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PLC Lab Station
Simulating an Automatic Quality Control of Loaf Products

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Abstract

ÅF Consults office in Sundsvall, Sweden, is in need of a new lab station. The purpose of the lab station is to introduce people within ÅF’s organization to PLC systems. The main goal with this thesis is therefore to construct a lab station according to ÅF Consults’ demands. These demands are for example a universal and a field related lab station. An additional goal of the thesis is to consider an improvement for an industrial process. Research was performed in this area and it was established that bakeries perform the quality control of loaf products manually. An automatic solution of this quality control is considered and simulated at the lab station. During the quality control, the loafs’ height, center temperature and weight are measured. Because of this, sensors capable of measuring these three quantities should be included in the lab station. The completed lab station consists of a robotic arm, a conveyor belt and three required sensors. The conveyor belt is a reliable construction able of transport and sort cubes, from the storage to its corresponding ramp. The robotic arm is capable of picking and placing cubes, but variations in sensors makes positioning difficult. In order to enable measurement of the required quantities, a load cell, an ultrasonic distance sensor and a PT-100 sensor was included in the lab station. The weight and temperature measurement could be completed with different accuracy. The height measurement could not be performed due to a too large reading area of the ultrasonic sensor. However, the simulation proved that an automatic quality control is possible to design.

Keywords: Lab station, PLC, PROFIBUS, Automatic quality control of loafs.
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Terminology

Abbreviations

DO  Digital output, toggled high or low.
DP  Decentralized periphery
EEPROM  Electrical-erasable permanent read-only memory
FBD  Function block diagram
IL  Instruction list
I/O  Inputs and outputs
LD  Ladder diagram
PLC  Programmable logic controller
PROFIBUS  Process field buss
PWM  Pulse width modulation
ROM  Read-only memory
ST  Structured text
1 Introduction

This thesis is one out of three regarding the construction of a lab station for ÅF’s office located in Sundsvall, Sweden. The other thesis works are: *PLC Lab Station – Solution for Automatic Unload of Paper Reels* and *PLC Lab Station – An implementation of external monitoring and control using OPC*. [1] [2]. The lab station will hopefully be universal and field related. This report will also cover the simulation of a process which can be used for quality control of loaves.

This chapter will first present a brief background on the project’s problem motivation. After that, clarifications about the project’s purpose and benefits are presented, followed by the scope of the project and the detailed problem statements. Finally, the other two theses included in the construction of the lab station are shortly explained.

1.1 Background and problem motivation

The increased focus on cheap and fast manufacturing has led to control systems and complex machines having eliminated the majority of the manual manufacturing processes. Some advantages of automation, or automatic control, are reduced labor costs, energy savings and increased manufacturing flow. One area in Sweden’s industry is the food and beverage industry.

A main area in the food industry is the formulation and packaging of bread. A modern bakery is a factory almost completely automated through control systems. One step in the bakery process, which is still done manually, is the quality control of finished products [3]. All loaf products need the correct weight, height and center temperature. [4]

ÅF Consult is a leading consult organization with about 7 000 employees around the world. ÅF Consult focus on areas, for example: energy, infrastructure and industrial projects [5]. Several of ÅF Consult’s solutions for projects in the industry include programmable logic controllers, or PLC systems. ÅF’s office in Sundsvall, Sweden, is in need of a new lab station. The main purpose of the lab station is to introduce employees and students within ÅF Consult’s organization to PLC systems. Another purpose of the lab station is to test programs before they are applied in the industry. [6]
1.2 Overall aim

The project's main aim is to construct a universal field related lab station which can introduce new employees and students within ÅF Consult's organization to PLC systems. The lab station should be small and portable. Hopefully, the completed lab station is also universal and includes some of the most common industrial tasks. A solution for an automatic quality control of loaf products in bakeries will be considered. Therefore the equipment at the lab station should be able to simulate the functionality of the new solution.

1.3 Scope

In order to create a suitable lab station with respect to the time frame the project should have an appropriate extent. Therefore the lab station has been restricted to include two PLC systems from the Siemens S7 series. The PLC systems that will be used are the Siemens S7 systems from the 300- respectively the 400-series [7] [8]. The manual quality control of loaf products in bakeries is a stage that could possibly be automated. Research will be performed in order to further investigate this possibility. The lab station will be designed to simulate this new solution, but with a narrow budget and a restricted timeframe, the simulation will not be precise and accurate.

1.4 Detailed problem statement

This thesis can be divided into two major parts, namely: an investigation about the possibility to automate the quality control of finished loafs and the construction of a lab station. Therefore, this subchapter has been divided into the same two areas. The goal of this thesis is to answer the following questions:

Construction of the lab station

- What equipment is needed to design a field related lab station?
- Can some of the different communication networks used in industry be included in the lab station?
- Is it possible to divide the lab station into small processes which can introduce peoples step by step to PLCs?
- Is it possible to test programs at the lab station before they are applied in the industry?
- Is the construction of the station reliable?
• Which lab tasks are appropriate to carry out at lab station?

**Automation of the quality control**

• Are there any other methods to control the quality of the loaf products, in addition to the manually performed quality control?
• How can the manual quality control of finished loaf products be automatized?
• What are the benefits of this automation?
• Which type of sensors would be the best alternative to measure the height, weight and center temperature of the loaf products?
• Can the solution for automated quality control of loaf products be simulated at the lab station?

1.5 **Outlines**

Chapter 1 presents the projects and describes the goals of this thesis. In Chapter 2 there is information about the theory needed for the completion of the project presented. Chapter 3 describes the methodology used during the project. Chapter 4 presents the design of the lab station and describes how the simulation of the automatic quality control will be performed. Chapter 5 presents the lab stations functionality and the simulation result. In chapter 6 each part of the project is discussed.

1.6 **Contributions**

The lab station will be constructed by three students from the Mid Sweden University, Sundsvall, and be a part of three bachelor theses works. The work regarding the design and construction of the lab station will be equally divided between the group members. Because of this, every detail about the lab station will not be covered in this report. If excluded information is needed, it can be found in the reports from one of the students below.

