatic solution for unloading of paper reels are fulfilled to some extent. The lab station was implemented according to the planned design but it was difficult to get the necessary accuracy of the equipment due to the low budget. One of the main goals of the design of the station was to include as much equipment as possible in order for the station to have many possibilities. A higher budget or the removal of some equipment would have resulted in better accuracy of the parts included. Due to problems during the construction of the station, which took more time than expected, the time limits of 10 weeks resulted in less time to research and to specify the solution for unloading of paper reels.

6.1.1 Lab station

The design and solution for the lab station and its related equipment are discussed in this part, where problems and solution suggestions are presented. The station could be implemented as a DCS setup on a small board, so the solution provided is portable and field related according to the demands from AF Consult. The goal of designing the station according to similar solutions in industrial processes is fulfilled since it works well to use each PLC to control the different stations of the setup.

Conveyor belt

The overall aim of the conveyor belt is reached even though some changes would be appropriate in order to reach higher accuracy. A higher project budget would have led to buying a ready-built conveyor belt which would have removed the current problems due to mechanical issues. The fact that the stockpile is unreliable for multiple cube handling removes one of the functionalities with the belt itself, which could have been resolved with a redesign or the usage of additional equipment.

Robotic arm

The robotic arm is the main station of the setup, which results in problem for the entire construction due to the low accuracy. The two flex sensors are the main issue since they both tend to give different results at each measurement. This could have been resolved by using stepper motors in the arm for
monitoring. The fact that the resistance ranges stated by the producers was 100 kΩ and turned out to be 40 kΩ and 4 kΩ respectively, results in a lower resolution and therefore less accurate monitoring. The grip claw sensor could also be improved with a different setup since the steep resistance curve of the sensor and the mechanics of the grip claw result in problems gripping objects using different pressures. Another issue with the positioning of the arm along the board is the provided ultrasonic range sensor. As stated earlier, the sensor tends to lose the focus of the arm as the distance from the sensor increases. Using laser range sensors could be a good solution if further accuracy is desired. The other solution (using limit switches and a photo diode) was implemented in order to be able to move the arm to all stations designed. This was possible due to the placement of the substations.

6.1.2 Unloading using robotic arm

The results of the research and development of the unloading solution are discussed in this subsection. The problem formulations stated in subsection 1.4 are evaluated and discussed first. Advantages and motivation of the presented solution are discussed.

How does currently used solutions for automatic unloading work?

Research of systems from Trancel Systems and Joloda International showed that current solutions for automated unloading can be optimized. The following criteria were considered and will be discussed:

1. Functionality
   The existing solutions with conveyor belts tend to unload fast but in a non-universal way. Rails and steel channels need to be provided as well as docking stations. Manual intervention is also common.

2. Universality
   Specific trailers are necessary for all unloading due to pre-installed equipment. Demands to position paper reels correct in the unloading station (either standing up or lying down) results in problems like extra reel handling and not completely filled trailers. A half loaded trailer due to non-stacking of reels cause problems in an environmental point of view.

3. Unloading time and reel weight
   An unloading time of approximately 3 minutes is fast and difficult to improve further. However, the fact that reels have to be handled before the unloading itself results in additional time. Paper reels are mainly transported lying down in the factories, leading to additional handling of reels before unloading.

4. Control system
   The system at SCA Ortviken uses Siemens S7 PLCs in a DCS setup with PROFINET connection.
Is an automatic unloading solution using DCS setup with a PLC controlled robotic arm possible?

Since the research showed that systems currently used have setups similar to the lab station provided to ÅF Consult and due to additional research of equipment, it has been proved that the solution would be appropriate in a control engineering point of view. Mechanical aspects and complete equipment setup for the solution are not considered. A DCS is a good choice for the solution to separate the control of the arm itself from the movement and monitoring of the system, which is confirmed as the designed setup at the lab station is implemented similarly.

What equipment is necessary?

Due to the scope of the project and the time limit of the project, research regarding equipment for the solution was not considered. However, since the solution at SCA Ortviken is very similar to the solution presented in this thesis, a good choice would be to use two S7 PLCs as a DCS setup with different control purposes. Having the arm controlled by one PLC and controlling the sensors and additional monitoring with another PLC would complete goals like: simplicity of system; easy to troubleshoot; less cabling.

Will this solution result in a more efficient way of unloading in terms of: functionality, universality, unloading time and heavy reel weight handling?

The solution would most likely not provide a faster unloading, even though the unloading time could be halved if two systems were implemented on each side of the unloading trailer. The functionality of the system itself would provide: a completely automated solution; a universal solution with the possibility of unloading to any trailer; less handling of reels. The solution would have the possibility of handling reels weighing up to 1 300 kg. The fact that the robotic arms constantly are improved results in the possibility for heavier reel handling as heavy duty arms are redesigned.

Can the solution be simulated accurately at the lab station?

