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Development of a system for X-ray analysis within the mining industry

Master's Thesis in the Master Degree Programme Intelligent Systems Design

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Technical report No. 2011:076
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Abstract

Companies within the mining industry perform exploration drilling (prospecting) in order to find new mineral resources. The prospecting results in a lot of rock samples which are analyzed to discover what minerals they may contain. Today's analysis process involves high investments, high risks, and is very time inefficient. A start-up company called Minalyze is developing a product that will be capable of analyzing rock samples using X-ray. The product will be used at the drill site, and will involve much lower investments and very short analysis times.

The purpose of this thesis is to design and develop Minalyze's first functional prototype called Minalyzer SCS. The aim is to implement different hardware components into a device that follows a concept which Minalyze has developed. Furthermore, a software architecture for controlling the hardware with a PLC will be developed, as well as a software architecture for controlling the PLC, from a PC, using LabView.

During this thesis a partial vertical prototype was developed. The required hardware components required were identified, and a safety system was implemented. The PLC software, which consist of a series of programs and functions that control the actuators and performs data acquisition, was developed. Finally, for the software in LabView, a layered system design was used, together with an OPC system for exchanging data between the PLC and LabView.

This thesis shows the importance of developing a prototype in an early stage of a product development process, for optimizing the product based on feedback received from investors, clients, and the development team. Prototyping also helps increasing the value of a start-up company.

The result of the thesis is that Minalyze now owns two functional SW architectures, in LabView and the PLC, and functional hardware, ready to be implemented with a graphical user interface. When the company has completed the remaining drivers for the X-ray generation components (including a high-voltage generator and a X-ray detector), and developed the graphical user interface, the prototype will be ready to be shown for investors and customers. It will greatly aid Minalyze in the development of their final product.

Keywords: X-ray analysis, PLC, LabVIEW, Mining industry, Prospecting, Prototyping

Acknowledgments

This master's thesis has been a time filled with challenges, has also been a great experience. We have learned a lot and gained knowledge that will aid us if we in the future decide to start our own companies.

We would like to send our deepest thanks to Mikael Artursson and Annelie Blomdahl at Minalyze. They have been our supervisors, colleagues and friends during this thesis work. They believed in us from the very start and their guidance and devotion to their company, supported and helped us greatly in our work. We are honored for having had the opportunity to make such an important contributions to the company, as this thesis is. We would also like to thank Lars and Mats a Chalmers for their help regarding LabView-programming. Furthermore we would like to thank Claes Strannegård at the IT-university. He has been the head of our masters programme and also our mentor during the thesis work.

We are for ever grateful for the great support we've received from our friends and class mates. Without them it would have been hard, if not impossible, to stand a chance against the seemingly never-ending pile of school work that is a students workday. Also, we would like to thank our colleagues, fellows and friends, specially David, Suvash, Magnus, and Selçuk (how could we forget the discussion about the point). They made our journey include not only geeky discussions, but also an exchange of ideas and philosophical talks and, most importantly, their friendship. Thank you guys for being there with us!

Following are personal thanks from each author:

> *I want to thank to my family for their support during this journey. But I also want to thank the people of Sweden for receiving me and opening the doors to receive this high quality education. Isac, I have to thank you for being an excellent teammate, and awesome friend, but over all thank you for being a window to the Swedish culture. Furthermore, I want to specially thank Julia for all her support and love, and because she still believes in me, inspite of me always trying to teas her. How could I forget all the new friends i did her? Well there is not enough space but thank you.*
> *I specially want to dedicate this work to my brother Ivan, because he shown me that it is possible to change for good, and because he has had the strength to carry his own cross and keeps going.*
> *Quiero agraceder a toda mi familia, especialmente a mis padres que simpre me han apoyado sin importar la distancia, recurden que siempre están conmigo en un rinconcinto de mi corazón, ustedes saben que no hubiera llegado hasta aquí si no fuera por ustedes. Y para finalizar, también quiero dar las gracias a todos mis amigos, que siempre creyeron mi y también me apoyaron desde tierras aztecas.*
>
> *Efrain Calderon Estrada*

> *I would like thank you Efrain for being the best teammate during this master and master's thesis. I also want to thank my family and will do that in Swedish below:*

Jag vill tacka mina föräldrar, Ingvar och Ann-Carin Zagerholm, som under hela min utbildning har stöttat och trott på mig och övertygat mig att vilja läsa vidare. Det är till stor del tack vare dem som jag har läst den här mastern och nu har kommit så här långt. Jag vill även tacka min bror, Martin Zagerholm, som har stöttat mig och, genom sitt tekniska intresse och yrke, motiverat mig att läsa vidare. Slutligen vill jag tacka min underbara fru, Katrin Zagerholm, som stöttat mig, trott på mig och stått ut med att jag de senaste åren ofta spenderat fler timmar med studierna än med henne.

Isac Zagerholm

Contents

1 Introduction

1.1 Minalyze

Minalyze is a start-up company, sprung from Chalmers School of Entrepreneurship, based on an idea proposed by inventor Gunnar Christiansson and the drilling company Styrud. The idea is to deliver instant and complete analyses of the geological composition of rock samples, drilled out during mine prospecting. In order to accomplish this, Minalyze intend to use an existing analyses method, common in sediment analyses, and "re-package" it in such a way that it can be operated on, or even inside the vicinity of the drilling site, implying that it needs to be transportable and robust. The analysis method that Minalyze uses, gives the possibility to analyze practically everything that comes out of a drill hole; consequently giving a more representative result than the process used today [1].

1.2 Background

Companies within the mining industry perform exploration drilling (prospecting) in order to find new mineral resources. Today this process is associated with high investments and high risks, mainly due to the extensive cost and time it takes to perform the analysis of the drill samples. Sample drilling is an intense process where the equipment is taken to the site of interest to drill holes through the bedrock in a pattern over the ground to get representative data of the area; thereafter, the samples, in the form of drill cores or rock chips, are taken out of the ground and analyzed to establish knowledge about the consistence in terms of minerals and metals.

To perform the analysis the cylindrical rock samples are split in two half cylindrical pieces. One half is saved as reference, and the other half is milled into a powder, which is mixed with the powder of all the other rock samples. This powder then represents the whole length of hundreds of meters of rock samples, and afterwards only a small portion of this powder is sent to an analysis firm. They do an additional selection and in the end only 0,2 % of the total amount of the drilled rock samples are chemically analyzed (see figure 1.1). The results from the analyses are returned to the geologist in 2-6 weeks and used in models to predict the presence of ore bodies [1] [2].

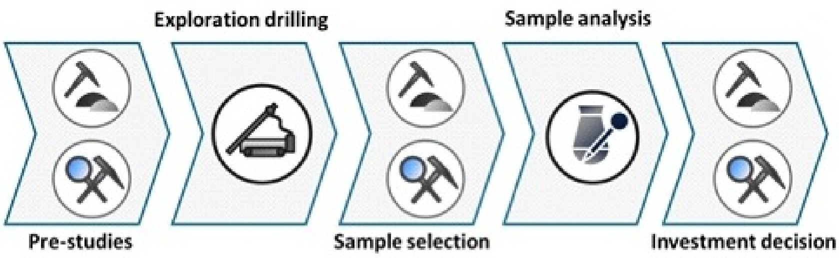


Figure 1.1: *The value chain for existing exploration process*

Prospecting is performed all over the world in areas where it is possible to find valuable minerals and metals. The prospecting sites are often located in remote places where there could be a lack of infrastructure and where the weather conditions could present an obstacle to be overcome [1].

Today Minalyze cooperates with the company that produce, and eventually will supply, the analysis technology that will be used. Together with them, representatives from possible customers and geologists from mining and prospecting companies, successful tests have been performed on drill samples in an existing laboratory. This has been done in order to verify the accuracy of the technology. Such technology is today packaged in such a way that it can only be used in a laboratory environment; consequently, it cannot be used in the way Minalyze wants to. Therefore, Minalyze recruited a product development team from Chalmers, to develop a prototype of the equipment [1].

Minalyze is currently developing an instrument, called Minalyzer CS (Core Scanner), for doing analyses of rock samples, for the exploration and mining industry. The analyses are based on a well-developed X-ray technology that will be able to provide instant results on-site.