PLC Lab Station – Solution for Automatic Unlading of Paper Reels [1]

PLC Lab Station – An Implementation of External Monitoring and Control Using OPC [2]
2 Theory

In this chapter information needed for the general understanding of the report is presented. The chapter will be divided into 4 parts: the industrial bread process, measurement equipment, programmable logic controllers and PROFIBUS.

2.1 The industrial bread process

A main area in the food industry is the formulation and packaging of bread. The baking industries trend is to move away from individual machines and towards integrated automation systems. A modern bakery is a mill completely automated by control systems. The manufacturing process consists of 4 main stages: the formulation of the dough; the shaping of the dough, which includes cutting, folding and rolling; placing into oven boxes and baking; and finally cutting and packaging. [9]

After the baking stage, quality insurance tests are performed on the finished bread products. During the quality insurance test on loafs, the breads height, weight and center temperature is measured. This is a stage in the bakery process that is still manually performed. The quality test is performed using the following method: The loaf is placed on a scale to measure the weight; a plate mounted over the scale is pushed down to measure the height; finally is the core temperature is measured with a temperature probe which is inserted into the loaf. After this, the values are manual recorded. This test is carried out each hour. An alternative method to this solution of the quality control could not be found during the research. [3]

2.2 Measurement equipment

Which type of sensors that are necessary in the automated quality control of loaf products, has to be researched. In sub sections 2.2.1-2.2.3 suitable alternatives to measure loafs weight, height and center temperature are presented.


2.2.1 Weight measurement

Depending on the type and size of a loaf, the weight of a normal loaf varies around from 0.5 to 1 kg. Two suitable sensor types to measure the weight of loaves could be a pneumatic load cell or a strain gauge load cell.

Pneumatic load cells are used to measure small weights in areas where cleanliness, safety and accuracy are important. Another advantage of this type of load cell is that it is insensitive to temperature variations. Disadvantages are a slow response time and a need of clean regulated air. [10]

The strain gauge load cell is the most commonly used sensor type for weight measuring. As their cost continues to decrease, and their accuracy continues to increase, the use of other types of load cells is decreasing. When weight is applied to the load cell the resistance of the sensor changes in proportion to the load. The primary benefit of this type of sensor is the low cost compared to the accuracy. A disadvantage of this sensor is the low output voltage. [10]

2.2.2 Height measurement

An alternative method to measure the height of the loaf, suitable for this project, is by using a distance sensor mounted above the loaf. Two examples of distance sensors commonly used in the industry, which could be used in the automatic quality control, are laser sensors and ultrasonic sensors.

The ultrasonic sensor measures the distance to a target by emitting sound waves and then measuring the time it takes for the sound echo to return. A measuring resolution of around 0.2 mm is usually guaranteed, which is enough when measuring the height of a loaf. A benefit of this type of sensor is the small construction. Disadvantages are that an ultrasonic sensor emits a wide cone, limiting their ability to measure small objects and making them sensitive to noise. [11]

There are two types of laser distance sensors suitable for this task, namely: the interferometer and the triangulation sensor. Both sensor types measure the distance to an object using the principle of calculating the travel time of the light. Since the light travel time is really short, highly sophisticated circuits are needed, which results in a high price for these sensors types. Benefits of these sensors are their resolution and concentrated measurement point. [12]
2.2.3 Temperature measurement

Temperature measurement sensors can be divided into two categories, contact and non-contact. Contact sensors measure their own temperature and non-contact measure the radiant power emitted by an object. During this thesis only contact temperature sensors have been researched. This is because non-contact sensors would result in an unnecessary complicated solution. [13]

Two types of temperature contact sensor that could be used in the quality control are thermistors and resistance temperature detectors. Both sensors read the temperature using the same principle. As the temperature around the sensors varies, the resistance of the sensor varies, proportional to the temperature change. A known constant current through the sensor would, because of this, result in a proportional voltage change over the temperature sensor. Benefits of these types of sensors are their simplicity and low price. [14]

2.3 Programmable Logic Controllers

Subchapter 2.3 will present some basic information about PLCs, which as mentioned, will be the control system used at the lab station to simulate the new quality control of loafs products.

2.3.1 General information

The programmable logic controller, or PLC, is a widely used control system for controlling industrial processes. The PLC systems were introduced in the 1970's with the purpose of replacing the existing relay logic systems. These PLC systems had no memory and only a few inputs and outputs. From the 1970's until today, the PLCs have been developed and have become the most common choice for industry control, mainly because of their simplicity and reliability. [15]

Advantages of PLC-systems are for example: a robust construction results in a reliable system; easy reprogramming; and cost effective for controlling of complex systems. These advantages result in PLCs being suitable for industrial environments and will probably remain so for the time to come. [16]
2.3.2 Hardware

The PLCs hardware structure can be divided into five major parts, which are: CPU, memory, power supply, communication board, respectively input and output units, or I/O:s. A brief introduction about each part can be found in the corresponding subchapter. [17]

CPU

The CPU is often referred to as a microprocessor that coordinates and handles the PLCs activities. The CPU contains a read-only memory, or ROM, where the basic instruction set and the boot loader are stored. Another part of the CPU is the electrically erasable permanent read-only memory, or EEPROM, which contains the programmed logics. [18]

Memory

The memory consists of a flash memory which contains a copy of the user control program converted into binary numbers. This memory is often referred to as the user memory and is divided into blocks, which have separate functions. For example one part of the memory is used for storing I/O values and one part is used for data storage. [19]

Power supply

The power supply is used as an energy resource and can be an external or an internal module. Common supply voltage levels are 24 VDC or 220 VAC. The power supply is normally not used to power the external equipment, in order to ensure a separate voltage supply to the PLC. This will lower the risk of the industrial environment affecting the PLCs’ power supply. [19]

