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A Graphical User Interface for IR-image-based process analysis

A tool for assessing root causes in paperboard variability

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Civilingenjörsprogrammet i system i teknik och samhälle

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Abstract

Paperboard is produced in a large and complex process where many parameters can affect its quality. The common methods of analysing paperboard quality are through traversing point-like sensors that only measure a very small fraction of the produced paperboard. Holmen Iggesund Paperboard has installed an IR-camera that measures the entire paperboard web and is looking for a tool to assess paperboard quality variation based on these measurements. The purpose of this thesis work is to develop such a tool. This was done through developing a user-friendly computer application (app) *IR-measurement Analysis* (IRMA).

The app is designed to help the process engineers of Iggesunds mill assess the paperboard variability, which strongly correlates with its quality. The quality improvements of paperboard mainly concern eliminating irregularities in thickness, grammage, and moisture. In IRMA, the user can prepare data, perform statistical analyses, execute a frequency analysis through Fast Fourier Transform and then compare the frequency peaks with the frequencies of possible sources for periodic process variation, for example rolls. Correlating frequency peaks and roll frequencies can indicate issues with rolls and make process engineers at the mill aware of maintenance needs. IRMA have been tested at the mill and these tests have indicated that IRMA can be beneficial in the process engineer's daily quality control measures. Furthermore, a manual has been written and the process engineers will be thoroughly educated in the use of IRMA.

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Populärvetenskaplig Sammanfattning

Kartong är en stor del av vårt dagliga liv, även om vi sällan reflekterar över det. Många är omedvetna om den komplexa process som krävs för att tillverka denna typ av förbrukningsvaror. Hos Holmen Iggesund Paperboard tillverkas kartong ämnad till olika typer av förpackningar. Den tillverkas genom att flera lager av massa sammanfogas, pressas och torkas i kartongmaskinen. Pressningen och torkningen görs med hjälp av ett stort antal valsar. Sedan kan kartongen täckas med olika beläggningar som påverkar egenskaperna gällande exempelvis tryckbarhet. Kartongmaskinen transformerar massan till färdig kartong genom denna process. Maskinen är ca 250 m lång och innehåller sektioner ämnade till olika delprocesser i produktionen.

Målet för kartongtillverkningen är att tillverka en produkt med så jämn kvalité som möjligt. Men tillverkningsprocessen är ett mycket komplext system och det kan därför vara svårt att identifiera orsakerna bakom kvalitetsvariationer. Detta är ett mycket aktuellt problem i produktionen hos Holmen Iggesund Paperboard och de söker en lösning för att identifiera orsakerna till kvalitétsvariationer. Denna rapport syftar till att dokumentera utvecklingen av en sådan lösning, nämligen datorapplikationen (appen) IR-Measurement Analysis (IRMA) vars främsta syfte är att användas i kvalitetsarbetet för att minska produktionsavvikelser. Appen används för att visualisera och analysera data insamlad av en IR-kamera som är riktad mot pappersbanan i maskinen. IRMA tillåter användaren att studera mätdatans medelvärde, avvikelsen från medelvärdet samt genomföra en frekvensanalys. Toppar i frekvensanalysen kan sedan jämföras med frekvenser hos specifika grupper av kartongmaskinens valsar, i syfte att identifiera orsaker för kvalitétsavvikelser.

Utöver appens funktionalitet läggs mycket fokus på dess användargränssnitt i syfte att förenkla processingenjörernas tillvaro med avseende på kvalitetsarbetet. Appen är tänkt att inkluderas i processingenjörernas arbetsflöde och därmed bör den vara enkel att använda. Analyser likt de som IRMA genomför har tidigare gjorts direkt i mjukvaran MATLAB. Dock är det endast ett fåtal personer som har tillräcklig kompetens av MATLAB för att kunna genomföra dessa. Ytterligare en anledning till utvecklingen av IRMA är att fler personer ska kunna genomföra analyserna och därmed bli mer inkluderade i arbetet mot produktvariationer. För närvarande är IRMA installerad på ett fåtal datorer hos Holmen Iggesund Paperboard. Den har testats i praktiken och visat sig förenkla arbetsflödet gällande analys av processvariationer. Appen har, efter användartester, visat sig vara nyttig i termer av att den åskådliggör relevant information om processavvikelser. Testerna har även visat att IRMAs användargränssnitt möjliggör avancerade analyser och jämförelser på ett tidseffektivt och lättillgängligt vis. Operatörerna kan själva välja delmängder av mätdata att analysera med hjälp av IRMA. Vidare har relevanta processparametrar, i termer av valsgrupper, inkluderats. En användarmanual har skapats för att operatörerna enkelt ska lära sig använda appen. Framöver kommer även en utbildning för operatörerna genomföras.

Acknowledgements

We would like to thank our supervisors at Holmen Iggesund Paperboard, Hannes Vomhoff and Eugenio Ciucani, for their great help and support with this thesis. Their insight into paperboard production and quality control measurements made it possible for us to venture into an unknown field and create a successful project. Furthermore, we really appreciated their support in overcoming challenges that arose.

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Lastly, we would like to thank our friends Maria Arvidsson and Alicia Söderlind for being a great support during this thesis. Because sometimes, the hardest problems can be solved through a discussion with friends over coffee.

Distribution of Work

The authors of this thesis are Agnes Höglund and Sabina Westergren Ahlin. The workload of this thesis and project has been distributed equally since most of the work has been a collaboration between both authors. However, the workload has been divided into different areas of responsibilities. Agnes Höglund oversaw the main communication and planning of the project whereas Sabina Westergren Ahlin has been responsible for defining and planning the functionalities of the GUI. The application and thesis have been created through equal efforts from both authors and both have contributed to all aspects of the thesis.

Abbreviations

MD – Machine Direction, the direction of the paperboard web in the direction of the production process.

CD – Cross Direction, the direction perpendicular to the machine direction.

TS – Tender Side, the side of the paperboard machine from where the machine is operated.

DS – Drive Side, the opposite side of the paperboard machine, where most drives are located.

DFT- Discrete Fourier Transform.

FFT – Fast Fourier Transform.

GUI – Graphical User Interface.

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1. Introduction

Large-scale manufacturing processes are usually complex systems of several sub-processes. Each of these subprocesses must work flawlessly to optimize both production speed and product quality and maximize the profitability of the process. Therefore, working on product quality control and machine maintenance are important aspects for the manufacturer. Both quantity and quality are relevant factors regarding the manufacturer's general profitability. Holmen Iggesund Paperboard is a paperboard manufacturer with paperboard production at Iggesund (Sweden) and Workington (England). Both mills strive towards continuously improving their production process. They are one of Sweden's main paperboard manufacturers and produce large quantities of paperboard on a daily basis. They market their products under two main brands: Invercote and Incada. These products are distributed globally and used in packaging and other paperboard products [1].

The mill in Iggesund produce the Invercote paperboard while Workington produce the Incada variety. The Invercote paperboard can be used in graphic paperboard products and exclusive packaging for perfume, liquor, confectionery etc. The Incada paperboard is primarily used in packaging for tobacco, cosmetics, and food. It is also used for greeting cards and similar products [2]. The mill in Strömsbruk is a laminating facility that primarily treats the Invercote and Incada paperboard from Iggesund and Workington [3].

Currently, Holmen Iggesund Paperboard are experiencing process variation issues with one of their paperboard-machines and are not able to utilize it to full capacity. The reduced production capacity affects their profit negatively. A paperboard-machine is complex, large and has many components. Hence, it can be difficult to identify maintenance needs of a specific component in the machine. Therefore, Holmen Iggesund Paperboard is looking for a tool that can assist them in maintenance of their machines as well as perform as a quality control measure. This tool will be able to display the frequency of rotating machine components and compare them to peaks of the frequency analysis. The frequency analysis is performed on measurement data from the paperboard web. The measurements are performed by an IR-camera directed towards the paperboard web inside the machine. Comparing peaks in the calculated spectral density of the data with specific components can therefore aid in identifying the root-cause of the process variation and needs for necessary maintenance. Today, they use a complex MATLAB-script to perform similar actions. Since the process engineers do not have experience with MATLAB, this format excludes them from independently analysing the product variability. Hence, an easy-to-use application can be an appreciated addition to the quality control procedures the process engineers perform.

The purpose of this thesis is to create a computer application (app) that can display relevant information about the variation of the paperboard production process. The process of designing the app include creating a graphical user interface (GUI), data preparation and implementation. This app will assist Holmen Iggesund Paperboard in their machine maintenance and quality control process. It will also be a part of increasing the production speed since identifying components in need of maintenance affects efficiency due to preventing unexpected faults. Since malfunctioning components in the paperboard machine are the root-cause, the identification of deviations can also increase the total profit of Holmen Iggesund Paperboard. To create a functional application, there are some goals that need to be fulfilled

- The app must display information that will be useful to the process operators at the paperboard plant.
- The user must be able to analyse specific subsets of the measurement data in terms of statistic evaluations and frequency.
- Relevant process parameters in terms of roll frequencies should be included as comparison points during the frequency analysis of data.
- A user manual must be written to assist the process engineers with how to use the app.
- The app must have a user-friendly GUI.

1.1 Delimitations

We have chosen to primarily focus on testing and implementing the application at the Iggesund mill. Since the production workflow is similar in both Workington and Iggesunds mill, it was decided that mainly focusing on implementation in Iggesund was enough. However, the app and user manual are written in English so that it can be used at both mills. This thesis will therefore focus on Iggesunds mill even if the app is to be implemented at Workington as well.