With Minalyzer CS the process will be shorten since the stage sample selection is eliminated because the samples no longer need to be selected, all this because Minalyzer CS can analyze 100 % of all drill cores. This will positively affect the exploration and mining companies because they will get better knowledge about the content in the drill holes they will have improved basis for decision-making [3].

The new process is shown in the figure 1.2:

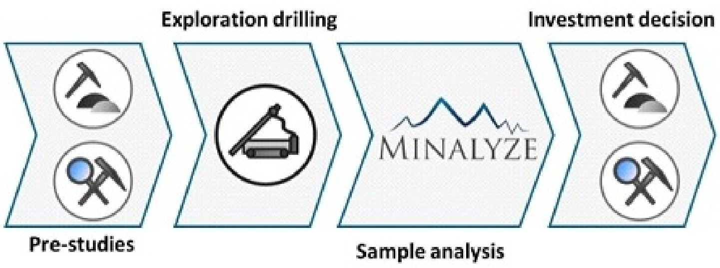


Figure 1.2: *Value chain with Minalyzer CS*

1.3 Purpose

The purpose of the thesis is to design and develop the first functional Minalyze prototype called Minalyzer SCS (Singel Core Scanner)[1]. This prototype will be capable of analyzing a rock sample using X-ray and will provide a report of the result of the analysis in a user-friendly graphical user interface.

The prototype will include an X-ray generator that beams radiation on the sample, and an X-ray detector that measures the scattered radiation; to do so, an actuator moves

[1]The Minalyzer CS is the intended final device that will be able to scan multiple cores at the same time, and the Minalyzer SCS is the first approach for one prototype

the sample under the X-ray beam. To ensure that the proper analyses are being done, the position of the X-ray detector is adjusted (using a second actuator) according on the distance measured by a laser sensor.

1.4 Goals

Following are the goals for the thesis:

- The first part of the master's thesis is to determine the different interfaces between hardware and software for the different components in the system. The system comprises of components such as PLCs, high-voltage generators, digital imaging and detectors. Most of the components can be controlled through DLLs while others require different I/O signals.
- The next step of the assignment is to determine a suitable software architecture that can act as an interface between the hardware and the user, i.e. to evaluate and decide on a suitable programming language, databases and interfaces that are needed.
- The final step is to create the architecture so that it could be used internally to extract and manage data and to interact with the hardware.

1.5 Delimitations

Minalyze has, on the basis of market intelligence, decided, as a start, to limit the use of the product to analyses of core samples. Their intention is to have the product prepared for redesign so that rock chip analyses can be made in a later version. The main reason for this is that core drilling is the predominant technique used in Sweden due to cultural aspects and the normal depths on which minerals are found in Sweden (usually deeper than the 450 meters that are possible with RC-drilling).

They also found out that there are several problems using a hand held XRF in the field and that the mining companies are unwilling to use that equipment. Some of the problems are, high exposure to human error, difficulty to operate in harsh environments etc. One of the major reasons why the companies do not want to use it is that they don't want to use such an expensive device on the field, since a hand-held unit is easy to misuse, drop or in other ways jeopardize its functionality.

Due to the complexity of the intended product and the time constraint, this project had to be limited in certain aspects. This following section states matters that will be covered by this project. Following areas will be developed during this thesis:

Hardware:

- Analyze the components that are included in the current design.
- Determine the different HW interfaces required among the components.

- Determine which components are additionally required.
- Design the interaction of the different components in the system.

Software:

- Determine the most suitable software platform for controlling the hardware.
- Design a Software Architecture suitable for the whole system.
- Estimate the required resources needed to develop the software.
- Develop a software for controlling the hardware.
- Develop a software for the system's main application.[2]
- Participate in the development of the graphical user interface (GUI).[3]

1.6 Related work

1.6.1 XRF scanner

The XRF scanner is an analytical instrument for scanning of sediment cores, rock cores and other samples. It combines XRF, radiographic x-ray imaging, and optical imaging. Long samples can be scanned in their entire length, at any step-size from centimeter and down to sub millimeter level. At each point an analysis is performed. These step-by-step analyses together build up element profiles that show the changes in composition along the sample. Each analysis can be as short as 1 second per point or longer, depending on the requirements. X-ray transmission image information is recorded to display the samples chemical and density features as a radiographic image. Optical image information displays the sample surface at high resolution. An optional magnetic susceptibility scanner completes the sensor range.

The XRF scanner offers high capacity with analyses reaching PPM sensitivity in a second for a wide range of elements. This speedy instrument also excels in precision and reproducibility. Elements from magnesium (Mg) and heavier can be distinguished, using a non-destructive and non contact method. The XRF scanner dimensions are 4500x820x1570 (LxWxH) millimetres with a weight of about 1000 kg. [4].

1.6.2 Product development in Minalyze

As a pre-study to this project, an analysis of customer/user needs and requirements was performed by a project team in the context of the course "Product planning and market

[2] This activity is to be developed with an extended team.

[3] The development of the GUI will be done by an external team and is not part of the thesis. What is included however, is to provide the necessary interfaces to the GUI, and to participate in the designing process.

analyses" at Chalmers, in December 2009. The major findings from the study are presented in this section. Together with Minalyze a list of customers, users, suppliers and other stakeholders were identified with the intention to cover the complete chain in which the product will be apart [1].

1.6.3 Concept

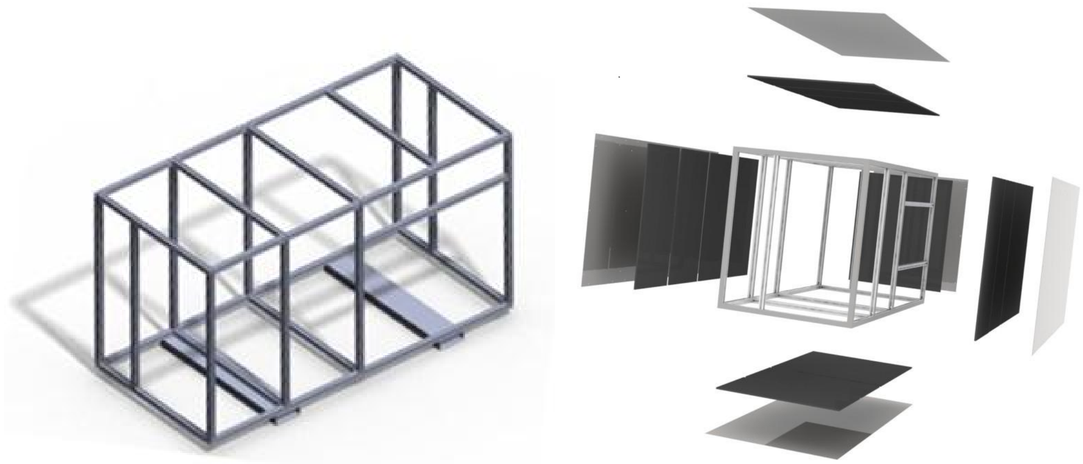
This section describes the final concept and the thoughts done by the Product Development Team. It is divided into the concepts different subfunctions; chassis, front panel, analyzing, core-handling, environmental protection and positioning of components [1].

The Chassis

It is built with an aluminum frame that supports the walls of the chassis since it makes it easier to achieve radiation protection. It is also used to fasten components to. The walls are made of an inner insulation layer and a stainless steel layer on the outside. The steel is 1.5 mm thick since that is required to shield against the radiation from the XRF.

On the long side of the machine there is a window made with special lead glass which makes it possible to look into the machine, which can be useful for troubleshooting.

The outer shell of the product has two functions. The first one is to cover the entire structure and the second is to insulate it to protect the inner components from the outer environment. It also acts as a second shield against X-rays that may leak out through the inner shell and could endanger personnel operating the machine.



(a) **(b)**

Figure 1.3: *On the left, the aluminum frame that supports the walls and is used to fasten components to. To the right, a exploded view of the different layer which makes up the shell is showed*

The front panel

The front panel is used be the operator that runs the machine, e.g at a drilling site. The interface is located at the short side of the machine so that all other sides could blocked, which makes the placement of the device easier. It has connections for cooling water and electricity, and there is a display[4] to provide the operator with status messages.

On the front panel is also a hatch for that covers a slider. This slider is used for inserting, and removing, core boxes into the machine. If this hatch is opened while the machine is running, an emergency stop is should activated to immediately stop all the activity in the machine.