Communication board

Communication boards can be used to connect to networks, for example PROFIBUS and Ethernet, but also for programming. The type of communication board will vary depending on the task. Usually, the PLC is provided with a communication board, which allows connection to a personal computer with the correct software installed. This results in the possibility to load programs directly into the CPU. [20]
Inputs and outputs
In order to monitor and control a process the PLC will need inputs and outputs. The inputs and outputs can, depending on the manufacturer, be mounted directly on the CPU-unit or added as external modules. Inputs are categorized into two major types, digital or analog. A common analog input level is a current signal of 4-20 mA. Outputs are also categorized into either digital or analog. [21]

2.3.3 PLC standards
The International Electro-technical Commission publishes standards for electronic and electric products. The international standard IEC 61131 offers a collection of standards for PLCs. IEC 61131 consists of nine parts, which explain technical descriptions to be fulfilled by the PLC manufacturers. The standards were developed to make it easier for the end user by coordinating the many different PLCs manufactures. [22]

2.3.4 Programming languages
PLCs can be programmed using various programming languages. Four of them, which are standardized in IEC 61131-3, will be covered in this subchapter [22]. These languages are: Instruction list, Ladder diagram, Structured text and Function block diagram [23].

Instruction list
Instruction list, or IL, uses simple instructions, which resemble assembly language programming [24]. It is the basic programming language for PLCs, which all other PLC programming languages can be converted into. When using this language each operation will be written on one line. [25]

Ladder diagram
Ladder diagram, or LD, is probably the most common choice for PLC programming. It is a graphical programming language, which resembles electrical schematics. Inputs are drawn as switches, either in series or in parallel, and connected to one or several outputs. This graphical design makes the language simple and even a non-programmer with electrical background can understand it. Ladder diagrams are the ideal choice for programming sequential event processes. However, more complex functions such as a PID controller are difficult to implement in this language. An example of code written in ladder diagram can be seen in Figure 1. [25]
Structured text

Structured text programming, or ST, uses predefined statements and program subroutines to change variable values. An important difference from instruction list programming is that the program is run several times in a seconds and not only when an event occurs. Structured text programming is more similar to common high level languages than other PLC programming languages. An example of a program section written in structured text can be seen below in Figure 2. [25]

```
A(
  O M 90.0
  O M 90.1
  O M 90.2
)
AN M 90.3
S M 90.4
A M 90.5
R M 90.4
A M 90.4
= Q 90.0
```

Function block diagram

Function block diagram, or FBD, is a graphical programming language where logic gates are connected in a sequence. Function block diagrams are most suitable for small program, since the program is still really easy to follow. The logical gates will require some space on the screen and therefore large programs will not be appropriate for this language. An example of a program section written in function block diagram can be seen below in Figure 3. [25]
2.4 PROFIBUS

A wide variety of bus networks are available on the market, each bus network has its disadvantage and advantages. In this chapter, the basic principles of PROFIBUS will be covered.

PROFIBUS is a simple field bus based on token passing and object oriented service communication. Devices in the network are defined as masters or slaves. PROFIBUS was first developed as a distributed system, but the industry was in need of a simple I/O communication system. Because of this, the PROFIBUS standard was extended with a protocol called decentralized periphery, or DP. In order to add additional functions to PROFIBUS another protocol was developed, called PROFIBUS PA. PROFIBUS DP and PROFIBUS PA are a part of the international standards IEC 61158 and IEC 61784. [26]

There are four different types of hardware transmission technologies in PROFIBUS, these are: RS 485, RS 485–IS, MBP and Fiber optics. The RS 485 is a two wire transmission medium and is the most common choice. Important when connecting the RS 485 stations is to always use shielded cable and always ensure that the data line is not reversed. [27]

2.4.1 PROFIBUS DP

PROFIBUS decentralized periphery supports connection of several masters to a single system. Specifications such as number of stations and assignment of station addresses to the I/O:s, need to be configured during the installation. The DP standard supports the following three types of members connected to the network:
- DP master class 1 (DPM1)
- DP master class 2 (DPM2)
- DP slaves (DPS)

DP masters class 1 are often controllers for example a PC or a PLC. DP master class 2 is connected during commission or maintenance and is often engineering or operating devices. DP slaves are nodes which reads information and/or uses outputs for controlling the process. [28]

### 2.4.2 PROFIBUS PA

PROFIBUS PA is based on the same principles as PROFIBUS DP the only difference is all voltage and current levels are reduced to be able to use Profibus in various explosive atmospheres. [29]
3 Methodology

Chapter 3 will present the methodology used during the project. In subchapter 3.1, the needed initial literary study will be presented. Subchapter 3.2 will present how the problem was solved, and finally subchapter 3.3, will present the method used during the evaluation.

3.1 Initial literary study

To be able to construct a suitable lab station according to ÅF Consult’s demands and simulate a new solution for the quality control of loafs using this lab station, a literary study is important. During the literary study general information about the following areas will be considered:

- PLC systems hardware and software
- Commonly used communication networks in the industry
- Currently used methods to perform the quality control of loafs
- Sensor types needed in the quality control of loafs

Information about PLC, communication networks and sensors types needed, will be obtained through web-based sources. Information about currently used methods of the quality control will be obtained through interviews with market-leading Swedish bakeries.

3.2 Solution approach

After completing the initial literary study, the information gathered will be used to construct and design a suitable lab station according to ÅF Consult’s demands. The solution implementation will be divided into three major parts:

- Design of the lab station
- Construction of the lab station
- Developing a test program for automatic solution
During the first stage a lab station which fulfills all demands will be designed. Electrical schematics will be drawn and the needed equipment will be ordered. During this stage suitable lab tasks which could be performed at the lab station will also be agreed upon. After that, the construction of the lab station will be carried out. This includes building each substation, connecting the control systems and all wiring. Finally, some test programs will be written and a simulation of the new quality control of loafs be performed.