2. Theory – Characterisation of process variations

2.1 Statistics

In statistics, the mean value is a commonly used measure. The mean value of sequence $x_1, x_2 \dots x_N$ is given by:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x(i)$$

where $x(i)$ is the *i:*th observation and *N* is the total number of observations in the sequence. Hence, the mean value can be explained as the sum of all measurement points divided with the total number of points. [4]

Standard deviation is a statistical measure used to quantify the variation of a population. A high standard deviation proves that the values are spread over a wider range whereas a low standard deviation indicates that the values are closer to the mean value, and the process is more stable. The standard deviation is calculated as follows:

$$\sigma = \sqrt{\frac{\sum(x(i) - \bar{x})^2}{N - 1}}$$

In statistical literature the standard deviation is often denoted with the Greek letter σ, $x(i)$ describes each value of the data, and $\bar{x}$ is the mean value. [4]

2.2 Frequency Analysis

In this thesis, frequency analyses in terms of Discrete Fourier Transform (DFT) are performed. This section explains the basics of frequency analysis and the necessary theory concerning the DFT. Measurement data is commonly displayed as a factor of time. This representation can often be beneficial when examining changes over time. However, at times it is more useful to convert the data so its frequency content is shown. Looking at data in the frequency domain can show how each frequency component is affected by the system [5]. The change from time domain to the frequency domain is commonly called transformation. In short, the data is parted into several sinusoids that represent the original signal. Using DFT is a way to perform such a transformation.

Assume there is a continuous time signal $x(t)$ which is sampled with the sampling interval T_s. This yields a time-discrete signal $x(kT_s)$ where k is an integer- For simplicity, $x(kT_s)$ is denoted $x(k)$ below. The aim of the frequency analysis in this thesis is to estimate a power-spectrum for the continuous time signal $x(t)$ based on the samples $x(k)$ where $k = 0, \dots, N-1$ (for simplicity we assume N to be even). This aim can be achieved by performing a DFT [6]:

$$X(k) = \sum_{n=0}^{N-1} x(n) \cdot e^{-\frac{i2\pi}{N}kn}, \qquad k = -\frac{N}{2}, \dots, 0, \dots, \frac{N}{2}$$

where $X(k)$ is a series of complex numbers representing sampled values of the continuous frequency spectrum of the original data $x(n)$ [7]. Since $\frac{2\pi}{N}k$ can be regarded as the frequency ω of a complex sinusoidal signal, the DFT can also be written as

$$X(\omega_k) = \sum_{n=0}^{N-1} x(n) \cdot e^{-i\omega_k}, \qquad k = -\frac{N}{2}, \dots, 0, \dots, \frac{N}{2}$$

where $\omega_k = \frac{2\pi}{N}k$.

A spectrum visualises the signal energy at given frequencies [5]. Based on $X(\omega_k)$, we estimated a power-spectrum to analyse the frequency composition of the signal. the double-sided spectrum is computed through [6] :

$$P_2(\omega_k) = \frac{1}{N}|X(\omega_k)|^2$$

where $P_2(\omega_k)$ is the double-sided spectrum. In our application, the frequency ω_k has been adjusted to represent frequencies of the original continuous time signal $x(t)$. When analysing real-world frequencies, it is common that only the positive half of the frequency spectrum is displayed. Consequently, the double-sided power spectrum, which displays half the energy in a positive frequency and the other half at a negative frequency, must be converted into a single-sided power spectrum ($\omega_k \geq 0$) . The conversion of a double-sided spectrum to a single-sided spectrum was done in two steps. Firstly, the negative half of the spectrum was eliminated and secondly the magnitude was multiplied by two [6] The single sided spectrum was then plotted against a frequency axis, which axis is affected by the sampling frequency of the data.

Additionally, it is important to take aliasing into consideration before working with DFT. Aliasing is a phenomenon where high frequencies of a sampled signal can be wrongfully interpreted as signals with lower frequencies. According to the Poisson summation formula, all frequencies higher than the Nyquist-frequency (half the sampling frequency) will be misinterpreted as lower frequencies [8]. In practice, aliasing is frequent when the sampling interval is too slow in comparison to the variations in the data [9]. To avoid aliasing, antialiasing filters could be used [10]. A common solution to the aliasing problem is applying an analogue lowpass filter to the continuous time signal x(t) which is designed to remove frequencies above the Nyquist frequency [11].

The basic concepts of DFT and frequency analysis have now been explained. However, there is one important aspect that must be addressed. The DFT is a very computationally expensive method, which means that it is very time consuming to apply on large data sets.

Hence, Fast Fourier Transform (FFT), was used to implement the DFT in this thesis. The FFT is an algorithm which significantly reduces the computational complexity of the DFT and therefore increases the speed of the frequency analysis [7]. Moving forward, we will denote the transformation DFT even though we use the FFT algorithm. In our project DFT has been used as means of analysing process variations since periodic deviations can be identified in the frequency plane.

In this thesis, calculating the rotating frequencies of the rolls in the paperboard machine was of relevance. The information provided about the rolls was their diameter and their speed-difference compared to the speed at the paperboard machines final production stages. The speed difference was calculated through:

$$v = v_m \cdot (1 + v_r)$$

where v is the speed of the roll, v_m is the speed of the paperboard machine and v_r is the speed deviation, commonly referred to as “draw”. The draw, which describes the elongation of the board web in the board machine can be up to 5%, which implies that the board moves approximately 5% slower in the beginning of the production process compared to the end of the production process. Therefore, the speed of each roll can differ compared to the overall machine speed. All speeds in this calculation are formulated in m/s. Since v_r is related to the speed at the end of the board machine, it has negative number. Hence, addition with 1 produces a factor <1 that is then multiplied with the total machine speed. Calculating the roll frequency was then done through:

$$R_{rf} = \frac{1}{2\pi r} v$$

where R_{rf} is the frequency in Hz, r is the radius of the roll in metres and v is the speed of the roll in m/s. The usage of rolls in the paperboard machine will be further explained in the following chapter.

3. Background

Producing paperboard is a complex process that involves several complicated sub-processes. Most consumers tend to disregard the effort that lies behind the paperboard packaging of products. In this section, the basics of paperboard production will be explained since it is essential to understand the functionality and purpose of the app. Furthermore, other aspects regarding presentation of data in the app will be explained, such as the statistical measurements used in paperboard quality control. Theory of GUI design will also be explained since the app is designed with the purpose of being efficient and user-friendly. However, the relevant mathematical background will be presented first. Since both statistical analysis and frequencies are relevant in this thesis, they are briefly explained below.

3.1 Introduction to Paperboard

Paperboard is a compact fibre-based material used for instance in packaging. Paperboard performs well for products that are to be printed since its' smooth surface yields precise lines and colour representation. The paperboard consists of mainly fibres and some

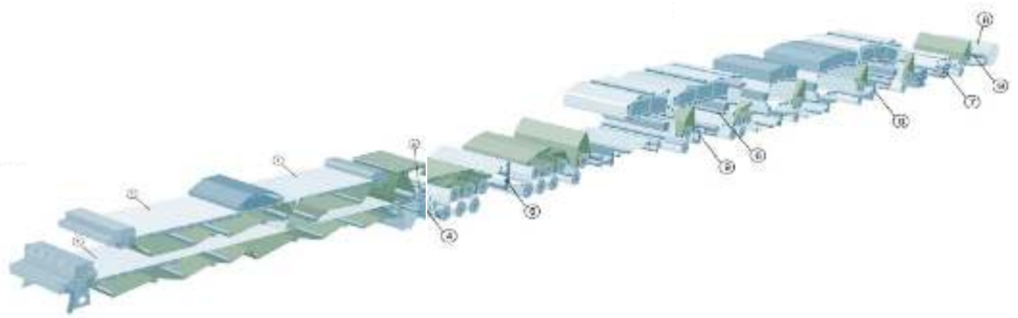

Figure 1. Illustration of one of the paperboard machines used in Iggesunds mill.

mineral fillers which are mixed with water into a wet mass called pulp. The pulp is a raw material and can be either chemical or mechanical depending on the method of production and the functional properties of the product [12]. The properties of the paperboard are heavily dependent on the customers' needs. Paperboard can be adapted regarding strength, durability, surface properties etc, depending on what the intended end use is. Nevertheless, using the right proportions of fibre, filler and water are of great importance during the quality management [12]. In this section, the production of paperboard is further explained, as well as quality measures and product variability.

3.1.1 Paperboard machine

The basic principle of making paperboard has not changed profoundly over time. A diluted suspension of fibers in water is formed to a sheet of an overlapping network of fiber. Then most of the water is removed progressively by drainage, pressure and drying [13]. This is still the main functionality of modern paper production, but the process now includes modern technology for paper to be produced on an industrial scale. The primary difference between paper and paperboard is the number of layers, or plies, of diluted pulp that is used. Paper consists of one ply while paperboard is created through adding several plies in an iterative process [14].

The process begins by harvesting timber in the forest. The logs are then shipped to the pulp mill where the bark is removed and repurposed for fuel or compost. Then the logs get chipped into smaller pieces and washed. To create the pulp, which will later become the paperboard, the chipped wood is treated to become either chemical or mechanical pulp. The pulp can then be bleached to achieve the desired degree of whiteness. Before the pulp can be used in the paperboard machine (pictured in Figure 1), it must be diluted with water. When the pulp solution is prepared, it can be used in the paperboard machine

[14]. Paperboard machines are large objects with many subsequent processes. Below follows a description of the production of paperboard in such a machine.

The first step in transforming the pulp solution to paperboard is distributing an even amount of it onto a plastic wire. This creates the first ply of the paperboard. It is important that the pulp solution contain mostly water to create an as uniformly distributed layer as possible. The solution contains approximately 99.7% water and 0.3% pulp. During the forming process, most of the water is drained. A second ply is the then produced on top of the first ply using the same dilution and dewatering process, and this process is then repeated until the desired number of plies has been achieved [14].