Figure 1.4: *The front panel located at one of the short sides of the machine.*

Graphical user interface

The interface is used to access the built in computer of the machine, and is required to give the operator or geologist the possibility to extract data.

The analysis equipment

The analysis equipment does not only include X-ray equipment and an X-ray detector, but also positioning systems and linear actuators. These components are necessary for scanning the cores, and for positioning the X-Ray detector correctly[5].

[4] The display is not part of the prototype presented in this thesis since the status messages will be shown in the GUI.

[5] For Minalyzer SCS the core sample moves in the X direction, and the analyzing equipment moves in the Y direction.

2 Prototyping

Prototyping is a key activity within the design of interactive systems, nowadays promoted as a key activity for innovation. Prototyping allows the designer to think of the design in terms of creating an integrate solution with a visualization of the system working as a whole, rather than thinking about specific artifacts. To do so, it is important to get a hands-on experience, to actively experience the sometimes subtle differences between various design solutions, and make the idea original. The reason is that experiencing the idea, in real life, is the best way to understand it. This was perfectly expressed by the Chinese philosopher Lao Tse: "What I hear I forget. What I see, I remember. What I do, I understand!" [5].

2.1 The importance of prototyping

The main purpose of prototyping is to involve the users in testing design ideas and to get feedback in the early stage of development, thus reducing time and costs. It provides an efficient and effective way to refine and optimize interfaces through discussion, exploration, testing and iterative revision. Early evaluation can be based on faster and cheaper prototypes before the start of a full-scale implementation. The prototypes can be changed many times until an optimized design of the user interface has been achieved, with the joint efforts of both the designers and the users [6].

From the designer's point of view, the more complex the design problem is, the more multidisciplinary techniques are required to solve it (e.g. interaction design, industrial design, designers of environments, software engineers, and electrical engineers). That is because each discipline brings a unique understanding of the presented issues and an individual approach for solving them. To work effectively as a design team, it is important to have the same understanding of the idea, and a common vision of what the team is trying to achieve with the prototype. Therefore, it is a powerful asset to have tools and techniques which create a shared experience, providing a foundation for a common point of view [5].

2.2 The Process of Prototyping

Prototyping involves creating a realistic model of a products user interface to get prospective customers involved early in the design of the product. Using rapid prototyping, the look and feel of the user interface is modeled without spending the time and effort required to implement the complete functionality. The prototype is then shown to prospective customers and revised to address their comments. These two steps are repeated as long as necessary.

2.3 Classification of prototypes

Prototypes are representations of a design made before final artifacts exist. They are created to inform both design process and design decisions. They may be simple sketches or complex models at different levels (such as "looks like", "behaves like", "works like") to communicate propositions and get insight of the design and its context [5].

There are many different approaches to classify the prototypes but in this thesis, classification by fidelity will be used. The classification by fidelity is based on how close the prototype is to the final artifact. This classification can be divided into:

- Low-Fidelity. They are quickly constructed to show the concept, to design possible alternatives and to generate layouts, rather than to model any interaction with the system. Low fidelity prototypes provide no functionality or very limited, if they do. They are more intended to demonstrate the look & feel of a product, rather than how the product should operate.
- Hi-Fidelity. They are more functional oriented and have many, or all, of the functionalities of the final product; therefore, users can operate the prototype, performing some task under more realistic conditions.

2.3.1 Low-Fidelity prototypes

Storyboard
It is a graphical depiction of the desired appearance of the intended system without any system functionality. It provides snapshots of the interface at specific points in the interaction so that the user can determine quickly if the design is heading in the right direction.
Advantages: Shows different scenarios, allows clients and investors to engage with the idea.
Disadvantages: May be unrealistic.
When to use: Start-up or design stages.

Sketches and paper prototypes
With this kind of prototyping, the design team and potential users, enhance the user participation in the design process, and the collaboration between the designers and the users.

Advantages: Low budget, easy to document, easy iterations, easy to get feedback.
Disadvantages: May not seem serious, doesn't show a real feel & look, hides timing issues.
When to use: When an specific problem needs to be solved, function definition stage.

2.3.2 Hi-Fidelity prototypes

Vertical prototyping
Vertical prototyping cuts down on the number of features, so that the result is a narrow system that includes in-depth functionality, but only for a few selected features, but the

most important is that it provides access to the components that will/may comprise the final product. Vertical prototypes allow users to perform and test some real tasks.

Advantages: Demonstrates a working system, very useful in later stages, allows to test details of the design.
Disadvantages: More effort and resources are required, bugs may halt the testing.
When to use: During the function definition stage.

Horizontal prototyping

Horizontal prototyping reduces the level of functionality so that the result is a surface layer that includes the entire user interface to a fully featured system, without the underlying functionality. Horizontal prototypes allow users to feel the entire interface, even though they can not perform any real tasks.

Advantages: It is fast to implement and demonstrates the human interface.
Disadvantages: Lack of functionality.
When to use: At the end of the function definition stage.

Scenario

Scenario reduces both the number of features and the level of functionality. It can simulate the user interface as long as the user follows a previously planned path, i.e., a user can use a specific set of computer facilities to achieve a specific outcome under specified circumstances.

Advantages: Is very simple since it is written in plain text, portrays the way in which a system is used in the context of daily activity, may be used to 'sell' the idea within the organization that is considering developing the system.
Disadvantages: Requires that the designer has enough insight of the project.
When to use: During the function definition stage [7].

Wizard of Oz

This method tests a system that doesn't exist, and allows to test ideas without implementing the system. This technique works as follow: the user interact with a screen but instead of a piece of software responding to the user's request, a developer (the wizard) is sitting in another room simulating the system intelligence and interacting with the user. The wizard may simulate all or part of the the system functionalities.

Advantages: creates realistic bounds, the system itself is not required.
Disadvantages: some functionalities may be too abstract to represent, specially in complex systems.
When to use: Early during the function definition stage.

Feasability

Proves out some technical assertions, to take a decision towards one preferred alternative. Its purpose is to verify that critical components are capable of meeting the artifact or business needs.

Advantages: very useful to take a decision since integration issues may be detected.
Disadvantages: Physical access to the equipment is required.

2.4 Characteristics of a good non-disposable prototype

1. Executability: Works good enough to be used and tested by an user or operator
2. Maturation: It can evolve, and in a future, it may become a final product.
3. Representation: It has a look and feel very similar to the desired product.
4. Scope: As a minimum, simulates the 20% of the functions that customers will use 80% of the time [8].

3 Minalyzer SCS Prototype

3.1 Minalyzer product development process

The first stage of the development process took place during the development of the business idea and the business plan, which were performed by Annelie and Mikael. During this stage the problem was clarified by identifying the problems in the mining industry, and later served as a foundation for the idea of how the process could be implemented. The output of this stage was a general specification plagued with unknown variables which, however, was clear enough for making a prototype.

In the second stage, a team performed a product development project for clarifying the requirements. This could later be used to develop a "proof of concept"-prototype. To do so, the team came up with many different concepts.[6] The outcome was a low-fidelity prototype where user iteration, safety, and robustness (for tough environments) were emphasized, together with clearer requirements. Even though the requirements were more realistic and clear than during the previous stage, they still lack details and required more specifications at low-level.[7]

At the third stage, the requirements were redefined in a technical point of view. This allowed the identification of new requirements, new risks, and new currently unknown requirements that would serve to build the Minalyzer SCS.

After the development of the Minalyzer SCS prototype is complete, Minalyze AB will have a functional prototype that can be reused when developing the next prototype. The next prototype will be able to scan multiple cores at the same time. That prototype will be called Minalyzer CS [3].

This iterative process can be summarized in the diagram in figure 3.1 on page 12.