3.3 Evaluation

During the evaluation the reliability of the lab station and the simulation of the new quality control of loaf products will be reviewed. Each substation at the lab station will be evaluated and questions formulated in the detailed problem statement will be answered. During the evaluation of the simulation of the new quality control of loafs, topics such as the efficiency and reliability of the simulation will be covered.
4 Construction

This chapter will mainly focus on the construction of the lab station’s different parts. Information about which control system will be used and the solution for the automatic quality control of loaf products will also be presented. First, information about the control systems will be presented, after that the construction of the lab station and finally the solution for the automatic quality control of loafs.

Electrical schematics with each PLCs input and output modules can be seen in Appendix A.

4.1 Control systems

The equipment at the lab station will be controlled using two PLCs, one Siemens S7-400 and one Siemens S7-300. The two PLCs will communicate using a PROFIBUS master-slave configuration, with the Siemens S7-400 as master and the Siemens S7-300 as slave. An OPC server will also be established, detailed information about this will not be covered in this report [2]. More detailed information about each PLC system can be found in sub section 4.1.1 and 4.1.2.

4.1.1 Siemens S7 300

The type of the Siemens S7-300 CPU can be seen in Figure 4. The CPU will have 4 additional modules connected to it: a digital input module, a digital output module, an analog input module and an analog output module. The output and input modules connected to the Siemens S7-300 CPU will handle all incoming and outgoing signals from the lab station, in addition to controlling the 6 motors in the robotic arm. Each input and output module has a corresponding electrical schematic, which can be seen in appendix A. The Siemens S7-300 will be configured as a DP-A slave device in the PROFIBUS network.
4.1.2 Siemens S7 400

The type of the Siemens S7-400 CPU can be seen in Figure 5. The S7-400 CPU will have 2 additional modules connected to it, one module which handles Ethernet communication and one digital output module. The digital output module will start and stop the motors involved in controlling the robotic arm. The Siemens S7-400 CPU will be configured as DP1 master in the PROFIBUS configuration. The Ethernet module will be connected to a PC using OPC.
4.2 **Lab station**

The equipment at the lab station was chosen based on the detailed problem statements presented. The result is that the station consists of 4 substations which are: the robotic arm, the conveyor belt, a combined height and temperature measurement station and a load cell respectively. A picture of the complete lab station can be seen in Figure 6. Detailed information about each substation can be found in the corresponding subchapter. With the budget from ÅF consult, 6 500 SEK, each substation will have to be constructed from suitable parts and cannot be bought. This will probably result in a less reliable station, compared to a bought ready-made lab station.

After having completed the construction, the different parts can hopefully be programmed independently of each other and so introduce people step by step to PLC programming. The different substations can hopefully also be used together to form a field related process chain.

![Figure 6: A picture over the complete lab station. The conveyor belt is located at the top of the picture, with the robotic arm below. The temperature and height measurement can be seen next to the PLCs.](image)

4.2.1 **Robotic arm**

The robotic arm is the main part of this lab station and will be used to transport metal and wood cubes between the different stations, in order to reach each substation it will be placed in the center of the lab station [30]. As seen in appendix A, the robotic arm is controlled by 5 different 3 VDC motors. To be able to move the arm around a larger part of the lab
station the robotic arm will also be placed on a wagon, directed along a chain. The wagon will be controlled by a 6 V motor. In order to get the correct voltage and control each motor in both directions, all motors will be connected to relays according to the schematic seen in Figure 7. All motors involved in the controlling of the robotic arm are connected to the Siemens S7-400 digital output module. The title of the different parts of the robotic arm and its corresponding motor number are shown in Figure 8.

![Figure 7: Connection used to be able to control each motor in two directions](image)

The positioning of the wagon carrying the robotic arm, moved by using motor 1, is planned to be controlled by two different methods: using a range sensor to sense the distance to the wagon; using a predefined position with limit switches and a photo resistive sensor. Because of the low budget, only an ultrasonic range sensor with a wide detection area could be afforded [31]. This may cause the positioning of the wagon using the range sensor to be sensitive to disturbance. Because of this, the function is secured with predefined positions using digital inputs. The photo resistive sensor and the limit switches are connected to the Siemens S7-300 digital input module; the range sensor is connected to the Siemens S7-300 analog input module.

The lower motor, motor 2, which controls the bottom rotation of the whole arm is limited to only be able to rotate 180 degrees, in order to not damage the cables connected to the robotic arm. This is done with a limit switch. The positioning of motor 2 will be done with an inductive sensor that passes over 2 small aluminum segments.
Motor 3, which controls a part of the robotic arm entitled bottom joint, will be positioned using 2 limit switches. The arm should still be able to reach each substation at the lab station.

Motor 4 and motor 5 control two parts which are entitled middle joint, and top joint respectively. These motors will be positioned using two flex sensors, connected to the Siemens S7-300 analog input module, with the purpose of serving as tilt sensors [32]. The flex sensor changes resistance as the sensor is curved. Hopefully the resistance of the flex sensors will change linearly, without too much variation, and the position of the middle and the top joint should be able to be controlled.

Finally motor 6, which control the opening and closing of the claw of the robotic arm, will be controlled by using a force sensitive resistor [33]. The sensor is a thin bar that can be glued to the inside of the claw. When the claw closes on an object, the resistance of the sensor will increase and the pressure from the claw should be able to be controlled.

![Image of robotic arm](image)

**Figure 8:** Clarifications about the different parts, their title and motor on the robotic arm.

### 4.2.2 Conveyor belt

The conveyor belt is designed to transport cubes between the storage and two end stations, where the cubes are picked up by the robotic arm. In addition to transportation, the conveyor belt is also designed to sort two different types of cubes, metal and plastic. Each type of cube will have a separate ramp, where the cubes slide to its end station. On each ramp there is also one limit switch that will indicate when a cube passes over it. At the end of the belt there is a limit switch mounted to serve as
an emergency stop. If any cube is detected by the limit switch, the belt should be stopped. A picture of the conveyor belt can be seen in Figure 9.