The solution could not be accurately simulated at the station due to the low accuracy of the flex sensors. It is also debatable how good a simulation of a system of this size could turn out at the implemented lab station. It is impossible to see results like unloading time, reel handling and mechanical solutions like the choice of equipment and safety precautions. However, the solution gave positive results to the problem formulations in terms of validation of the control setup. This, in combination with additional research of present solutions and choices for robotic arms, proved that a system like this could be implemented in a real situation after further research and designing.
6.2 Ethical and social aspects

Since the project presented in this thesis concerns consultant work for ÅF Consult, ethics have been considered towards the company as is stated in the following paragraphs:

- An honest and realistic approach has been considered when presenting the lab station to ÅF Consult. The results have been presented honestly in regards to functionality, where the problems and defects of the station have been clearly stated.

- Understanding of the provided technology and the functionality of the equipment have been considered during the whole project to minimize potential negative consequences. This mostly applies to the fact that the equipment has been handled with caution and been tested before implementation to minimize risks.

- The equipment of the station is implemented with precautions in order to eliminate the risk of breaking any part of the station. This is mainly secured by having physical stops for the moving objects of the station, i.e. the robotic arm and the conveyor belt. An emergency stop button is installed on the setup in order to stop all subprocesses at the station if an error occurs.

6.3 Future work

Suggestions for future work are shortly discussed in this subsection in regards to the lab station in subsection 6.3.1 and the unloading solution in subsection 6.3.2.

6.3.1 Lab station

Even though the aim of the project has been reached, there are many areas to work further on regarding the functionality of the station. There is always a possibility to change the equipment for a more accurate system and the station has some free space to facilitate the option. One of the goals of the project was to implement control regulation, but it could not be achieved due to the time limit. Further work would be to implement closed loop PID-control to the conveyor belt in order to efficiently control different input flows of the cubes directed on the belt. The speed regulation should be proportional to the input flow. Further on, regulation could be added to the resistive flex sensors of the robotic arm in order to get a more accurate positioning. The current implementation tends to miss positions due to non-linear behavior of the sensors. Implementation of PI- or PID-control could result in reaching a value closer to the threshold.
6.3.2 Unloading using robotic arm

The simulation of the unloading system showed that the control engineering setup is a working solution, although the entire unloading system needs further research and consideration. A good approach could be to: find out if the solution provides more advantages to systems currently used; complete the design with appropriate choices of equipment; implement the control system to the robotic arm for tests. Another aspect to look deeper into is the fact that the arm would handle heavy objects above the surface. Precautions needs to be considered for safe handling of the reels and the mechanics of the system should be further analyzed.
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Appendix A: Test program

Unloading of paper reels

Start

Cubes in stockpile?

Yes

Push out cube

No

Metal?

No

Wood?

Yes

Weighing station

Correct weight?

Yes

Unloading station

Stop

No

Stockpile
Appendix B: Siemens S7-400
Digital Outputs
Appendix C: Siemens S7-300

Digital Outputs
Appendix D: Siemens S7-300

Digital Inputs
Appendix E: Siemens S7-300

Analog Outputs
Appendix F: Siemens S7-300

Analog Inputs
Appendix G: Lab tasks
An introduction to lab station possibilities

These lab instructions are a basic introduction to the possibilities provided at the station. All three theses regarding this project have lab tasks provided for different implementations and this part will cover the setup of the PLCs and PROFIBUS as well as introducing the conveyor belt station. Information and tips can be obtained in this report.

1. Set up the hardware configuration for each PLC, which includes:

   - Add all modules in the HW configuration
   - Set appropriate addresses for each module

2. Set up the PROFIBUS configuration for the network.

   - Set up the nodes in the network to DP1M(S7-400), DP2M(PC) and DPS (S7-300)
   - Configure the Siemens S7-400 PLC as master. Make sure that the digital outputs are connected to the robotic arm.
   - Configure the Siemens S7-300 PLC as slave. Make sure to check that the inputs and outputs from the station are correct according to provided schematics.
   - Provide an address configuration for communication between each node.

3. Write a program to configure the conveyor belt.

   - Check that all related sensors and equipment function properly (make sure to implement the stations emergency stop button and the emergency limit switch at the end of the belt)
   - Set a value on the memory word (MW) of the speed control in order to have an appropriate speed. (Value between 6 000 and 20 000).
   - Design the stockpile motor to push out a cube if one is present.
   - Implement a sorting function where metal cubes are directed to the first ramp and wood cubes to the second. The inductive sensor and the photo cell are at your disposal.

4. Implement functionality for the two ramps.

   - Stop the conveyor belt when a limit switch is pressed on either ramp.
5. Implement counters for monitoring of objects.

- Design counters that monitor how many metal and wood cubes that are present at the conveyor belt station. Make sure to decrease the count if the robotic arm picks up a cube from a ramp.