[6] In this context, a concept is being considered as the idea to develop a high fidelity prototype, and could be considered as low-fidelity prototype. They are usually sketches or or paper prototypes

[7] Layered systems use layers to separate different units of functionality. Lower layers are more domain specific, closer to the machine's hardware. A higher layer requires its lower layer to perform its function.[9]

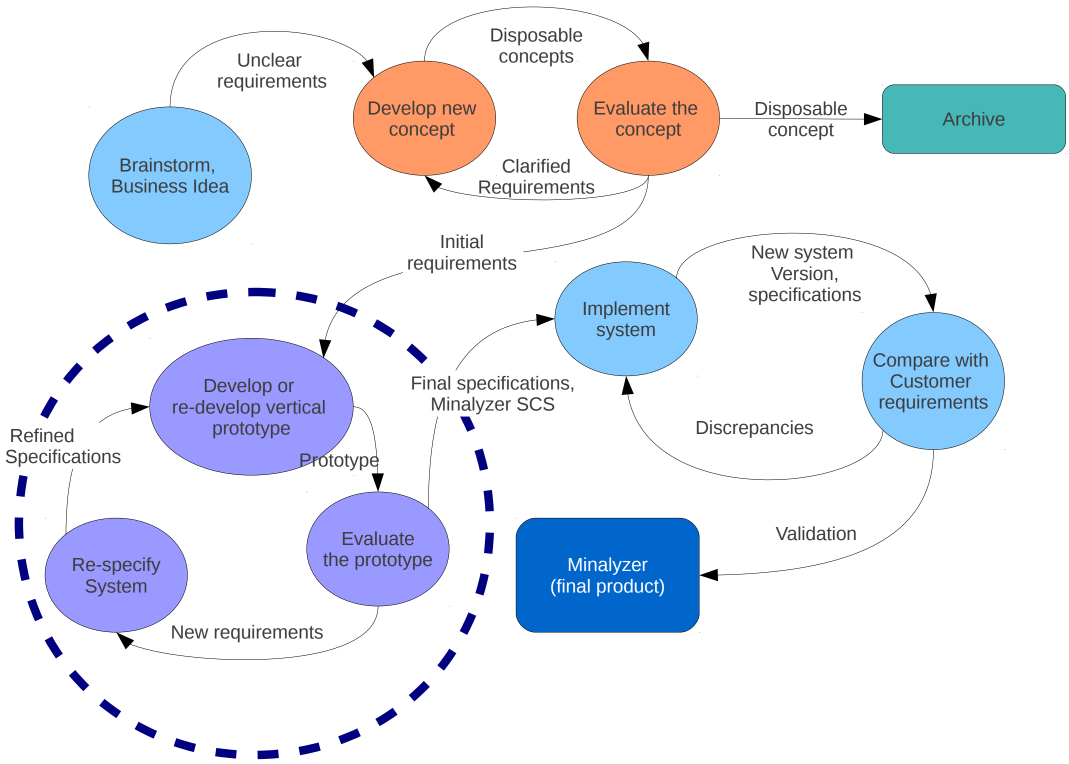


Figure 3.1: *The product development process at Minalyze AB. The area in the dotted circle is the part of the development that this thesis consists of.*

3.1.1 The Minalyzer prototype in the product development process

As shown in the evolutionary development process carried out by Minalyze, a high quality prototype is developed during this master's thesis. This prototype will allow the company to develop new prototypes with new features before a final version has been reached, which meets the needs of the customers and has the required characteristics. This prototype is crucial for the company, since it will be shown to stakeholders and investors to get new investments and finance the development of new prototypes. Therefore, during the development, there is special attention payed to features that show functionality, or mimic relevant functionality.

3.2 Overview of the system

3.3 Features

Following is a set of features that will be implemented in the prototype:

- A PLC which will control the motors which moves the actuators

- The PLC shall also have control over the electronics of the system. E.g. it shall get the distance measured by a laser sensor, it shall control relays to enable/disable parts of the system such as the X-ray housing and a lamp.
- It shall include a proper electrical installation, including required fuses, correct grounding, and appropriate coupling.
- The systems shall be safely interrupted in case of an emergency or if any of the devices fail.
- That the PLC should be controlled from LabView.
- When a drill sample is scanned, a graph with the height profile of the sample should be provided.
- The user should get a picture of the drill sample.
- A graphical user interface should be implemented in LabView. This is the interface that the operator of the Minalyzer SCS will use for controlling the device, as well as viewing the results of the scans.
- A driver for LabView, for controlling the high-voltage generator via RS-232, will be implemented
- Another driver is required for extracting data from the X-ray detector
- A lamp which shows the status of the system using different colors and states (blinking/static)

3.3.1 Components

After analyzing the required features, a set of components, which will be briefly explained, were identified as well as the interaction required among them to operate as a system. In figure 3.2 an overview of the system is given:

Computer

The computer used in the Minalyze prototype is a standard stationary computer configured to work with the prototype hardware. The computer will control the PLC, the camera, the XRF detector, and the X-ray system through LabView.

Safety system

The safety system is the part of the machine that makes it safe to be operated by a human. For this purpose some hatch sensors and an emergency stop buttons are implemented. Basically, the safety system deactivates the devices that may be harmful, in this case the X-ray.

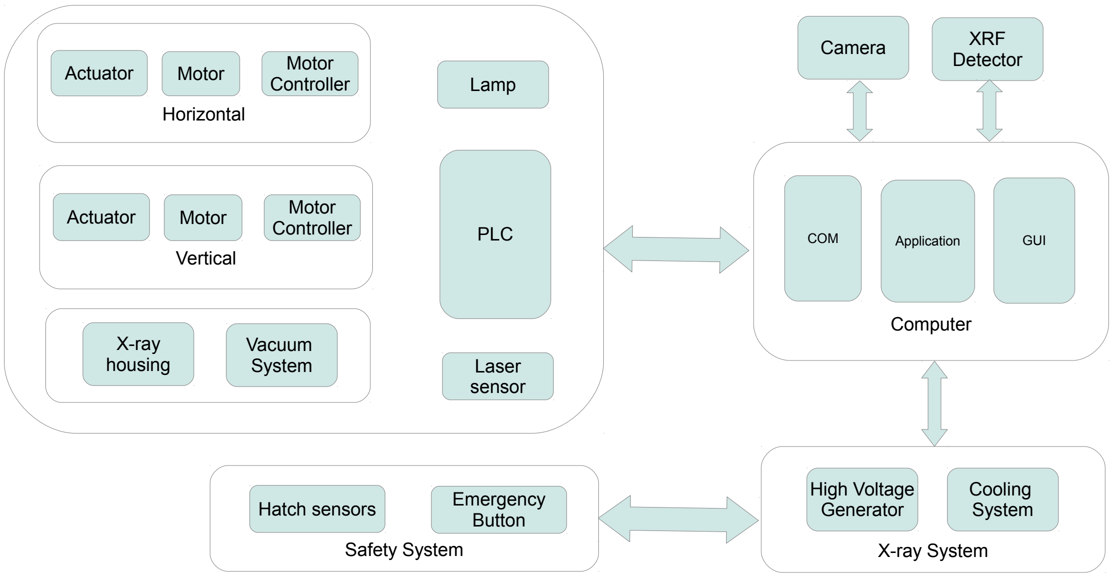


Figure 3.2: *System diagram of the Minalyze SCS*

Electrical system

The system requires a proper electric installation capable of supplying the required current, but also with the required fuses or circuit breakers to protect the devices. To avoid human harm, or at least reduce it to a minimum, a proper installation of the protective earth is required.

PLC

A Programmable Logic Controller (PLC) is an electronic control unit, used to control processes and machines, and is very common in the industry. It contains a microprocessor and a programmable memory in which a program with instructions is stored. It uses analogue and/or digital inputs from e.g. switches, sensors and, depending on the program, changes the states of the outputs. In PLCs, it's also very common that the communication with sensors, or other controllers or systems, is done through a field bus.

The controller module is programmed from a PC using a software called CoDeSys. CoDeSys is one of the most common programming system for PLCs. More than 200 different PLC manufacturers use it today [10].

The developed program is downloaded through the Ethernet port and can be run without the need of a computer.[8]

Actuators

The actuators used in the Minalyze prototype are electro-mechanical actuators which perform linear motion. The actuators convert the rotary motion of the servo motors, which are powered by electricity, to linear motion. The prototype includes two actuators, one for horizontal movement and one for vertical movement.

[8] As long as the program is created as a boot project

Servo motors

A servo motor is an electrical motor equipped with a servo, which regulates the movement of the motor in terms of position, speed and direction. The motor can be a DC or AC motor, but in the industry it's more common with AC motors, since these can be considerably more powerful than DC motors.