![Image of conveyor belt with labels](image)

**Figure 9:** A picture of the conveyor belt substation, the most important parts is marked with labels.

A photo diode will be connected to the digital input. This photo diode will be mounted under the conveyor belt and will be used to measure the conveyor belt’s rotation speed. Because of this, the speed of the conveyor belt can be monitored and possibly be implemented as a control process. The conveyor belt is driven by a 6-12 VDC motor, connected to a pulse width modulation card [34], in turn controlled by the S7-300 analog output module.

In order to solve the sorting function, two sensors are mounted on the conveyor belt, one inductive and one photo cell. The inductive sensor will sense the metal cubes and start an actuator, which will direct the cubes to the correct ramp. The photocell will be mounted after the inductive sensor. If the photocell indicates a cube and the inductive sensor has not been enabled, another actuator should direct the plastic cubes to its correct ramp. The actuators are two 12 V solenoids, connected to the Siemens S7-300 digital output module.

The storage will be designed to contain multiple cubes. These cubes will be pushed out to the conveyor belt using a 6 VDC motor. The arm mounted on the motor shaft will pass over a photo resistive sensor, indicating that a cube has been pushed on to the conveyor belt.
4.2.3 Measurement stations

The lab station is also provided with two measurement stations, one station is a combined height and temperature measurement station, the other one is a load cell capable of measuring the weight of the cubes. All sensors used in the measurement stations will be connected to the analog input module. Information about each station can be found in subchapter 1.1.1 and 1.1.2.

Height and temperature measurement station

The combined height and temperature measurement station have a simple construction. A PT-100 sensor is placed under a metal sheet and above the metal sheet an ultrasonic distance sensor is placed [35] [31]. The ultrasonic range sensor will be supplied with 3 volt DC and will therefore have a resolution of around 600 μV per mm. This resolution should be good enough to measure the height of the cubes. A noise insensitive height measurement can hopefully be performed using this setup.

The PT100 sensor will be connected to a constant current circuit using a MC3403PG amplifier [36]. This should result in about 2 mV/degree change over the PT100 sensor. This voltage will be amplified using an AD620 instrumentation amplifier, with about 10 times gain and transferred to the Siemens S7-300 analog input module. This connection can be seen in Figure 10.

![Figure 10: Schematic over the PT 100's amplification connection.](image)
Load cell

The load cell is a strain gauge based a sensor capable of measuring an objects mass up to 0.6 kg [37]. Due to the small voltage change across a strain gauge sensor, the load cell will have to be connected to an amplifier. The load cell have an offset voltage output on two wires, the voltage difference between the wires is changed in proportion to an increased or a decreased load. Therefore the load cell will be connected to a MC3403PG amplifier used as a differential amplifier with about 5000 times gain. This connection can be seen in Figure 11.

![Diagram of load cell connection to amplifier MC3403PG](image)

Figure 11: The load cells connection to the amplifier MC3403PG. The amplifier setup used is a differential amplifier with about 5000 times gain.

4.3 Solution for the automatic quality control

A solution for the automatic quality control of loafs will be constructed at the lab station. The process at the lab station will simulate the actual solution. The simulation will, as mentioned, not be precise and accurate, because it would not be economically sustainable to construct the actual solution at the lab station. The simulation of the automatic control will hopefully prove that an actual solution is possible. The actual solution for the industry would be implemented with the same process stages as the simulation in the lab setup, which is further discussed in subchapter 6.1.2.

4.3.1 Simulation at the lab station

The simulation of the solution for the automatic quality control will be performed according to the flow chart in appendix B. The metal cubes in the lab station will be used to imitate loaf products. Metal cubes were chosen because of their thermal conductivity and mass. As seen in the flow chart, wood cubes will be directly transported back to the storage.
The robotic arm will be used to transport the cubes between the stations. After each measurement has been executed, the values obtained can be recorded by the PC. The communication with the PC will be covered in *PLC Lab Station – An implementation of external monitoring and control using OPC* [2].

The first measurement to be performed is the weight measurement. A pneumatic load cell was excluded due to lack of compressed air and its expanses. Instead the strain gauge load cell explained in subchapter 4.2.3.2 will be used.

After the weighing, the temperature measurement will be performed. This measurement will be performed at the combined height and measurement station introduced in chapter 4.2.3.1. It would be too difficult for the robotic arm to hit a measurement probe; therefore a temperature measurement at the center of an object was excluded. Instead, the PT-100 will measure the metal cubes surface temperature.

The final stage in the process is the height measurement. Just like the temperature measurement, the height measurement will be performed at the combined temperature and height measurement station. In order to not exceed the budget, an ultrasonic distance sensor is chosen to perform this measurement. The ultrasonic sensor will have a resolution which should be enough to measure the height of the cubes. But the width of the ultrasonic sensor’s emitted beam will be wide, which may cause measurement problems.

### 4.3.2 Software structure

The programs for the lab station are written in the environment Siemens SIMATIC S7. The programming for the simulation of the automatic quality control does not require any complicated functions such as PID processes, because of this Ladder diagram is selected as programming language. In order to simplify the understanding of the program and to facilitate troubleshooting, the software structure will be divided into several function blocks. These function blocks are for example commonly used positions for the robotic arm, calculations blocks and a block for the conveyor belt.
Robotic arm

In order to facilitate the positioning of the robotic arm, some of the different substations have been placed at the same distance from the robotic arm, with merely the bottom rotation and positioning along the chain differing. This results in the robotic arm having to be positioned at three different substations, namely: the off-ramps at the conveyor belt, the two measurement stations and the storage. These positions will have a separate function block, which is called when needed. In order to further facilitate the programming, all movement of the robotic arm will be done in a sequence, where one motor is powered at a time.

The joints monitored by the two flex sensor and the grip claw is positioned using compare functions. Positioning along the chain using the ultrasonic distance sensors can also be done using the same compare block. When a flex sensor or the pressure sensor reaches the expected value, the compare block will be set low and that sequence stage is completed. An example of the compare block used for positioning the robotic arm, can be seen in Figure 12.