Then, the process advances to pressing the wet paperboard, or paperboard web, with the purpose of removing more water and to consolidate the fiber network. When the paperboard web reaches this step, the water content is about 80-85%. It is placed between two layers of press fabrics and is then run between sections of rolls. There are many rolls in the machine, and they serve diverse purposes during the different manufacturing steps. When the pressing is done, the water content of the paperboard web has decreased to 60-65% [14].

After the pressing, the paperboard web is forwarded to the drying section of the paperboard machine. The drying is conducted by running the paperboard web over heated rolls. The rolls are polished and heated through steam. This step ensures that the drying process is controlled, and that the paperboard web reaches a uniform moisture content and flatness [14].

The next step of the process is sizing, where a starch-solution is applied to the paperboard web. The solution can be applied on one, or both sides of the paperboard and the purpose is to bind the fibers of the pulp onto the surface. This enhances the paperboard uniform surface and increases its' density. Starch is also pressed into the core of the board where is increases the internal bonding strength. After the sizing, the paperboard is processed through calendaring. Here, the paperboard is run between smooth rolls to increase the smoothness of the surface. The rolls are made of metal and impacts the density and the thickness of the paperboard [14].

When the paperboard has been calendared, it proceeds to the surface coating process. Here, a liquid containing white mineral pigments is applied onto the surface of the paperboard. It can be applied on one or both sides of the paperboard. The amount of applied coating is controlled using a blade, where excess coating is scraped off. The coating is then dried through hot air and infrared dryers. The paperboard machine is designed so that the paperboard can be coated several times on one or both surfaces of the paperboard. This results in a smoother, whiter, and glossier paperboard [14].

It is now time for the final steps in the paperboard-making process. This can be performed using gloss calendaring or brush polishing. Gloss calendaring is when the paperboard is passed between a heated steel roll and a polymer roll. The polymer roll is soft and creates a smoother surface on the paperboard. If brush polishing is used, the paperboard passes through rotating brushes, which also helps smoothen the surfaces. These types of processes are essential to achieve a smooth and printable surface of the paperboard. The production-line ends with paperboard being rolled up on steel cylinders, called popes, and marked with an identification number. Then the paperboard can be shipped to the printing and coating facilities to be transformed into different kinds of paperboard products [14].

During the entire production process, the paperboard web is measured by different sensors to ensure its' quality. The measurements are performed while the paperboard is moving through the machine. The primary quality control indicators are thickness, grammage, water content, colour, gloss, and coating weight. The measurements are crucial to control the production process and ensure a uniform, high quality product [14].

3.1.2 Paperboard Quality and Variability

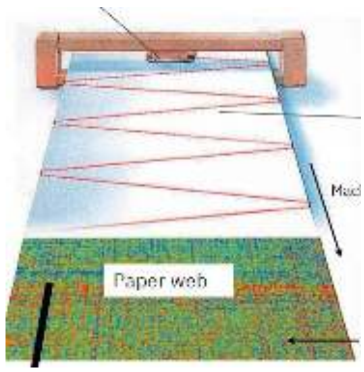

Figure 2. Measuring pattern of the sensor on a paperboard web.

Retaining a high level of quality in paperboard production is important to minimize production loss and unnecessary stops. Quality is also important to produce consistent products that fulfils customer expectations. Regarding paperboard, there are many ways to evaluate quality. This is, for instance, done through several point-like sensors placed in the paperboard machine with the purpose of measuring the paperboard in various stages of the production process. Many of the measuring devices share a problematic property, which is that they only can measure a single point at a time [9].

Many of the sensors today are mounted in a measurement frame. The measuring is performed by moving the sensor over the width of the moving paperboard web. This method creates a zig-zag pattern and less than 1% of the total paperboard area is measured [15]. This pattern is displayed in Figure 2.

Product variability is caused by the fluctuations in product properties due to process variation. The less variability a product has, the better the quality it has. A decreased level of variability also implies that there are less stops in production, a smaller need of reworking the products and a reduced risk of machine breakdowns. These are all factors that increase production cost. Hence a low degree of variability implies reduced cost during production [9].

There are two distinct ways of viewing variability. It can be seen as one-dimensional or multi-dimensional. One-dimensional variability can for instance be the difference of pressure in a waterpipe, which is a single changing variable. Multi-dimensional variability can be the variations of thickness or temperature on a sheet of paper. Hence it includes multiple changing variables. Multidimensional variability is more complex to measure compared to the one-dimensional case since the measurements must be conducted in several directions [9].

With the current traversing sensor, it is not possible to achieve a complete measurement of multi-dimensional variability. This is due to the movement of the sensor. When the sensor moves from one side of the paperboard web to the other, the paper is moving with a speed of around 450 m/min. These two movements result in the sensor only actively measuring a strip that is a centimetre wide. Due to the measurement not being continuous in either length or width directions, multi-dimensional variability measurements cannot be fully characterised by traversing point sensors [9].

Another important aspect of using traversing sensors to measure the variability of paperboard concerns the sampling and the sample sizes. We have already established that only a small fraction of the paperboard area is measured. This can result in inaccurate or misleading interpretations of the measurement results [9]. The sampling interval can affect the results if it is too low. A too high sampling interval creates redundant data and therefore occupy more resources than necessary. A too low sampling interval can yield misleading results due to several reasons [8]. One reason is that an extremely slow sampling interval can miss important changes. For example, the traversing sensor might not be able to measure the entire paperboard web fast enough to detect important inconsistencies.

3.2 Thermography

In this thesis, an IR-camera is used to perform measurements of the paperboard surface. This section explains the basics of the IR-measurement technology, or thermography. Objects consist of atoms which in turn has electrons that are constantly moving. The movement of electrons produces energy which radiates from the object. This explanation holds for every object with a temperature above absolute zero. Depending on the temperature of the object, different wavelengths of energy is emitted. The purpose of IR-measurement technology is to interpret the radiation from objects and convert it to measurements in terms of temperature [16].

The IR-camera used in this thesis can be seen in Figure 3. It is mounted inside one of the paperboard machines at Holmen Iggesund Paperboard and directed towards the moving paperboard web.

Figure 3 The location of the IR-camera (labelled Termisk Systemteknik) aimed at the paperboard web (the white area in the middle of the picture)

3.3 Creating a GUI

A well-designed Graphic User Interface (GUI) is important for the users of an app. Hence, it is of great importance to have this in mind during the development process. Many GUIs today are flawed when it comes to a user-friendly design. There is also a large difference between apps used in work settings compared to apps aimed at private usage. This is since attractiveness and ease are a marketing aspect in private consumption, while it is not considered as important in the workplace [17]. In this section, the background and importance of a well functional GUI are further explained. The primary focus will be GUIs designated for usage in a professional setting.

A user interface (UI) is the part of the computer that the user can interact with in some way. It can be the things we see, communicate with, hear or in other ways direct or understand. There are two primary components in a UI, namely input and output. The input is how we as humans communicate with the computer, and the output is how the computer communicates the result of the inputs to us. An example of an output is the computer screen. The difference between an UI and a GUI is that a GUI has a more graphic oriented interactive style. Interacting with a GUI is commonly performed through the usage of a pointer, or a cursor, that serves as a digital human hand. [18]

3.3.1 Cognition and Design

A user of the GUI interacts with the system through objects in the interface. These objects can be interacted with in various ways and are used to perform different tasks. The interactions with objects are commonly called actions, or operations. The actions serve to access the objects [18]. An example of this can be using a zoom button to enlarge an image in a photo editor.

Furthermore, a well-functioning GUI utilizes the human capability of information-processing to a greater extent than a UI without graphics. The graphic elements enhance the information processing speed since it makes the interaction between human and computer easier. The visual elements allow easier comparison between information such as datasets [18]. But even though a GUI eases interaction, it is important to define the users of the system and adapt the app to their specific needs. The needs may vary between different user-types and that must be taken into consideration when designing the GUI [19].

There are a few design aspects related to human cognition. A study was conducted regarding designing a GUI for forestry operators based on cognitive science research [20]. When designing their GUI prototype, they used various design aspects based on cognition. One primary design aspect is that of attention-invoking design elements. That is, important objects in the GUI should be more forthcoming than the less important. This can be done using size, colour, and placement of objects. Therefore, information considered less important can be smaller and less brightly coloured. Furthermore, studies have concluded that the placement of words and images in relation with visual fields play a role in the information processing. Words are comprehended faster when placed in the right field of vision. Images are quicker identified when placed in the left visual field. Another aspect of object placement is the culture of the user. People of the western world tend to look at a GUI in the same order as they read. Hence, they often begin looking at the top-left corner and then finish at the bottom right corner [20]. The GUI should be designed so that information is placed according to the user's visual search pattern [21].

Furthermore, humans tend to process information faster when it is clearly categorized. This eases the visual search pattern and clarifies the use of objects in the same category. Using effective labelling of objects and categories, the user can receive even more information about the functionality of objects. This will result in a faster and more pleasant experience of learning to use the system [21].

The order of reading can be affected by adjusting brightness and size of objects regardless of optimal cognitive placement theories. Colour is a big part of GUI-design and can be used to communicate tacit information to the user. For example, the colour red is associated with warnings or stop-actions while green tend to be associated with go-actions and safety [20].

Hence, it is important not to use these colours in a conflicting setting. For example, a bright green stop-button could confuse users and cause a slower interaction with the object. Efficient human-computer interaction is an aspect that should be taken into consideration when designing a GUI. Furthermore, it is important not to have too many distracting elements in the GUI. Humans have a limited capacity of processing visual information and elements like backgrounds should not distract the user from the important information. A too prominent background yields an unnecessary load on our visual system. Using a blue background is preferable since its low wavelength makes it difficult for the eye to focus on. This instead enhances the other, more important, objects in the GUI [21]. Figure 4 visualises the principles discussed above.