Motor controllers

A motor controller is a device used to do the low level controlling of an electrical motor. If a motor should run with a certain speed in a certain direction for a certain time, a more high level controller, e.g. a PLC, only needs to send a few signals to the motor controller. It sends the speed, direction and time to the motor controller and it then handles all the electrical signals that the motor requires for making the movement.

X-ray detector

The X-ray detector is one of the most important parts of the Minalyze's prototype, it's the device that reads the secondary radiation. The secondary radiation is the X-ray beams that have hit the drill core and then are reflected. The secondary radiation contains valuable information about the elements in the surface of the drill core, since different elements gives different kinds of secondary radiation. What differs is the charge that the particles in the secondary radiation have when they have been reflected. The X-ray detector reads the energy levels in the secondary radiation and counts the particles at the different energy levels. Using this data it is later possible to determine what elements the drill core consists of. For more details, see appendix section C.5.
The X-ray detector is connected to a computer using USB, and is controlled from LabView.

High-voltage generator

A high-voltage generator for X-ray has two main functions. One is to provide high-voltage(kV) with low-current(mA) to accelerate a stream of electrons; the other functionality is to provide a high current for a filament at 10 VAC. For more details, see appendix section (see C.3.1).

X-ray housing

For safety reasons, the housing has a shutter that should be open only when the system is secure enough to operate. When the shutter is closed it blocks the X-rays. For more details, see appendix section (see C.3.5).

X-ray optics

The X-ray optics are used to make a narrow beam of X-rays, therefore it is attached to the X-ray housing. For more details, see appendix section (see C.3.4).

X-ray tube

The tube is the part of the system the generates X-rays, and it consists of two main parts: cathode and anode. When the cathode, or filament, is heated by the high voltage generator, the electrons that break free are attracted to the anode. The electrons that are passing through the tube are called tube current. For more details, see appendix section (see C.3.2).

Cooling system
It is necessary to cool down the X-ray tube using water and therefore a cooling system is used. The cooling system is active whenever the high-voltage generator is running. For more details, see appendix section (see C.3.3).

Vacuum system
A vacuum is required between the sample and the XRF detector since it's known that the readings will be improved if the scattered radiation from the sample travels through vacuum to the detector .

Camera
The Minalyzer SCS prototype includes a camera that takes a photo of the core before it's analyzed. The photo can be used to let the user select a specific area of the core, on which an analysis should be carried out. The photo is also used together with a graph to display the results after an analysis is completed .

Laser sensor
To measure the height of the sample lying in the sample holder mounted on the horizontal actuator, the prototype is equipped with a distance sensor that uses laser to measure the distance. It is a high precision sensor with fast response time, high performance and flexibility. The laser sensor is mounted perpendicular to the horizontal actuator approximately 30 cm straight above it .

3.4 The team

In the working team different ideas and possible solutions to problems are discussed. Feedback is provided to develop better solutions, and the team members have taken different roles according to their interests and backgrounds.

Table 3.1 shows that each team member has expertise in different areas of knowledge. This creates a balance in the team to compensate the weaknesses of the other team members.

	Efrain	Isac	Mikael
Radiation			X
Industrial Design			X
Mechanics		X	X
Programming	X	X	
LabView			X
Software Development	X		
PLC		X	
Real-time Systems	X		
Electronics	X	X	

Table 3.1: *Areas of expertise*

Efrain Calderon Estrada. Developed the most of the LabViewapplication, designed the electric diagrams, and developed the electronic solutions such as PCBs.

Isac Zagerholm. Developed most of the PLC application, Safety systemapplication, and has been more hands-on the assembly/disassembly of the system.

Mikael. As the CTO, he is the leader of the team and the one that decides what the team members should work on and what to prioritize, and has a better overview of the whole project. As a developer, he has a better understanding of the "big picture", and is in charge of the industrial design.

External resources

Two developers outside of Minalyze have developed LabView-drivers for the X-ray detector, the high-voltage generator, and a graphical user interface. Meetings have been set up periodically on which brainstorming about the main requirements of the GUI have been done.[9] The developers are LabViewexperts, therefore they have given to the team, continuous advice about the best practices when programming in LabView.

3.5 Development

3.5.1 Limitations

There are some limitations on the project:

- **Budget:** The company needs to raise funding to afford the development of more prototypes. To do so, it is necessary to show functionality of Minalyze's upcoming product.
- **Time:** Minalyze needs a skilled development team to have a functional prototype after the 6-8 months developing time.

[9] They are called main requirements since there is not a full set of requirements, but have been considered the most important for showing functionality to investors.

- **Knowledge:** Minalyze doesn't any have previous experience of developing X-ray machines. Nevertheless, support is received from a supplier but it is rather limited. Isac and Efrain are the experts in PLC programming, mechanics, and software development. Support in LabView will be provided from the external LabView developers.
- **Decision making:** Minalyze will make the decisions about equipment purchasing and changes of priorities.

3.5.2 Identifying risks

Risk	Consequences	Severity	Solution
PLC don't arrive on time	Since this is a core part of the system, it would delay the start of the project	High	Decide which PLC is suitable and purchase it as soon as possible
Equipment not available in time	The project will be delayed	Medium	According to the priorities, work can be be done in other parts of the development while waiting for equipment.
Interfaces not compatible	Additional components, software or hardware may be required,	High	Identify the adapters available by the suppliers. Design and make the customized interfaces.

Table 3.2: *Risks identified*

3.5.3 Defining priorities

The prototype consists of a considerable number of different components and includes many functions. These will be implemented using different tools, such as software, and electrical components. Consequently, it is necessary to define priorities and identify the critical modules, to ensure a efficient development.

1. **Safety:** The equipment operates with high voltage (~30 kV), and high current (~35 A), which is lethal for humans. Additionally, the X-rays are dangerous in combination with long periods of exposure. Since a safe working environment is very important, safety is priority number one.
2. **Time:** Minalyze will need to get more funds from investors soon. To do this it is important to be able to show a working prototype to the investors. Therefore this project is very time limited and time is highly prioritized.
3. **Cost:** Minalyze have a very limited budget and therefore equipment and solutions have to be evaluated to get a cost efficient prototype.

4. **Show functionality:** To get more funds from investors it is important to show them a functional prototype.

5. **Quality:** Good practices should be followed, according to the standard.

6. **Documentation:** All produced code should be well documented to aid future development.

The development of the components is prioritized based upon the components interdependency. The priorities are as follows:

1. **PLC**. It is in charge of controlling the hardware, therefore it is the most critical component.

2. **OPC Client**. It handles the exchange of data between the PLC and the PC.

3. **Motor controllers**. They are slave units to the PLC and they control the motors.

4. **HVG**. Provides the power to generate the X-rays.

5. **Cooling system**. It is required to cool down the tube while X-rays are being generated.

6. **X-ray detector**. It has less priority than the other parts, since a functional X-ray generation is required to test it properly.

3.5.4 Characteristics of the prototype

First, to define the characteristic of the prototype, an understanding of Minalyze's goals is needed, especially at mid and short term. Thereafter, the limitations that the project will have need to be understood.

But that is not all, an understanding of the big picture of the system and the functions of all components within the system is needed. This is to find any missing pieces and to develop a solution that will make the system work as a whole.

Initial Conditions

- The GUI will be implemented in LabView because of the LabView expertise provided by external resources. An other reason is that a company which Minalyze collaborates with has developed a software for analyzing minerals using LabView.[10]

- No computer available in the start of the thesis.

- The safety system was not well defined, but it was determined that an emergency stop button and hatch sensors are required.

[10] The collaborating company has a long experience of using X-ray for analyzing minerals. They will provide Minalyze with some advice and will sell them X-ray optics, and some other equipment

- No electric system had been designed.
- Minalyze had not yet decided what equipment should be used for controlling the actuators.
- Actuators, motors and motor controllers will be provided by an automation company.
- The X-ray detector was already acquired. It was tested with a radioactive sample and is provided with a driver for LabView.
- Different suppliers for the high-voltage generator had to be analyzed and a high-voltage cable had to be decided.
- The X-ray housing and optics will be bought from the collaborating company.
- The cooling system had not yet been decided, since it has be compatible with the high-voltage generator.
- The vacuum system had not been specified.
- No camera had been chosen.
- No laser sensor had been chosen.