![Figure 12: A compare block used for the positioning of the top joint, when the bending sensor exceeds 18000 the block will be set low.](image)

Conveyor belt

All program code needed for the controlling of the conveyor belt is written in a separate function block. This block is run parallel to the other processes and has two counters as output to the other function blocks. These counters contain the quantity of wood, respective metal cubes. The robotic arm will use these counters for prioritizing between the two different types of cubes. The motor which drives the conveyor belt is controlled by an analog output. The voltage level on the output is set by a constant value using a move block. The transfer of all analog values between the Siemens S7-300 and the Siemens S7-400 is performed with the same move block, an example of this can be seen in Figure13.
Measurement calculations

Calculations of the values from the three needed measurements is done using a similar principle. An example of calculations from the height measurement can be seen in Figure 14. Values from the load cell are calculated using a similar principle, with the exception that constants used for removing the offset and dividing the actual value are different. When calculating the temperature, the subtraction block is removed and the output from the instrumentation amplifier is directly divided by the voltage change corresponding to 1 degree Celsius.

Figure 13: Move block used to transfer values between the Siemens S7 300 and Siemens S7 400. The same block is used to power the conveyor belt’s motor.

Figure 14: A code scrap used in the height measurement. A constant corresponding to the height of the measurement station is subtracted from the output from the range sensor. The result of this calculation is divided by a constant that corresponds to the voltage 1 mm voltage change.
5 Results

Chapter 5 will present the constructed lab stations functionality and the simulation results of the automatic quality control. The questions from the detailed problem statements chapter will be partially answered. The chapter will be divided into 2 parts, subchapter 5.1 presents the lab stations results and subchapter 5.2 describes the simulations results.

5.1 The lab station

In this chapter, each substation of the lab station will be evaluated in its corresponding subchapter. Similarly solutions will also be presented. A universal field related lab station could successfully be designed. Unfortunately, because of the instability in the sensors, the construction is considered unreliable. The research has shown that PROFIBUS is an established communication protocol in the industry, therefore it was included as the communication method between the two PLCs. Together with the research provided from the other thesis works, a final lab setup is implemented with industrial solutions for transportation, measuring, monitoring and sorting.

5.1.1 Robotic arm

An advantage of the robotic arm is that it can be used for different tasks, which makes the lab station universal. Due to variations in sensors, the construction of the robotic arm cannot be considered a reliable construction.

The wagon carrying the robotic arm was meant to be positioned using two different methods, with an ultrasonic distance sensor or three predefined positions. The ultrasonic distance sensor operates properly until the last part of the chain, when it loses focus due to surrounding devices. Because of this the wagon can only be controlled using the predefined positions and a combination of the two methods.

Positioning of the two joints controlled by the flex sensor was difficult due to variation in the sensors. Figure 15 and 16 show examples of how the resistance changes as the flex sensors are bent. As seen in the figures, the resistance varies between different movements, which results in a variations of the robotic arms positions.
Figure 15: Voltage output signal to the Siemens 300 analog input module, as the angle on the top flex sensor increases, starting from a horizontal position.

Figure 16: Voltage output signal to the Siemens 300 analog input module, as the angle on the middle flex sensor increases, starting from a vertical position.
The purpose of the force sensitive resistor in the robotic arms grip claw was to allow adjustment of the grip pressure. But, the delays caused by the controlling equipment and a fast resistance change in the sensor results in the force sensitive resistor only being able to be used as a switch. All remaining sensors work according to the specification in subchapter 4.2.1.

5.1.2 Conveyor belt

The conveyor belts purpose was to transport the cubes between its two end stations and the storage, which works as planned. The conveyor belt should also include sorting of the two cube types, which works as described in subchapter 4.2.2. A problem with the conveyor belt occurs when the cubes are supposed to slide down to the end stations. The angle of the ramp is too steep, which is causes the cubes to be positioned wrong. Manual intervention is necessary to solve this. The speed of the conveyor could also be controlled, but because of mechanical resistance, with a smaller range than expected.

The storage unit was meant to contain up to 10 metal and wood cubes, but this idea was excluded due to mechanical issues. The result is that the storage can only contain 1 cube and successfully push it down to the conveyor belt. However, there can be several cubes out in the lab stations process.

5.1.3 Measurement stations

With the research as basis, it could be established that the three sensors used in the lab stations two measuring stations are commonly used in the industry. Because of this they contributed to the conclusion that the lab station is field related. Information about each measurement stations results can be found in the paragraphs below.

Height and temperature measurement

The temperature and height measurement stations construction does not work as planned. The ultrasonic range sensor has a resolution of around 600 µV per mm, which is enough to measure the height of the cubes. But since the range sensor has a blind spot of up to 30 cm, the emitted ultrasonic cone has already distributed on area with 15 cm radius. The cubes are squares measuring 2 cm in length, which is too small to be detected by the ultrasonic range sensor among the other equipment.
Tests were carried out to measure the distance to larger objects, which worked as planned.

The temperature sensor setup works according to the specifications in subchapter 4.2.3.2. Each degree change corresponds to a 20 mV change in the output signal without considerable noise, which can be measured by the PLC. Unfortunately, the location of the sensor results in a required thermal conduction over an aluminum plate. This conduction requires energy and results in a slow temperature transmission. The problems caused by the plate will because of this cause temperature measurement to not be precise.

**Load cell**

The load cell and its connection to the amplifier is a reliable design, able to measure the mass of the cubes. In Figure 17 the voltage output from the load cell setup to the PLC is shown. The analog input on the Siemens 300 module is adjusted for 0-10 V reading, resulting in weights up to 300 g being possible to measure. Due to variations in the resistors the differential amplifier will amplify a common mode voltage, which causes an offset of around 6 V, limiting the measuring range. The load cell is only used for measuring the weights of the cubes, which varies between 8-110 grams, resulting in the limited range not causing a problem.