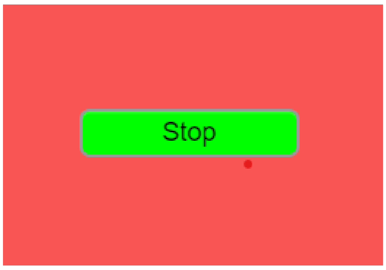

Figure 4 Example of a poor choice of colour for a button and its' background.

The choice of colours should be done carefully and using a too large variety of colours can tend to confuse the user and therefore serve as a distraction. Humans have a limited capability of retaining process information in memory. Usually, we can remember 5-9 different things during a short time frame. Colour is a factor that needs to be chosen with this in mind. A GUI with many different coloured objects can occupy unnecessary memory if not used properly [21].

Another important design aspect to consider is that of Transference. Users are heavily influenced by their experience and knowledge, which creates expectations about how a system should work. Since most users have previous knowledge of other systems, they have pre-defined expectations on how the new system should work regarding functionality. For example, they might have expectations on navigation, meaning of icons and functionality of buttons. If the new system does not fulfil the pre-defined expectations of the user, it creates a negative transference. But when the GUI behaves as the user expects, it creates a positive transference [21]. Therefore, performing user testing with a prototype of the GUI is beneficial to creating an app with a positive transference.

Transference is closely related to a user’s mental imagery. Mental imagery implies that a user has a pre-defined expectation of how objects should look [21]. For example, most of us have a pre-existing view of the icon for a save-action, namely a visual representation of a floppy-disc. If the floppy-disc icon would be replaced with a green checkmark, it would take a significantly longer time to understand how we could save our work in a system. Using familiar imagery in the system eases the user’s learning process. The mental imagery is heavily dependent on the background of the intended user and can differ between users of different culture, educational backgrounds, and tradition [21].

3.3.2 Adapting the GUI to its Users

Testing of a system plays an important role when forming a GUI to its end-users. To achieve a well-functioning app the system is evaluated several times during the developing phase. The testing is preferably done by different users during real-time scenarios. The main goal of testing the system on users is to identify issues or flaws within the system. Moreover, the testing is preferably done on a variety of users, such as expert users and regular users [22].

The main purpose of testing is to get an overview of the quality of the software. The experts play an important role when evaluating the validation of the software during the testing phase. If the software is malfunctioning it is more costly to fix it later in the process. In addition, continuous testing decreases potential misunderstanding between developers and end-users.

4. Method

The aim of this thesis is to create an application that visualises data needed to aid the process engineers in the mill of Iggesund. Therefore, this project spans over different areas such as data preparation, data visualisation, programming the application and creating a user-friendly GUI. The practical methodology regarding the application development process will be explained in Chapter 4. A brief overview of it can be seen in Figure 5. However, this chapter will primarily discuss the workflow and planning aspects of the project.

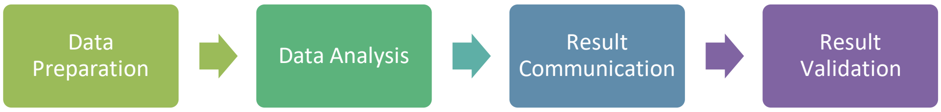

Figure 5 Workflow of creating the application for Holmen Iggesund

4.1 Planning the Project

To create a well-functioning application there are a wide range of aspects that need to be considered such as, designing the GUI, defining user requirements, planning the functionalities, programming, testing, etc. To keep track of the different elements, planning the work and defining sub-goals are crucial. At the start of the project, a rough weekly time-plan was defined. This plan created an outline for when certain milestones were to be finished, such as testing the application and writing parts of the thesis. As a complement to this plan, smaller goals were also defined to help advancement of the weekly work.

4.2 Working Agile

The application development has been performed through somewhat agile methods. In short, agile methods can be describes as working in sprints, periods of set time, to achieve small goals. In the case of IRMA, the sprints have commonly been weekly. The sprints begun with a client meeting where the weekly goals were set. The clients in this case were Hannes Vomhoff and Eugenio Ciucani, the thesis supervisors from Holmen Iggesund Paperboard. The meetings began with a demonstration of the application and the work of the previous sprint, and then followed discussion and the supervisors presented their requests for the upcoming week.

4.3 Application Requirements

A crucial step in creating a GUI for Holmen Iggesund Paperboard was to concretise the functionality of the application. The main objective of this process is to set clear goals for development and ensure that the app achieves the desired purpose. Defining the functionalities was primarily done in collaboration with the supervisors. The primary functionalities were set to be:

- **Importing Excel-file in CSV format**
  The measurement data achieved from the thermal camera is automatically stored in an excel file with comma separated values. Since the object of the application is to create a user friendly and simple analysis tool, it is important that it is easy to import the measurement data into the application.
- **Choosing specific datapoints for analysis**
  Since the purpose of the application is to analyse data to determine quality aspects of the paperboard, it is beneficial to be able to choose specific parts of the data to analyse. For example, if deviations are found in a specific CD-position (Cross Direction) of the paperboard web during a limited time interval, analysing only the affected area can be relevant. Furthermore, the thermal camera occasionally recalibrates itself during a measurement session. This yields inconsistencies in the dataset and could produce misleading results during analysis. Hence, it is important that the user can choose specific parts of the dataset and use it during the analysis to produce more reliable results.
- **Statistical analysis of data**
  Furthermore, the app calculates the temperature map, the CD mean along with the MD mean. The temperature map gives a picture from above of the imported data. Moreover, the standard deviation and mean value are being calculated in the CD – and MD plot.
- **DFT of data**
  Since we want to compare the variations in the measurement data to the performance of the rolls they must be represented in the same way. Since we know the frequencies of the rolls, we need to represent the data in the frequency plane as well. This is done through performing a DFT on the measurement data.
- **Combination of frequency analysis with process parameters**
  The inclusion of process parameters is including the rolls and their frequencies as comparison points in the DFT. This is one of the functions that are very valuable in practice since it compares the frequencies for deviations in measurement data to frequencies of specific rolls. This indicates where the deviations originate and can assist the process engineers with finding the sources of variability in the paperboard.

The creation and implementation of these functionalities will be discussed in the following chapter.

4.4 Matlab App Designer

MATLAB App Designer is the environment in which IRMA was created. It is a part of the software MATLAB created by MathWorks. The MATLAB App Designer allows its users to create computer applications by relatively simple means. The software is constructed of two main parts, the design, and the programming. Designing the GUI is done by choosing pre-defined visual components and placing them in the workspace. Then, these components can be programmed to perform the desired actions. When the app is completed, the MATLAB compiler can be used to compile the app into an .exe-file which can be installed on computers independently of the MATLAB software [23].

4.5 Application Development Process

The application is designed to fulfil the previously discussed functionalities. This section aims at further elaborating on the process of implementing these functionalities as well as explaining how they work. However, before any of these functionalities could be implemented, the data had to be prepared and studied. The preparation of data, analysis and communication of results will be further elaborated below.

4.5.1 Data and Preparation

The available data was measured by an IR-camera placed above the moving paperboard web before the section *machine calender* in the paperboard machine. The model of the current IR-camera is FLIR A655sc and it can detect temperature variations <30mK. The FLIR A655sc has a maximum sampling frequency of 200Hz [24]. At Holmen Iggesund Paperboard, the camera measures a horizontal line creating a number of measurement points (in this thesis, referred to as pixels). The camera measures according to a set sampling frequency. At Holmen Iggesund Paperboard, the commonly used sampling frequency is 200Hz. Hence, the IR-camera measures 200 samples per second. The measurements are stored in a *.csv*-file and each sample are represented by a row.

One sample of data contains three different timestamps. The first timestamp is date and time. The second timestamp is built-in computer time, and the third timestamp consists of built-in camera time. When studying the imported data, the different time-measurements is problematic. It became clear that the different time-measurements were inconsistent and therefore would be problematic when used in practice. Therefore, we chose to only utilize the date and time measurement when sorting and visualizing the measurement data. The built-in timestamps from the computer and the thermal camera are disregarded. Hence, removing the problem with inconsistent automatic time measurements. Since very detailed timestamps are irrelevant in analysing process variability, this is regarded as a functional solution.

Another step in preparing the measurement data was to transform the datapoints from milli-Kelvin to Celsius. This was done by using the following formula:

$$C = \left(\frac{mK}{1000}\right) - 273.15$$

where C is the datapoint in Celsius and mK is the original datapoint in millikelvin.

Another aspect regarding the preparation of data is making a plausibility check. This has been done both before and after the previously mentioned data transformations by plotting the data and studying its behaviour. This manual plausibility check aims to evaluate the data and find deviations such as outliers and extreme values. During this process, the edges of the data was found to have significant deviations. This can be seen in Figure 6.

The graph in Figure 6 also depicts the data after conversion from millikelvin to Celsius. The edges of the plot are found to be significantly cooler than the rest of the data. This is due to the IR-camera being set to record data slightly wider than the actual paperboard web. Hence, the cooler temperatures are due to it being no paperboard present at the measurement points. Variations like these might offset statistical analysis and the FFT. Therefore, a functionality to filter these edges was implemented in the application. This functionality removes a user defined number of pixels from each side of the dataset and therefore excludes measurements outside the paperboard web.