Execution

The work performed during this thesis can be summarized in a series of tasks:

- Plan the activities of the project.
- Suggest and give advice about the required components.
- Decide a suitable hardware for controlling the CAN communication between the PC and the CAN hardware .
- Develop a software for the CAN controller.
- Develop a software for the safety-PLC.
- Develop a software architecture in LabView.
- Design the communication between the CAN controller and LabView.
- Assemble the components.
- Do the electrical installation.
- Implement electronic interfaces.
- Test the system.
- Participate in the design of the GUI.

3.6 Knowledge Management

- All the code and all the documentation is stored in the cloud which provides automatic backups of all the work. Furthermore it allows sharing with the other team members.
- All the manuals and documents are managed by the CTO.
- All the developed software is documented with diagrams and comments.
- The designs, or ideas about the design, are discussed within the team, before they are implemented.
- The CTO is always kept in the loop to ensure that he is informed about all parts of the development.

4 Results

The purpose of this Master thesis was to design and develop the first functional Minalyze prototype called Minalyzer SCS. The result is a prototype that contain a lot of functionality, however not all the functionality that was intended at the start of the thesis. The reasons for this are two: lack of time, and delays. The reason for the delays are explained in section 5.3.

The prototype includes many components, including a high-voltage generator, a cooling system, an X-ray generator, X-ray, motors, a PLC, a laser distance sensor, a pc, electronic components, a safety system and a vacuum pump. Most of this components where bought and implemented during the thesis, but some of them, the high-voltage generator and the cooling system, where delayed and therefore not implemented in this thesis.

The preliminary tests that were done of the Minalyzer SCS turned out to be satisfying. They were done without the missing hardware and were focused on limited functions of the prototype, since a complete test could not be done without the missing hardware.

Minalyze will continue the development of the prototype and will use it to develop another prototype and then the final product.

4.1 Achievements

4.1.1 Determine the interfaces between the hardware and software

This part of the thesis was fully completed. All the interfaces between the different hardware and software where determined even though some hardware never physically arrived to the development site. This was possible by using the data sheets and manuals for the hardware components and from them determine the appropriate interfaces.

4.1.2 Determine a suitable software architecture

This part of the thesis was fully completed. The software architecture that was decided to be used is LabView installed on a PC. On a lower level it was decided to use a PLC that communicates with hardware over a CAN-bus or using I/Os. This PLC is controlled by LabView.

4.1.3 Create the software architecture

This part of the thesis was partly completed. A LabView program was made, as well as a PLC program. The LabView was not complete since not all the hardware was physically available, and thereby was not either the prototype complete. The interaction with the hardware was done with the hardware that was available and the extraction and management of data could not be completed.

5 Discussion

5.1 Benefits for Minalyze

- The company gets a functional, safe prototype that can be used for further testing and development.
- Good feedback in an early stage of the development of Minalyzer CS.
- Increase of the company's value which makes it easier to raise funds from investors.
- Well designed and documented software.
- Added knowledge.

5.2 Good Practices

5.2.1 Good working environment

There was no need for strict supervision since all the members knew their role in the team. The development was on-site, which gave the team direct access to the equipment. The stress level was good during the development. To continue with this practice, the company should keep the development on-site avoiding outsourcing in this early stage. It should instead be considered when the product is more mature.

5.2.2 Good balance of expertise

Even though Minalyze didn't have any expertise in X-ray machine development, the knowledge and experience in the development team covered many areas which allowed the project to move forward and tackle any roadblocks. Minalyze should have the same conditions when recruiting new personnel, keeping the balance of expertise.

5.2.3 Negotiation with suppliers

During the project, the negotiation with suppliers was a very important part. The use of verbal communication through phone or personal meetings, made it successful. The team should continue making deals by phone instead of using email.

5.2.4 Attitude

The whole team had a great attitude, with a positive mindset. The mindset should always be positive when new projects are started and each member should push themselves to achieve new goals.

5.2.5 Free software

Many different tools are available for free, at least as trials. Using free tools during the implementation of the prototype made the work easier and more efficient. Tools for desktop and documents sharing were extensible used with good results.

5.2.6 Online resources

There are free libraries for LabView and other software that have been used during the project. Different forums and web resources have been used as to solve issues and request support.

5.3 Opportunities for Improvements

5.3.1 Components ordered late

Some of the most important components were not ordered on time. Therefore, during the beginning of the project, the progress was slow and ineffective. In future projects, this can be avoided by detecting which are the most important components. This will provide time for the developers to get familiar with the components, instead of waiting for the components to arrive.

5.3.2 Plans don't always go as planned

Two separate plans were created during the project, one in the beginning (see appendix section A) and another in the 8th week of the thesis. The plans were followed and updated the first months but after a few more weeks they where not updated any more. This made them more and more inaccurate as the weeks went by. One improvement that could be done in this area is to better keep track of the planning, and have frequent follow-up meetings.

5.3.3 Buying components indirectly

There were some issues with some components that were purchased through another supplier that is running a similar business as Minalyze. The supplier provided components without the proper documentation and gave misleading information. This caused many issues and more effort had to be done to fix them. In the future, it is better to only buy essential components from this kind of suppliers, and set clear delivery requirements.

5.3.4 Overoptimism in the delivery time

The delivery time of some components was much longer than expected which delayed other activities. This was not always caused only by the delivery time, but in some cases also because the devices were produced on demand, or because of bad communication from the supplier. This may be avoided by asking potential suppliers in advance about delivery times, especially with products that are not mass-produced.

5.3.5 Missing perspective

During the thesis, some implementations were aimed too much on the design aspect, although such solutions required more time to implement. One reason for this is because possible solutions were not always analyzed in detail. To avoid focusing too much on the design aspect, the whole development team should participate in the decision making. If a simple solution seems likely to work, it is better to give that a try, rather than spending a lot of development time on creating a fancy solution.

5.3.6 No version control available

At the beginning, the team didn't use any kind of version control to track and synchronize the code when collaborative work was done. In the middle of the project it was more difficult to maintain the code for all the developers, which caused re-work being done many times. A version control system[11] could be implemented with open source tools at no cost. This is definitely a must in the future.

5.3.7 Clarify which language to use

In the team, not everyone speaks Swedish, and when working in a multi-lingual environment, speaking a language that other person doesn't speak may decrease the cohesion in the team. To avoid this in the future, the team should encourage to the non-Swedish speakers to learn Swedish, or to always use English when a non-Swedish team member is in the vicinity.

5.4 Tackled challenges

During this project the team had to overcome many different challenges:

- **Limited expertise in the company:** The thesis workers where the ones who became the experts of the system.
- **Making a new combination of hardware and software:** The new mix of two platforms, LabView on PC, and CoDeSys on a PLC, made it hard to find support.

[11] Often abbreviated SVN, after the command name "svn".

A communication layer (OPC) had to be added which made the system a lot more complex.

- **Bad support from CoDeSys:** The CoDeSys software had many bugs in the latest versions of Windows. Some of them were fixed with the release of new builds, but it was hard to find what the problem was since there was no notification about a new release, nor any release information.

- **Short time to make important decisions:** Taking good and well founded decisions is important in a project. But it is not always easy to take decisions, especially as a student, when the future of a company may depend upon those decisions.

- **Bad documentation from the suppliers:** It turned out that some suppliers had very bad documentation of their products. This made it difficult to make the right actions at the first attempt.

- **Stability or functionality:** Because of the importance of showing functionality, a sacrifice of stability had to be done. Therefore, the focus was to make the system stable enough to proof the concept.

- **Lack of equipment:** There were not a lot of equipment and tools to work with. Therefore proper tools had to be found and this was not very time efficient.

6 Conclusions and recommendations

When developing a prototype of a product that is new on the market, it may be so that it contain a lot of components that in themselves are well known and well developed, but the combination or utility of them is to some extent unexplored area. That was the situation for Minalyze when their first prototype was developed during and after this masters thesis. For this reason the acquirement and development of individual hardware took approximately as much time and effort as planned. However, the task of combining the hardware and getting it to work in the desired way took much more time than planned. The conclusion of this is that if some part of the prototype development includes an, from previous experiences, unknown combination of hardware and software, it is important to have big margins in the time planning. This would most probably also apply if was the opposite: the combination of the hardware is known from previous experience, but the hardware components are in some extent undeveloped and unknown.