![Load Cell Graph](image)

**Figure 17**: Voltage output from the differential amplifier to the Siemens 300 analog input module, as the mass on the load cell increases.
5.1.4 Similar lab stations

There are several companies which manufactures ready-made PLC lab setups. Two lab stations, which have similar functionality as the lab station provided for ÅF, are for comparative reasons presented in the following paragraphs.

A Transport and Sorting Line from Staudinger GMBH is seen in Figure 18. This lab setup simulates a handling device, which transport cubes using a conveyor belt from a storage to three unloading stations. The lab setup does not use any pneumatic. It requires a control system with 16 digital inputs and 6 digital outputs, hence does not included any analog sensors. The weight of the station is 7.2 kg and the components are mounted on a 540 x 390 x 270 mm board. [38]

![Figure 18: A transport and sorting lab station from Staudinger GMBH](image)

An additional lab setup from Staudinger GMBH, which includes analog values, can be seen in Figure 19. The lab station is a regulation process for adjusting a room temperature, using for example: a fan with various speeds, a temperature measuring device and heating equipment. The lab station requires a control system with 3 analog inputs, 2 analog outputs, 4 digital inputs and 4 digital outputs. The weight of the station is 8.4 kg and it is all mounted on a 540 x 390 x 350 mm board. [39]
5.2 Lab task

A lab task which includes the usage of the conveyor belt, the robotic arm and monitoring will be divided into three parts. The first part of the assignment will be covered in *PLC Lab Station – Solution for Automatic Unload of Paper Reels* [1], which includes the hardware configuration and programming of the conveyor belt. The second part will include the programming of the robotic arm, which will be explained in this report. The third part is about monitoring using OPC and can be found in *PLC Lab Station – An implementation of external monitoring and control using OPC* [2].

In order to get this part of the lab assignment to function properly the hardware configuration from the previous assignment is required. Understanding how to use function blocks such as timers and counters is also required.

The robotic arm should pick the cubes from the conveyor belts off-ramps and transfer them directly back to the storage. A suggestion is to create two functions blocks, one for picking up at the off-ramps and one for placing in the storage.

**Picking up from the ramps and placing in the storage**

1. A flow chart should be created which explains the process needed for picking up from the off-ramps and placing in the storage
2. Write a program which moves the robotic arm along the chain to the conveyor belts ramps, using partly digital sensors and partly the ultrasonic distance sensors

3. Write a function block for picking up cubes from the conveyor belts off-ramps

4. Write a function block for dropping cubes in the storage

5. Use the counters from the previous assignment, which monitor the amount of cubes in the ramps, to prioritize between the plastic and metal cubes

6. Combine the four created programs in order to get the robotic arm to pick up the cubes from the off-ramps and place them in the storage

5.3 Simulation of automatic quality control

The research performed could not prove that an alternative method to manually performed quality control of loaf products. Therefore, an attempt was carried out to simulate the actual solution of an automated quality control of loafs. The simulation could not measure all of the three required quantities: height, weight and center temperature. All process stages used in the simulation would also be used in actual solution for the industry. The PLC could successfully handle all events in the simulation and is not the cause why not all measurements could be performed. This proves that the PLC could be a suitable alternative as control system in the industry solution.

The weight of the cubes could successfully be measured, therefore the simulation has proved that a strain gauge load cell is a suitable option for measuring the weight of loafs. Loafs weigh considerably more than the cubes used in the simulation. Because of this a load cell with a higher maximum load has to be used, but the principle would be exactly the same.

Even though the ultrasonic sensor could not measure the heights of the cubes, it would be a suitable alternative for measuring the height of loafs. Loafs are considerably larger than the metal cubes used on the lab setup, therefore an ultrasonic distance sensor would be able to measure the height of a loaf.
The temperature measurement performed during the simulation is not an alternative for industry application. The temperature was only measured at the surface of the cubes and not the required center temperature. In the test performed, the delay and energy losses caused by the aluminum plate would result in a measurement of the medium temperature between the plate and the cubes, rather than the actual temperature of the cubes. In an application for the industry a center temperature measurement with a temperature resistance detector placed in the middle of the loaf would be more appropriate.
Chapter 6 discusses the construction of the lab station and the automatic quality control of loafs. The detailed problem statements not answered in the previous chapter will be answered in chapter 6. The chapter will be divided into three subchapters, namely: solution evaluation in subchapter 6.1, future work in subchapter 6.2 and related work in subchapter 6.3.

The construction and wiring of the lab station consumed too much time, which resulted in less time than expected could be spent on the research regarding the automatic quality control of loafs.

### 6.1 Solution evaluation

This chapter will discuss advantages, defects and ethical perspectives of the lab station. A solution for the automatic quality control for the industry will also be considered. First the lab station will be discussed, after that the automatic quality control of loafs, and finally the social and ethical perspectives.

#### 6.1.1 Lab station

The main goal of the project was to provide a universal field related lab station for ÅF Consult. The completed lab station includes processes and sensors commonly used in the industry. The lab station also provides several possibilities for lab tasks. Due to this, the main goal of the project has been fulfilled.

The different substations of the lab setup require different programs, all with its own difficulties to function properly. For example the robotic arm requires usage of PROFIBUS, analog signals, digital signals and timers, whereas, the conveyor belt can be controlled using only digital values. Because of this, the lab station can be divided into smaller processes, which introduce people step by step to the programming of PLCs.

Another request from ÅF Consult was that the lab station should be small and portable. The lab station with all its equipment has been built on a 1 square meter board, which can easily be transported.
Another demand was a reliable construction, the results of which can be discussed. The conveyor belt and the robotic arm have defects which require manual involvement for a correct process flow. The defects can be fixed by using different, more expansive, sensors. The budget from ÅF Consult did not allow the purchase of these types of sensors. Therefore, the demand for a reliable construction is not fulfilled.