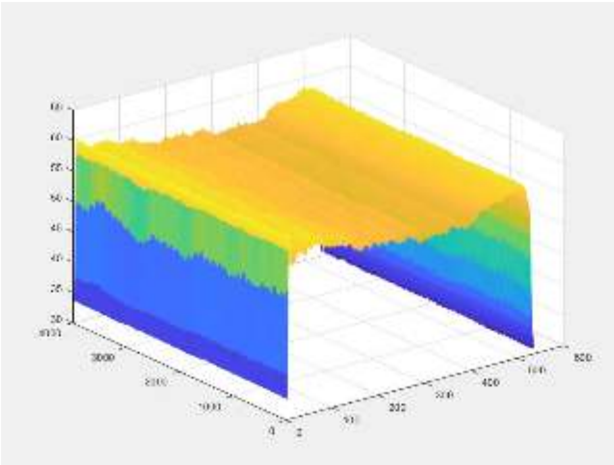

Figure 6 Plot of untreated measurement data

4.5.2 Data Analysis

After the data has been properly prepared, it can be used as the base for analysis. One crucial functionality in IRMA is the option to choose only a subset of the data in terms of the time-window and paperboard web-width. This is enabled through the option to view the data between set intervals for both time and paperboard web width. The specified subset of data can then be processed through analysis. If no specific subset is chosen by the user, the analysis will be performed on the entire imported dataset.

The application is designed to analyse the data in terms of statistic measurements and to perform a frequency analysis through DFT. MATLAB App Designer provides built-in functions regarding both statistics and DFT. The statistic measurements used in the applications are mean and standard deviation. The mean is calculated in both MD and CD to achieve multiple perspectives on the possible variations in measurement data.

Furthermore, the MD and CD mean graphs contain visualisations of the standard deviation to provide information about the spread of the measurement data.

4.5.3 Result Communication

When designing an application, it is important to communicate information clearly and efficiently to the user. For example, it can be easier to interpret changes in a graph compared to a large table of data. The placement of elements also contributes to the user's ability to comprehend the presented information. Therefore, deciding how to present information to a user is a large part of an efficient design. In the case of IRMA, the results of analysis are always represented using graphs. This yields a fast visual comprehension of the information as well as making it simple to present to other operators at the mills.

4.5.4 Result Validation

Since the app is supposed to help Holmen Iggesund Paperboard with their quality control measurements, it is important that the analysis is performed correctly. As previously mentioned, MATLAB has built in functionalities for analysis of mean, standard deviation and FFT. Calculating the mean and standard deviation does not acquire any particular preparation of data, hence there are less need of validating the results. When performing an FFT, the treatment of data has a larger role and therefore validating the results is important.

The FFT method had to be validated through testing it with sinusoids of known frequencies. Hence, function consisting of a few different sinusoids were generated and treated according to the methodology above. The magnitude and frequency of the sinusoids in the frequency plane was then compared to the expected results. For example, a sinusoid with amplitude 10 and period of 10Hz, would in the frequency plane, show a peak of amplitude 10 at 10 Hz. This methodology was also tested using sinusoids with added noise since it would be a more correct representation of the real dataset. After the tests were performed, it was decided that the methodology was accurate enough to be used in the app.

4.5.5 User Testing

Feedback from users is highly beneficial when designing an application. The user testing of IRMA has primarily been performed on our supervisors. They have been supplied with the installation file of the application and therefore able to test the application freely. These tests have, towards the final stages of the thesis, been performed on a weekly basis and the application have been continuously improved based on the received feedback. The feedback has provided useful results regarding the GUI-design as well as features of certain functionalities. For example, the ability to adjust the colour spectrum of the FFT-visualisation were created upon request after user testing. Furthermore, the clear adaption of the GUI to the workflow-of process engineers have been improved by the user tests.

However, one purpose of creating a GUI was to include more process engineers in the process of analysing product variability. Hence, feedback from process engineers was an important aspect to include. IRMA have been presented to several process engineers during the development process. Yet, there have been a limited amount of feedback received from them during the demonstrations. Due to the process engineers mainly being given demonstrations of IRMA, they might not have so much feedback to provide. If they were to use the software on their own, more feedback could have been achieved. IRMA will continue to be developed by Holmen Iggesund Paperboard in the future. Hence, when the process engineers have begun using IRMA in their daily routine, their feedback can be included in a later stage of development. Therefore, the main user testing has been performed through the supervisors. The feedback from supervisors has been deemed enough for the scope of the project.

4.5.6 User Manual

To ensure that the process engineers can use IRMA comfortably, a user manual was written (Appendix A). The manual contains an overview of all input fields and brief explanations of their purposes. The overview contains images of each page of the app, numerations of each element and a numerated list briefly explaining each elements functionality. The manual also include a more detailed explanation of each tab of IRMA, similar to the sections 4.1.1-4.1.4 of this thesis. However, the manual is more focused on the practical use of IRMA. Additionally, instructions for installing the app are included. The user manual will be given to all users of IRMA.

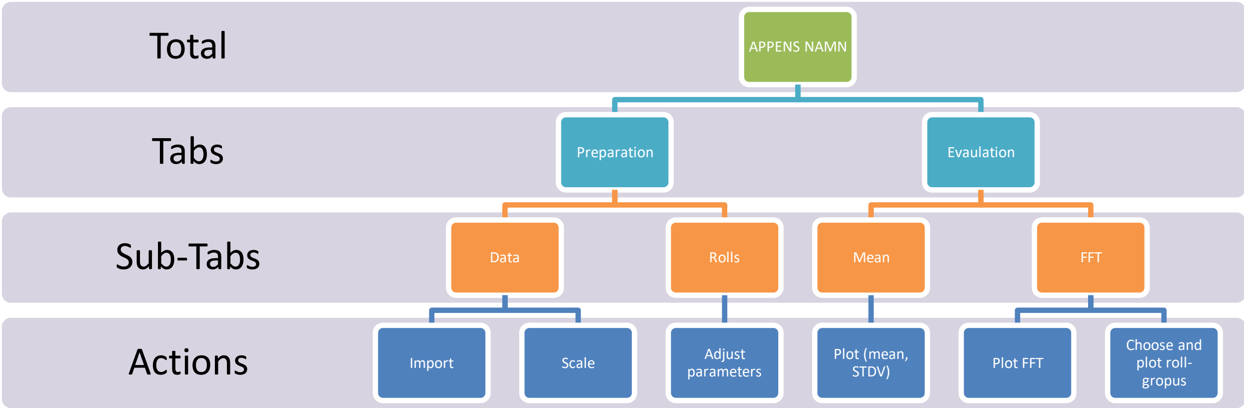

Figure 7 Overview of the applications architecture

5. Results

This chapter presents the application, its functionalities and the decisions made regarding design and placement of elements. First, an overview of the application architecture will be presented together with the final functionalities of the app. Then, the design will be explained. Lastly, an example of the usage of the application will be presented. The example will show how the app can be used at Holmen Iggesund Paperboard.

5.1 Application Architecture

IRMA is divided into tabs aimed at performing certain tasks. The division aims at simplifying the interaction between the user and the GUI. This section will explain how the app is structured and elaborate on the different functionalities it contains. IRMA is divided into two main tabs, *Preparation* and *Evaluation.* The Preparation tab serves to let the user prepare the dataset before performing any kind of analysis. The tab contains two sub-tabs, namely *Data* and *Rolls.* The other tab, Evaluation, also contains two sub-tabs: *Mean* and *FFT.* This section of the app lets the user analyse the previously chosen subset of data. Figure 7 depicts a visual overview of the application architecture described above.

5.1.1 Preparation - Data

The data-tab is where the user chooses a subset of the measurement data. The workflow begins with the user choosing a CSV-file to import. The data from the file is displayed in a 3D-graph with the filename as a headline. The user can then choose a specific time-interval as well as specify intervals regarding paperboard web width. However, the data is initially displayed with the width as number of rows in the CSV-file. Hence, the user must manually enter the paperboard web width (in centimetres). This action must be performed manually by the process engineers since the width differs between different paperboard machines. As previously mentioned, the IR-camera measures temperature outside the paperboard web. This results in the edges of data (outside the web) being colder than the actual web. The cold edges will disturb the accuracy of the analyses and therefore must be removed. To accommodate this, the user can filter out a number of pixels from the edges of the dataset and thereby remove the data that negatively affects the analyses. After defining a potential subset of measurement data, the user can press an update-button to update the graph and display the revisions that has been performed. The dataset specified in this tab, is the set that will be analysed in other parts of the app.

5.1.2 Preparation – Rolls

The rolls in the paperboard machine are crucial elements of the paperboard production. A machine contains a very large number of rolls of different sizes and purposes. The rolls are categorized into groups depending on where in the machine they are placed. In the tab named Rolls, the user can import an excel file containing relevant rolls for the paperboard machine in question. This file is then displayed as a table in the app. The file contains the name of each roll, its group, its diameter, and the difference in speed compared to the paperboard machine. Since the speed difference is not always constant over time, it is important that the process engineers can change it in the app. Therefore, after importing the file, the user can change the values of all fields in the table. However, the changes are not saved onto the original excel file, and permanent changes therefore must be made outside the app. This is done to preserve the integrity of the original excel-file and avoid unintentional permanent changes to it.

5.1.3 Evaluation – Mean

Identifying deviations in the mean for both MD and CD can be valuable regarding paperboard quality control measures. The first subtab in evaluation serves to create an overview of the data through a 2D-graph of the untreated data and two additional graphs displaying MD- and CD-mean maps. These maps also contain the mean ± the standard deviation. This tab does not offer any other functionalities than the option to plot the data onto these graphs. Hence, the data that is displayed is chosen in the preparation-part of the application.

5.1.4 Evaluation – FFT

This subtab focuses on performing a DFT on the measurement data and comparing the results to the process parameters in terms of roll frequencies. This functionality plays a large role in identifying errors in production since deviations detected through DFT can be connected to specific rolls. The page contains two graphs, a 3D-plot of the raw DFT analysis and a 2D-plot displaying the MD DFT mean. Users can perform a DFT on the measurement data and specify the frequency interval (in Hz) of interest. The graph is accompanied by a colourbar to enhance differences in the magnitude of the graph. Intervals of colours in the bar can be adjusted by the user. Furthermore, the page contains an input field for inputting the paperboard machine-speed and checkboxes where the user can choose which roll-groups to display. Inputting the correct machine-speed is important since the speed is used to calculate the roll frequency. The roll frequencies are displayed in the 2D-plot together with the MD DFT mean.