The purpose of this thesis was to proof the concept and get results to show them to the executive board, potential investors and potential customers. This was achieved in a big extent, even though the worked carried out was not sufficient to show the functionality due to time limitations and equipment availability, since the core devices are up and running and the new functionality can smoothly be aggregated because the SW architectures was design to do so. Now, the prototype is in the final stage and the result will be seen soon.

6.1 Lessons learned

6.1.1 Evaluation time versus product price

During the project there was a situation where a component should be chosen where there where two alternatives, one cheap and one that was twice the price. The expensive one was known to be compatible with all other components, but the cheaper one was unknown. After one month of evaluation time of the cheap alternative, the expensive one was chosen. A lesson that was learned from this is to not always stare blindly on the price and try to get a cheaper solution to work. In the end, getting that solution to work can be just as expensive as just buying another more expensive solution from the start. In worst case the cheap solution doesn't work at all, and a lot of evaluation time have been spent in vane. Therefore, evaluation time may be more expensive than buying a more expensive product.

6.1.2 A nice solution is not always the best

Sometimes a developer favorite a solution that is better designed but requires more resources, especially when the case is hardware. This may however have a higher cost or be less space efficient, compared to a simpler solution. Therefore, a simpler solution should also be considered and be used as a backup plan.

6.1.3 Showing functionality to investors pays off

It is well known that during the development of a system, the core functions of a system are not seen from "out of the box", but it is usually what takes most time and effort to develop. Consequently, from the investors point of view, the progress may seem slow since there is nothing new to show. Therefore, it is important to prioritize the functions that can be shown and somehow amaze potential customers or investors, which may bring funds in the future.

6.1.4 When a supplier may become a competitor, get a plan B

Because of the inexperience in developing X-ray machines, Minalyze has tried to make business with a radiation technology provider. The deal is to purchase optics and other components from them and in exchange Minalyze get advice to make the development process easier. Nevertheless, the supplier has provided incomplete, or misleading information, making the development more difficult, probably because that company fears that Minalyze may become a competitor. Therefore, when a deal of this nature is done with a company, some research should be done about how to get special deals in such components with other providers.

6.1.5 Good communication provide benefits

Nowadays there are many different ways to communicate, but still the oral communication, face-to-face or by phone, is the best and most beneficial way to make business. For instance, during the project some equipment where borrowed to check if it actually fulfilled the requirements. This eased the decision making about what components to use. An other case is the LabView license: the company got a full- development demo license to use for 90-days for many developers instead of the regular 30-days that is offered by National Instruments.

6.1.6 The importance of planning

A plan serve as a reference during the development and can be very helpful, and even it's not followed exactly. Planning can help identifying the priorities and the critical activities, and how to react to events that are not planned.

6.1.7 There is no such thing as too much safety

Even an experienced developer needs to be careful when working with high-voltage devices or radioactive components. However, time has the ability to make dangerous things, seem less dangerous when no accidents happen. Therefore it's easy to over time get less and less cautious. This is however not good and it's important to, by using signs and clear instructions, ensure that the work is always carried out as safe as possible.

6.1.8 When the management truly believes in an idea, it creates excitement and motivation in the team

Annelie and Mikael initiated the adventure of making their own company during their studies at Chalmers School of Entrepreneurship. After 1,5 years of strong belief in their business idea, together with hard work, their product is now something tangible and is moving towards a big success. Such belief was externalized during the whole development of the project, and it created excitement and motivation in the rest of the team.

6.2 Recommendation for the future

Minalyzer SCS is the first prototype of Minalyze of AB, therefore in this one is we find many opportunities for improvements, it could be added in the next prototypes or final products:

Develop a software for detecting the minerals instead of using a third party software, this will increase the flexibility of the whole system to include new feature. One feature that may be useful is to provide information about what other minerals that may be found in the area, based on the data from previous analysis or other statistic data. This can be done with learning algorithms. Use LabView scripting to auto generate the blocks that used in the OPC client to read/write data from/to the OPC server, this will provide faster development when multiple similar blocks are developed.

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Appendices

A Thesis time plan

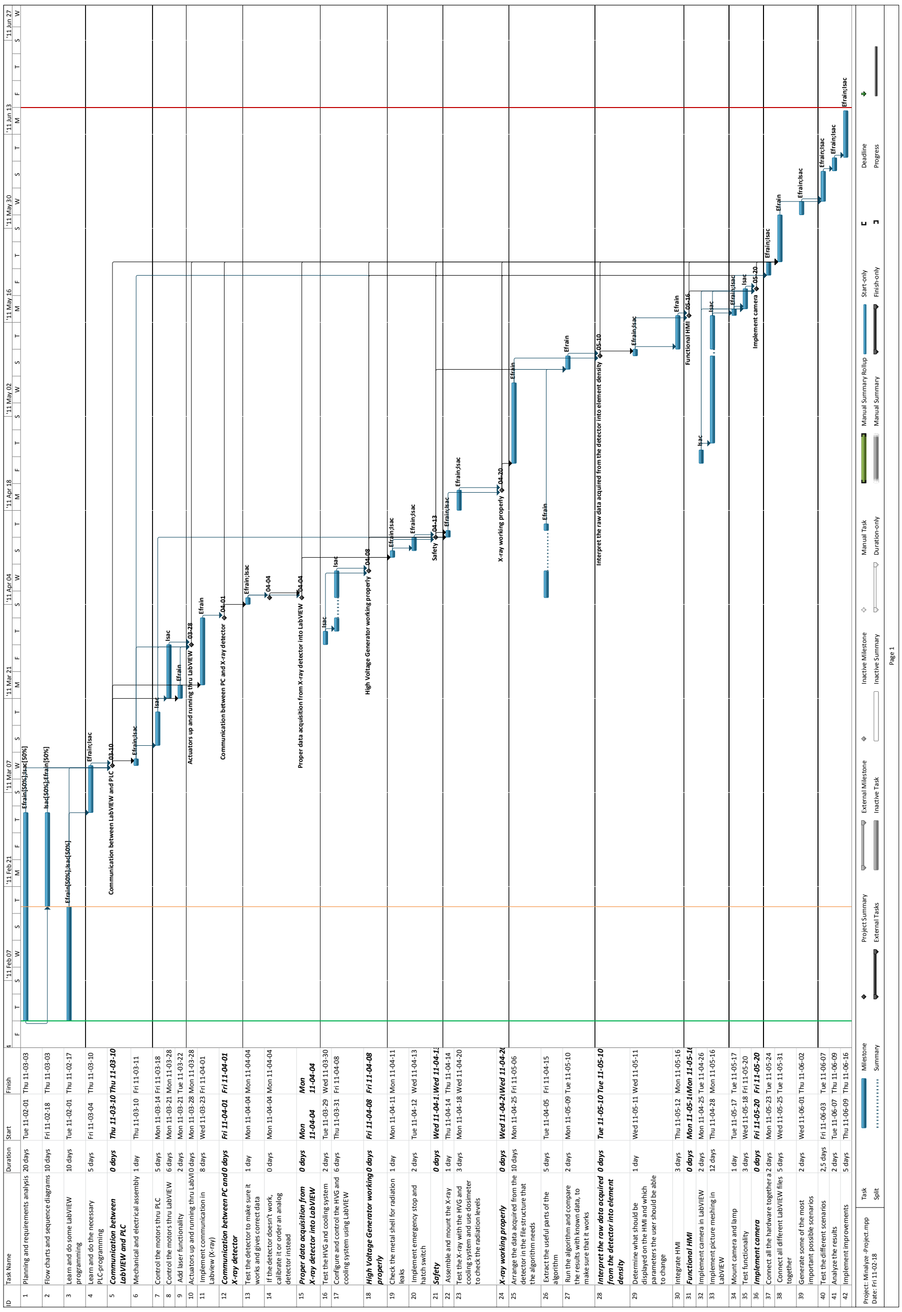

Figure A.1: *The time plan that was made in the first weeks of the thesis work*

B Thesis description

The thesis description that was handed in at the start of the thesis

Development of a system for X-ray analysis within the mining industry

Background

Companies within the mining industry perform exploration drilling in order to find new mineral resources. Currently this process is associated with high investments and high risks mainly due to the extensive cost and time it takes to perform the analysis of the rock samples. Minalyze is developing instruments for analysis of rock samples for the exploration and mining industry. The analysis is based on a well-developed X-ray technology that can provide instant results on-site. Minalyze is currently developing the system comprising of hardware and software for performing the analysis.