An alternative solution to the problem with the unreliable construction would have been to reduce the number of substations. With fewer substations more time could have been spent during the pre-studies on the design of the specific substation, resulting in a more reliable design. This would have been implemented at the cost of the size of the setup, which results in a less universal station with fewer lab tasks possible.

The robotic arm, which is the main part of the lab station, uses sensors with variations that sometimes affect the functionality of the robotic arm. As seen in Figure 15 and 16, the problem is that the whole resistance range of the flex sensors is offset. This will cause the robotic arm to stop at different positions, resulting in picking up and placing of the cubes being difficult. The problem could possibly be solved by using ready-made tilt sensors or mounting a potentiometer on the motor shafts. Another problem with the robotic arm is the force sensitive sensors used to control the grip claw. Delays will sometimes cause the motor to release the pressure and as a result not grip the cubes.

The lab station includes two ultrasonic range sensors; neither of these sensors work as planned, which was an expected result. One of the sensors was meant to be used while controlling the position of the wagon carrying the robotic arm. The other sensor was meant to measure the height of cubes, which could not be performed. To measure the distance to the small objects used at the lab station, laser sensors with a concentrated measuring point should be used. Laser sensors have a cost, significantly higher than the ultrasonic range sensors. Therefore, the ultrasonic sensors were used anyway.

There are several similar lab stations, but a lab setup with exactly the same functionality does probably not exist. The presented lab setups in subchapter 5.1.4 together have similar functionality as the constructed lab station. Both the stations’ weight and size make them portable, just like the setup provided for ÅF. No price statement of the lab stations are available. However, they are believed to be priced higher than the lab station constructed for ÅF Consult.
6.1.2 **Automatic quality control**

This chapter discusses the automatic quality control. The questions from subchapter 1.4 that were not covered in the result chapter will be presented in this part. The goals of the project regarding the automatic quality control have been partially fulfilled. Some of the detailed problem statements could successfully be answered. Less time than expected could be spent on an actual solution for industry. Therefore, all goals cannot be considered fulfilled.

*What are the benefits of this automation?*

An automation of the quality control of loaf products is according to this research a new application for the industry. The quality control does not consume any material and since only random samples are tested, it does not affect the productivity. Still there are several benefits with an automated quality control, for example:

- The process would not require any significant supervision, resulting in a reduced labor cost
- More frequent quality controls could be performed since the process would have low operating costs
- Because machinery removes the human factor as source of error a higher production safety would be achieved
- Recorded values from each measurement could be more effectively handled

*How can the manual quality control of finished loaf products be automatized?*

The main duty of an automatic quality control is to ensure a correct measurement of the three quantities height, weight and center temperature. It would also require a method to separate and return a random sample of loafs from the production flow. Finally measured values need to be recorded and saved.
Is it possible to simulate the solution for automated quality control of loaf products at the lab station?

The required height measurement of the cubes could not be performed and therefore the simulation cannot be considered complete. The parts of the simulation that could be successfully carried out are: weight and temperature measurements, transportation and recording.

**Industrial application**

There is considerably more work that has to be performed before an automatic quality control can be constructed. Some of this work was planned to be covered during the thesis but was excluded due to problems during the construction of the lab station.

The temperature measurement performed during the simulation only measured the surface temperature of the cubes, which it should not be in actual solution. An alternative construction could be to use a cylinder with a resistance temperature detector in a probe mounted at the top.

The simulation at the lab station uses a robotic arm to transport the cubes. This is an unnecessary construction and it would be simpler to use conveyor belts instead.

### 6.1.3 Social and ethical perspectives

The construction of the lab station can be seen as a consultant work at the request of ÅF Consult, because of this, the construction of the lab station has been carried out with the aim of ensuring a functional lab station. The following social and ethical statements have been considered:

- All defects on the delivered lab station and possible solution to those defects have been acknowledged in the report. During the work all equipment has also been handled with care to avoid damages.

- In order to create a safe work environment the lab station has been designed to minimize the risk of injury for the users and people in its vicinity. This involves the connection of emergency switches in order to not damage the equipment or injure people.
- The results stated, concerning the construction of the lab station and simulation of the automatic quality control have been honest estimations.

- It has been ensured that equipment at the lab station can be controlled incorrectly and run against end positions without causing permanent damages.

6.2 Further development

This chapter has been divided into three major parts, namely construction of the lab station, control processes and automatic quality control of loafs. Information about future work regarding each part is presented in the corresponding chapters.

6.2.1 Lab station

The construction of the lab station has some defects that could be solved by using different sensors. A possible solution to all defects has been presented in one out of the three reports. If any of the defects need to be fixed it is possible, but additional equipment have to be purchased. Space has also been left on the board, in order to allow additional equipment.

In order to enable a monitoring of the rotation speed on the conveyor belt, a photo resistive sensor has been mounted under the conveyor belt. This software implementation was not carried out during the project, but is possible to carry out in the future.

6.2.2 Control processes

The ambitions of the project was to also include a regulation process in the lab station, but this was not done. Implementing a control process for the positioning of the joints controlled by the flex sensors would increase the precision of the robotic arm. This is because a reduced movement speed close to the end position would result in less surpassing. A disadvantage is that it would require a possibility to regulate the voltage level to the motors, in order to allow a continuous control signal. One part of the lab station that is currently possible to implement as a regulation process is the speed of the conveyor belt. This would be a closed loop system, since the analog sensors give feedback. It could be implemented as a P, PI or PID process.
6.2.3 **Automatic quality control of loaves**

Considerably more work has to be done before it is possible to design an automatic quality control. Finding suitable equipment alternatives for the transportation is a crucial part of this work. Equipment which control the process flow and equipment for separating and returning a random sample of loaves is also required. An investigation in order to check if the quality control is possible according to the demands of a possible international certification is also needed.
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Appendix A: Electrical schematics

Siemens S7-400 digital output module
Siemens S7-300 digital output module
Siemens S7-300 digital output module
Siemens S7-300 analog input module
Siemens S7-300 analog output module
Appendix B: Flow chart used in the simulation