The tabs described above differ a lot in functionality and purpose. However, all tabs containing graphs can be saved as .jpg files by pressing the "export figures" button on each page. This function is of relevance if the user wants to present the results in an external presenting tool such as Powerpoint. It also eases the comparison between different analyses since the app only can analyse one dataset at a time.

5.2 GUI Design

Designing the GUI of the app has been a large part of the development process. The GUI is important for the user since a good design can ease the use of the app. In this section, placement of elements, colour choices and other design aspects will be further explained.

5.2.1 Placement of elements

The process engineers at Holmen Iggesund Paperboard will follow a clearly defined workflow when working with IRMA. Firstly, they will import the data and prepare it for analysis. They will then import the list of rolls of the paperboard machine. The user will navigate from the preparation tab to the evaluation tab and therefrom, the analyses can begin. The analyses can be performed independently. However, both the mean and DFT are of relevance regarding quality control measures. Figure 8 presents the basis for the common workflow.

Figure 8 An overview of a user's workflow

IRMA is designed according to the workflow described above. Since the user must begin with importing and preparing the data for analysis, the preparation-tab is set to be the main page of the app. Hence, when the user opens the app, they are first directed to the preparation tab. Even though the general workflow is established, each tab has its own flow of actions that initially must be performed in a certain order. The elements of each tab are therefore placed in a manner that coheres with the workflow of each individual tab and subtab. For example, the button for importing measurement data in the preparation-data-tab is placed at the top-left side of the app. This placement is mainly a result of the human cognitive abilities. As previously mentioned, users of western origin tend to see elements in the top left corner first and then view the page similarly to the pattern of reading a book. Below the import-button, the user can input their choices of preparation and below the elements designated to input, the update- and export figure-buttons are placed, since they are normally the last elements the user interacts with according to the workflow. This reasoning is the same for all tabs in the application since consistency also is an important aspect. Since the app is divided into tabs, it enhances the efficiency of user interaction when the tabs are structured similarly.

5.2.2 Colour Scheme

The colour scheme of the app has been chosen with the intent of being discrete and effective. The overall theme of IRMA is blue, since it is easy on the eye and does not catch the focus of the user unnecessarily. Blue is also a colour that is represented in the logo of Holmen Iggesund Paperboard, which makes it very appropriate to use in the app. Furthermore, colour has been used to separate the header from the body of the application and to create a coherent feeling between the tabs of the application. The separation was primarily done through using different hues of blue. In Figure 10, the colour scheme of the app can be seen. Furthermore, colour has been used as error prevention measures which will be further discussed in section 5.3, below.

5.3 Error Handling and Mitigation

When designing a GUI, it is important to guide the user towards correct usage. That is, design the application and GUI so it aids the user in performing the correct actions in the correct order. In the case of IRMA, we wanted the user to begin with importing a *.csv*-file before starting the analysis process. To achieve this user behaviour, the app is designed with the import-button in the top-left section of the application. As previously mentioned, when discussing design aspects (section 2.2 Designing a GUI), the user tends to see elements in the top left corner first. The button is also brightly coloured before a file has been imported which is supposed to attract the user's attention and further enhance the behaviour of beginning the process with importing the file.

Even though steps are taken to motivate the user to a specific behaviour, it is important to design the app in a manner that it can handle faulty usage patterns. This is primarily done through interactive elements and the use of error messages. The main goal when implementing error handling in the app, is to avoid an app failure because of accidental misuse. Matlab Appdesigner has built in error handling functions in the form of *Try and Catch-Statements.* Most functionalities in IRMA are surrounded with such statements. For example, if the user were to choose a negative time-interval of measurement length (i.e. a time from 5 seconds to 0 seconds), the app displays a popup window containing a message explaining the error.

Error handling is important for applications, but it is even more important to mitigate faulty use before an error occurs. Hence, the IRMA is designed to have interactive input fields that indicates faulty values before execution of the program. So again, if the user were to input a negative time-window, the time-input fields would become coloured red to indicate the potential error before it occurs. Additionally, some values are pre-set into the input fields to further avoid faulty input values. For example, when importing new data, the time interval input fields display the interval from zero to the end of the measurement in seconds. This will ease the workload of the users and simultaneously avoid faulty input.

5.4 Example of Practical Use

IRMA were implemented and thoroughly tested during two days towards the final stages of the project. These tests provided much necessary feedback and caused further developments of the application. After the app had been updated accordingly, it was deemed to be finished. Below will results of practical tests be presented and explained to further clarify the functionalities of the app. The measurement was performed at paperboard machine 1 (KM1) at Iggesunds mill during the 4:th of May 2022 at 12.47 pm.

Firstly, the raw data was imported to IRMA. The app displays the measurement data accompanied by a colourbar. The visualisation of the raw data can be seen in Figure 9. No other settings were chosen for this dataset, hence the full time interval and web-width were used in the analyses. The cold edges outside the paperboard web became apparent and had to be removed to ensure the accuracy of further analyses. Therefore, 16 pixels were removed from the tender side (TS) and 15 pixels were removed from drive side (DS). The removal of pixels was manually performed by the use of the Edge removal input fields. The GUI of the app after removing pixels can be seen in Figure 10. The data now had a prominent slope, and this is not desirable during production. This indicated a noticeable variability between TS and DS. IRMA also indicates the length of the measurement, the total number of pixels and the sampling frequency. In this particular case, the duration of measurement were 60 seconds, the sampling frequency was 200 Hz and it consisted of 631 pixels.