The objective

The objective is to create a software architecture and software environment that can communicate with and extract data from the hardware comprised in the system.

The assignment

The first part of the assignment is to determine the different interfaces between hardware and software for the different components in the system. The system comprises of components such as PLCs, high-voltage generators, digital imaging and detectors. Most of the components can be controlled through DLLs while others require different I/O signals. The next step of the assignment is to determine a suitable software architecture that can act as an interface between the hardware and the user i.e. to evaluate and decide on a suitable programming language, databases and interfaces that are needed. The final step is to create the architecture so that it could be used internally to extract and manage data and to interact with the hardware.

C X-Ray System

C.1 Radiation

X-rays and gamma rays differ only in their source of origin. X-rays are produced by an x-ray generator and gamma radiation is the product of radioactive atoms. They are both part of the electromagnetic spectrum. They are waveforms, as are light rays, microwaves, and radio waves. X-rays and gamma rays cannot been seen, felt, or heard. They possess no charge and no mass and, therefore, are not influenced by electrical and magnetic fields and will generally travel in straight lines. However, they can be diffracted (bent) in a manner similar to light[29].

Both X-rays and gamma rays can be characterized by frequency, wavelength, and velocity. However, they act somewhat like a particle at times in that they occur as small "packets" of energy and are referred to as "photons." Electromagnetic radiation has also been described in terms of a stream of photons (massless particles) each traveling in a wave-like pattern and moving at the speed of light[29].

Each photon contains a certain amount (or bundle) of energy, and all electromagnetic radiation consists of these photons. The only difference between the various types of electromagnetic radiation is the amount of energy found in the photons. Due to their short wavelength they have more energy to pass through matter than do the other forms of energy in the electromagnetic spectrum. As they pass through matter, they are scattered and absorbed and the degree of penetration depends on the kind of matter and the energy of the rays[29].

C.2 X-Rays

X-rays are just like any other kind of electromagnetic radiation. They can be produced in parcels of energy called photons, just like light. There are two different atomic processes that can produce X-ray photons. One is called Bremsstrahlung and is a German term meaning "braking radiation." The other is called K-shell emission. They can both occur in the heavy atoms of tungsten. Tungsten is often the material chosen for the target or anode of the X-ray tube [29].

Both ways of making X-rays involve a change in the state of electrons. However, Bremsstrahlung is easier to understand using the classical idea that radiation is emitted when the velocity of the electron shot at the tungsten changes. The negatively charged electron slows down after swinging around the nucleus of a positively charged tungsten atom. This energy loss produces X-radiation. Electrons are scattered elastically and inelastically by the positively charged nucleus. The inelastically scattered electron loses energy, which appears as Bremsstrahlung. Elastically scattered electrons (which include backscattered electrons) are generally scattered through larger angles. In the interaction, many photons of different wavelengths are produced, but none of the photons have more energy than the electron had to begin with. After emitting the spectrum of X-ray radiation, the original electron is slowed down or stopped[29].

C.3 X-ray Generator

The heart of an X-ray generator is the X-ray tube. Like any vacuum tube, the X-ray tube contains a cathode, which directs a stream of electrons into a vacuum, and an anode, which collects the electrons. The anode in an X-ray tube is made of tungsten, molybdenum, or copper; when electrons collide with the anode, about 1% of the resulting energy is emitted as X-rays, with the remaining 99% released as heat.

The tube cathode (filament) is heated with a low-voltage current of a few amps. The filament heats up and the electrons in the wire become loosely held. A large electrical potential is created between the cathode and the anode by the high-voltage generator. Electrons that break free of the cathode are strongly attracted to the anode target. The stream of electrons between the cathode and the anode is the tube current. The tube current is measured in milliamps and is controlled by regulating the low-voltage, heating current applied to the cathode. The higher the temperature of the filament, the larger the number of electrons that leave the cathode and travel to the anode. The milliamp or current setting on the control console regulates the filament temperature, which relates to the intensity of the X-ray output [29].

C.3.1 High Voltage Generator

Together with the tube, the control console, and the cooling system, the high voltage generator is one of the most important parts of an X-ray generator. The tube cathode (filament) is heated with a low-voltage current of a few amps. The filament heats up and the electrons in the wire become loosely held. A large electrical potential is created between the cathode and the anode by the high-voltage generator. Electrons that break free of the cathode are strongly attracted to the anode target. The stream of electrons between the cathode and the anode is the tube current. The high-voltage between the cathode and the anode affects the speed at which the electrons travel and strike the anode. The higher the kilovoltage, the more speed and, therefore, energy the electrons have when they strike the anode. Electrons striking with more energy results in X-rays with more penetrating power. The high-voltage potential is measured in kilovolts, and this is controlled with the voltage or kilovoltage control on the control console. An increase in the kilovoltage will also result in an increase in the intensity of the radiation [29].

C.3.2 X-Ray Tube

X-rays are generated by directing a stream of high speed electrons at a target material such as tungsten, which has a high atomic number. The tube cathode (filament) is heated with a low-voltage current of a few amps and the electrons in the wire become loosely held. When the electrons are slowed or stopped by the interaction with the atomic particles of the target, X-radiation is produced. Much of the energy applied to the tube is transformed into heat at the focal spot of the anode, therefore a cooling system is required. As mentioned above, the anode target is commonly made from tungsten, which has a high melting point in addition to a high atomic number. In order to prevent the cathode from burning up and to prevent arcing between the anode and the cathode, all of the oxygen is removed from the tube by pulling a vacuum. Some systems have external vacuum pumps to remove any oxygen that may have leaked into the tube [29]. The X-ray tube is one of the components of an X-ray generator and tubes come a variety of shapes and sizes.

C.3.3 Cooling System

Cooling of the anode by active or passive is necessary to cool the tubes, for this purpose water or oil recirculating systems are often used. Some low power tubes are cooled simply with the use of thermally conductive materials and heat radiating fins [29].

C.3.4 X-ray optics

A focusing cup is used to concentrate the stream of electrons to a small area of the target called the focal spot. The focal spot size is an important factor in the system's ability to produce a sharp image. The usual objective in radiography is to produce an image showing the highest amount of detail possible. This requires careful control of a number of different variables that can affect image quality. Radio-graphic sensitivity is a measure of the quality of an image in terms of the smallest detail or discontinuity that may be detected. Radio-graphic sensitivity is dependent on the combined effects of two independent sets of variables. One set of variables affects the contrast and the other set of variables affects the definition of the image [29].

C.3.5 X-ray housing

In order to provide more safety to the operator, an X-ray typically has a robust metallic housing made of lead(typically 10kg) that provides one or more windows to let the radiation pass through, this is done by opening/closing a shutter. Those windows are controlled by the system in such way that they are only open when X-ray is activated in the front panel; therefore, under any abnormal circumstance, the shutter remains closed.

C.4 X-ray Diffraction

X-ray scattering techniques are a family of non-destructive analytic techniques which reveal information about the crystallographic structure, chemical composition, and physical properties of materials and thin films. These techniques are based on observing the scattered intensity of an X-ray beam hitting a sample as a function of incident and scattered angle, polarization, and wavelength or energy.

C.5 X-ray Detection

There are many techniques to detect X-rays, so because of the scope of this thesis, only the operation of the Silicon Drift Detector is briefly described, since it is the one used in the system.

C.5.1 X-Ray Detector

Silicon drift detectors (SDDs) are X-ray radiation detectors used in x-ray spectrometry (EDXRF) and electron microscopy (EDX). Their chief characteristics compared with other X-ray detectors are:

- High count rates.
- Comparatively high energy resolution (e.g. 140 eV for Mn K wavelength).
- Peltier cooling.

Principal of operation

Like other solid state X-ray detectors, silicon drift detectors measure the energy of an incoming photon by the amount of ionization it produces in the detector material. In the SDD, this material is high purity silicon with a very low leakage current. The high purity allows for the use of Peltier cooling instead of the traditional liquid nitrogen. The major distinguishing feature of an SDD is the transversal field generated by a series of ring electrodes that causes charge carriers to "drift" to a small collection electrode. The "drift" concept of the SDD (which was imported from particle physics) allows significantly higher count rates coupled with a very low capacitance of the detector [30].