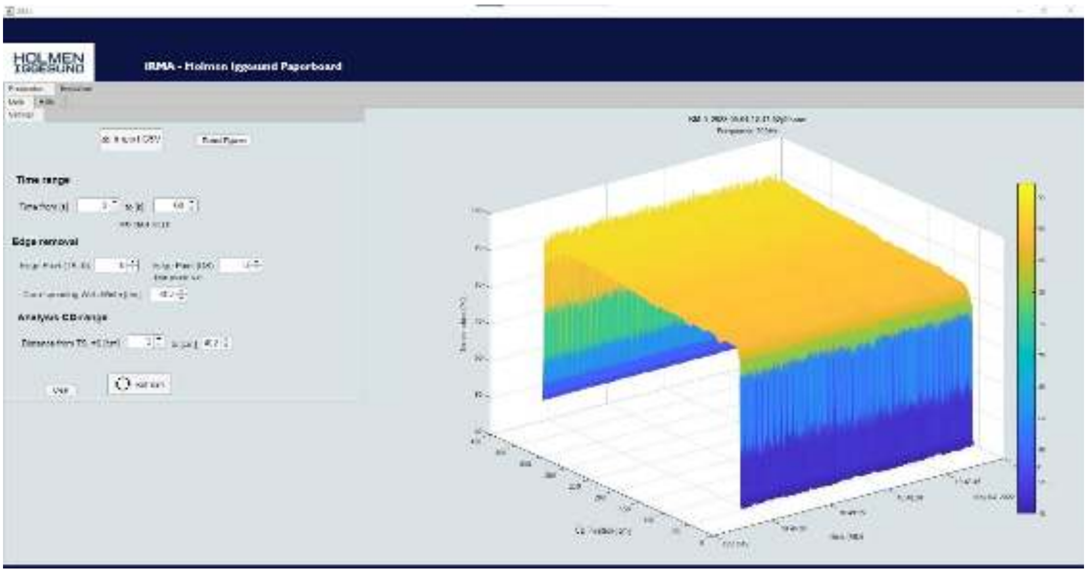

Figure 9 The display of untreated data in IRMA

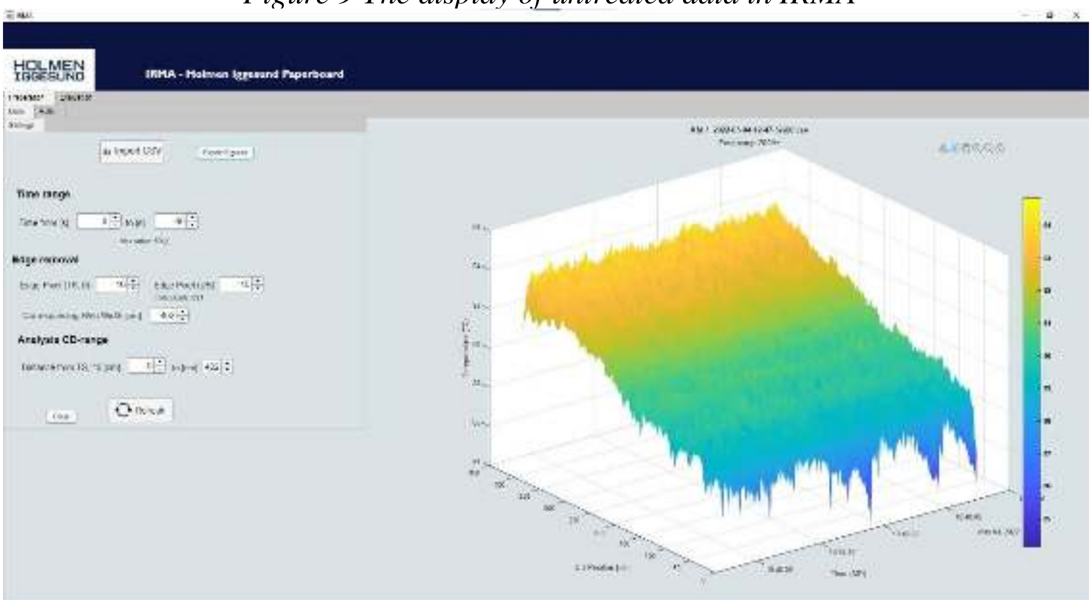

Figure 10 The data after edge removal

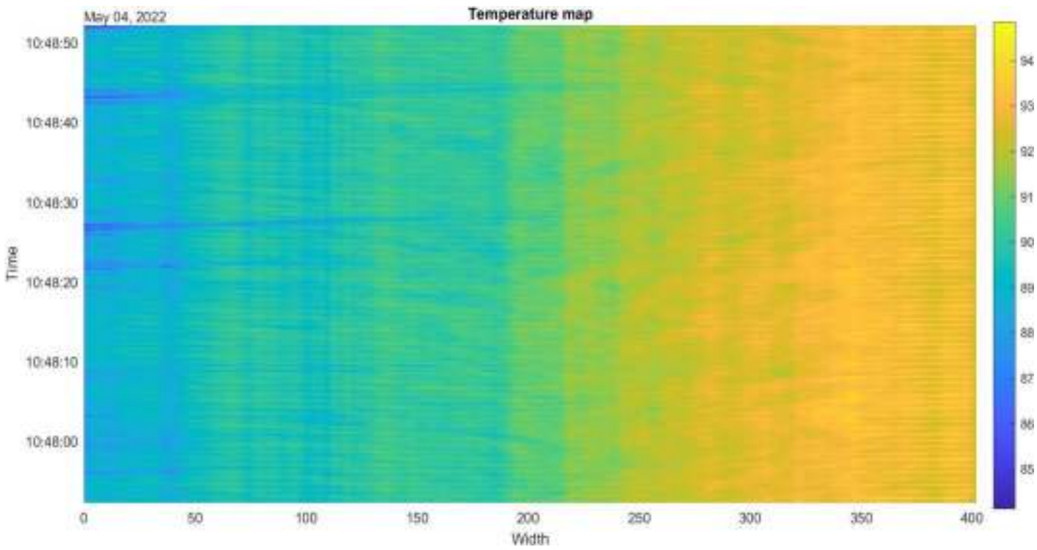

Figure 11 The temperature map of the data

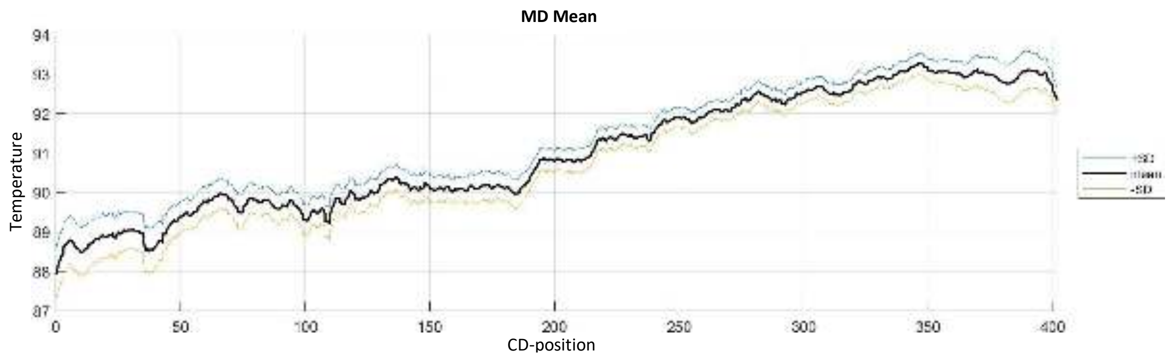

Figure 12 The graph of MD-mean as a function of CD-position, depicting the slope.

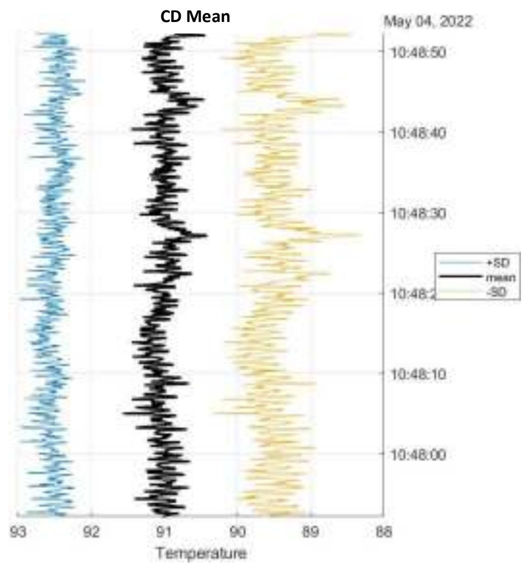

Figure 13 The graph displaying the CD-mean as a function of time.

When the preparation of data was complete, a *.csv*-file containing the specifications for the rolls of KM1 was imported in the rolls-tab of IRMA. The roll specifications were used during the FFT-analysis. Then, the first analysis was made through navigating to the Evaluation-tab and pressing the plot-button in the Mean-sub-tab. Figure 11 depicts the 2D visualisation of the treated measurement data. The colour-shift further indicates the uneven temperature distribution. Furthermore, the MD- and CD-mean is displayed in Figure 12 and Figure 13 respectively. The CD-mean shows a relatively stable mean value while the MD-mean further indicates the temperature variations. The standard deviation accompanied the mean-value in both graphs.

Lastly, the frequency analysis were performed on the prepared measurement data. Some settings were applied previously to visualising the data. The frequency interval was set to 1-25 Hz since the majority of relevant peaks commonly is found at <10 Hz. The lower interval at 1 Hz is primarily due to practical purposes since there are many peaks with high amplitudes between 0-1 Hz and this will become very yellow when applying the colourbar-settings. The colourbar were set to display the colour-range in the magnitude interval 0-0.02. In Figure 14, both settings and visualisations of the FFT is displayed.

The machine speed during this sample was approximately 357 m/min and hence this speed was entered into IRMA. In the 2D visualisation of the FFT, a large peak at 1.26 Hz was detected. This was found to match the roll-group *Glättork* as can be seen in Figure 15. Then, the overtones of this specific peak were examined through IRMAS overtone-functionality. The Frequency 1.26 Hz was chosen and five overtones were displayed. As seen in the figure, there are peaks corresponding with each overtone which indicate that they are created by the *Glättork.* The frequency peak indicates that a specific roll contributes to the paperboard variability. There is a possibility that the roll is in need of maintenance or that the roll has other problems causing these variations.

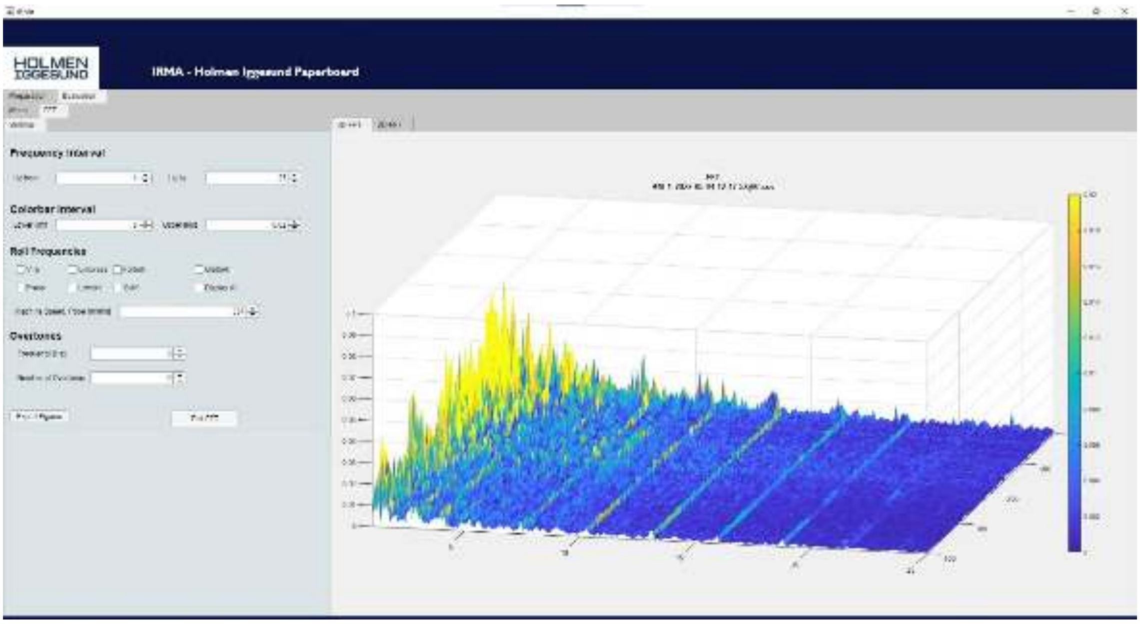

Figure 14 IRMAs page for FFT analysis displaying the DFT of the measurement data and the relevant settings.

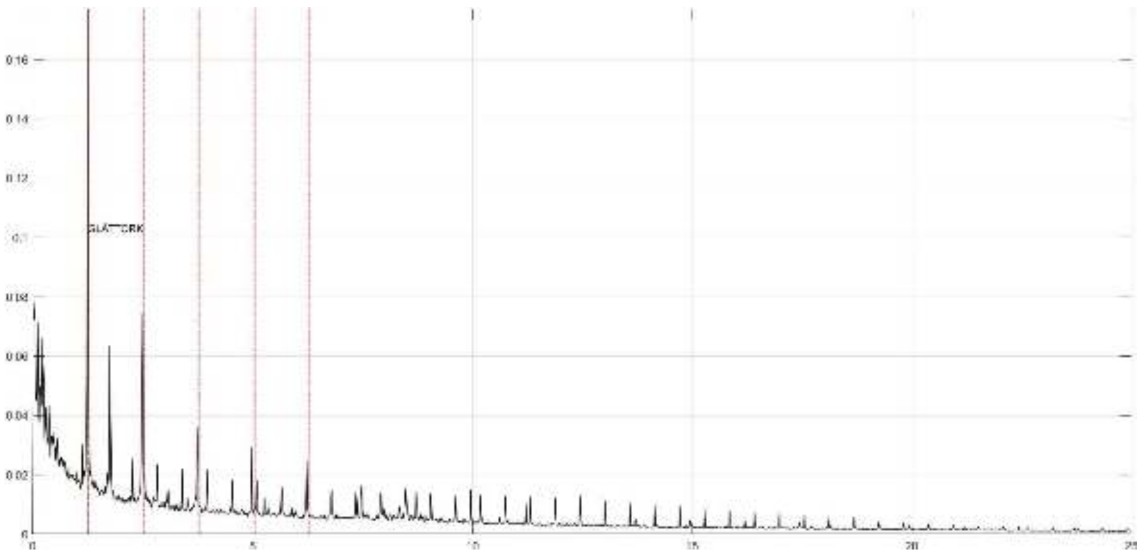

Figure 15 The 2D-FFT graph together with the Glättork and its corresponding overtones.

6. Discussion

The aim of IRMA is to provide Holmen Iggesund Paperboard with a tool for IR measurement analysis and thus quantifying and identifying the contribution of different process to the temperature variations in paperboard production. Since they currently must reduce their production speed due to issues with the rolls in one of the paperboard machines, identifying the problematic rolls is important. Consequently, the production loss for Holmen Iggesund Paperboard is minimized if the fluctuations and damages are discovered in time. Furthermore, less product variability results in higher quality paperboard and therefore a larger degree of customer satisfaction.

During the development phase we realized that the MATLAB App Designer had some limitations compared to other programming tools. In particular, the design opportunities are quite limited within the MATLAB App Designer. For example, the input fields of the app can only be adjusted in terms of size and colour. It is not possible to change the layout of the input fields regarding for example shape. Therefore, creative freedom is limited regarding the elements in the app. There are also limited design opportunities regarding visualizations and interactivity. However, MATLAB App Designer provides the user with efficient built-in functions which are useful when analysing and visualising raw data. Additionally, the MATLAB App Designer enables the user to compile the developed app into an *.exe*-file which can easily be installed on other computers. The compiled version of the app does not require MATLAB. The compiling function has been essential when using the developed app on other computers which are not provided with MATLAB.

The first version of IRMA was a basic draft-app aimed at importing and visualising raw data. This draft has since been expanded and developed including the necessary functionalities for quality control regarding IR-measurements of paperboard. The final app makes it a lot easier for process engineers in Iggesund since it provides them with appropriate technical information. Moreover, process engineers can analyse specific subsets of the measurement data since IRMA makes it possible to scale the measured data. This is a procedure that has previously been performed manually in MATLAB before each analysis. Generally, the process engineers do not have experience with MATLAB which limits the analyses to be performed by few people in Iggesund. Through the implementation of the app, the scaling and analysis of data have been made more accessible and can now technically be performed by every process engineer at the mill.

Even though IRMA have been tested by the supervisors and demonstrated to several process engineers, the user testing could have been performed more thoroughly. The workflow that has become the basis of the app, could have been studied more closely before developing began. This would have increased the insight into the work of process engineers and could therefore have led to an even more effective GUI-design. However, the usage of IRMA will be a new addition to the work of process engineers. Hence, they have not yet set a workflow for performing the analyses presented in the app. This implies that the workflow specified in IRMA will be learned by the users over time. In conclusion, the development of IRMA has been accomplished in accordance with the proposed workflow. Additionally, the supervisors and process engineers was satisfied with the final product. We are happy to see that the app met the needs of the staff at Holmen Iggesund Paperboard and eases the quality control processes through implementation at the mill. However, IRMA is a newly developed software and therefore has a lot of potential regarding further improvements and expansion. These opportunities will be further discussed below.

6.1 Future Development Opportunitites

IRMA is a tool that has a lot of potential for further development and expansion. The app can be developed to provide the user with a wide range of additional functionalities. However, expanding IRMA is out of range for this thesis and will be left to Holmen Iggesund Paperboard if they see the need for further development. In this section, the possible future extensions of the app will be discussed in terms of functionality, efficiency, and complexity.

A further development of this app in terms of flexibility will provide the user with a range of other specific purposes, e.g., an app which automatically imports measurement data at set times. Such a functionality would not only be more time efficient, but it would also increase the scope of data that can be analysed. However, the analyses are currently performed on data that have been manually prepared. If IRMA were to be automatised to this extent, Holmen Iggesund Paperboard would have to investigate if the settings for data preparation could be applied consistently for several measurement sessions. Furthermore, the IR-camera will occasionally recalibrate and therefore disturb the accuracy of measurements at those times. Hence, analyses performed on data recorded during a calibration, would create inaccurate results. One way of mitigating the calibration issue is to invest in a different camera or perform manual calibrations. Another expansion of IRMA would be identification and removal of data that has been affected by recalibration during a sample. This would remove the risk of inaccuracy due to automatic calibration during measurements.

Another possible development of IRMA is the inclusion of process parameters in terms of rolls. Today, the options for displaying roll-groups in the FFT-tab are pre-set and cannot be changed by the user. One functionality that would be beneficial is if the relevant roll-groups would be included based on the file of rolls imported by the user in the preparation-tab. This would increase the scope of analyses in relation to process parameters. Since the IR-camera is currently placed in the middle of the paperboard machine, there are roll-groups that are excluded from the app since they are located after the camera. If the IR-camera were to be moved in the future, including more roll-groups would be relevant. Hence, automatically loading all roll-groups from the file imported during preparation, would increase the flexibility and overall quality of IRMA.

Since IRMA is a newly developed software and has not been used much in practice, other functionalities might be included in the future. Since paperboard-making is a very complex process, there are a lot of quality control measures that can be further included. However, the need for further analyses will be decided by Holmen Iggesund Paperboard since implementation of future analyses are out of the scope of this thesis. Also, since this project have given us insight into a very limited section of paperboard production, it would be irrelevant for us to speculate in possible analyses of advanced procedures that we lack deeper knowledge of.

One large development for IRMA would be to implement real-time analyses of data during production. The current version of the app is offline and not connected directly to the IR-camera. If such a connection were to be made, IRMA could possibly analyse the measurements in real-time. However, this would be much more computationally expensive compared to the current operations, and would require a further efficiency-optimizations of the app. The aspect of efficiency during development has seldom been considered since IRMA can perform its analyses in a timely manner at the current state. But efficiency would be a very important aspect if any kind of real-time analysis were to be implemented.

If IRMA were to be expanded to include more functionalities, efficiency would also be affected. At the current state, there are no extremely complex analyses implemented. For example, the DFT is made more efficient through the implementation of the FFT-algorithm. Hence, reducing the computational load of the analysis. However, efficient algorithms might not always be an option for all analyses. Therefore, optimising the efficiency of IRMA will be important if it were to include more complex functionalities.

As previously mentioned, MATLAB App Designer has limited opportunities regarding GUI-design. Focusing more on a professional and elaborated GUI could therefore be beneficial in the future. At IRMAs current state, the design is highly limited to the basic functionalities of MATLAB App Designer. If more focus were to be concentrated to the design, the GUI could be further improved and thereby increase the visual quality of the app. The first version of IRMA paves the way for further expansion and improvements. The direction of IRMAs future will be decided by Holmen Iggesund Paperboard who will continue to improve the app.

7. Conclusions

This thesis has described the development of an app named IRMA which has been implemented at Holmen Iggesund Paperboard. Currently, IRMA supports the scaling of IR-measurement data regarding time, edge pixels and CD-position intervals as well as analyses in terms of simple statistics and frequency. IRMA also display information about the sampling frequency, total amount of measurement points, and the total duration of the sample in seconds. Besides these functionalities, IRMA supports comparing frequency peaks with roll frequencies and overtones. Peaks in the DFT that correspond to a certain roll indicate that the roll is responsible for process variations. The identification of problematic rolls in the process might indicate flaws or maintenance needs. Due to the complexity and scale of the paperboard machine, identifying rolls causing the variations, without the aid of IRMA can be very difficult. Furthermore, a lower degree of process variability correlates with higher quality, reducing the variations will be highly beneficial for Holmen Iggesund Paperboard. Additionally, a user manual has been written that will accompany IRMA when it is implemented at the mill in a larger scale. However, we will first educate the process engineers in the use of IRMA. This education will be held after this thesis has been finished.

Regarding the GUI design, it has focused primarily on simplicity and functionality. MATLAB App Designer offers limited freedom regarding creativity of elements in the app and the main options available in terms of design are placement, colour, and size of elements. Even though there are limitations to the design, the active design decisions that have been made have been thought through and continuously evaluated through user testing. However, design have been used not only in terms of design but also as a measure of error mitigation, for example through input-fields changing colour with faulty inputs. Other error mitigation methods have been pre-defining some input field values and placing elements according to the defined workflow as well as considering user behaviour.

Both design and functionality has been developed through close contact with the thesis supervisors. However, IRMA has also been demonstrated to process engineers during development. IRMA has been demonstrated and evaluated together with a few process engineers. Currently, IRMA is implemented at a few computers at Holmen Iggesund Paperboard. As previously mentioned, the future users will be educated in the software and therefore it is believed that IRMA will be implemented on many more computers at the mill in the near future. However, IRMA is a new software and have many development opportunities in the future. The responsibilities for future development of both functionalities and GUI will be in the hands of Holmen Iggesund Paperboard. Because, with IRMA, the possibilities are endless.

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Appendix A

(Manual on next page)

IR-Measurement Analysis

User Manual

HOLMEN IGGESUND

Table of Contents

1. Introduction

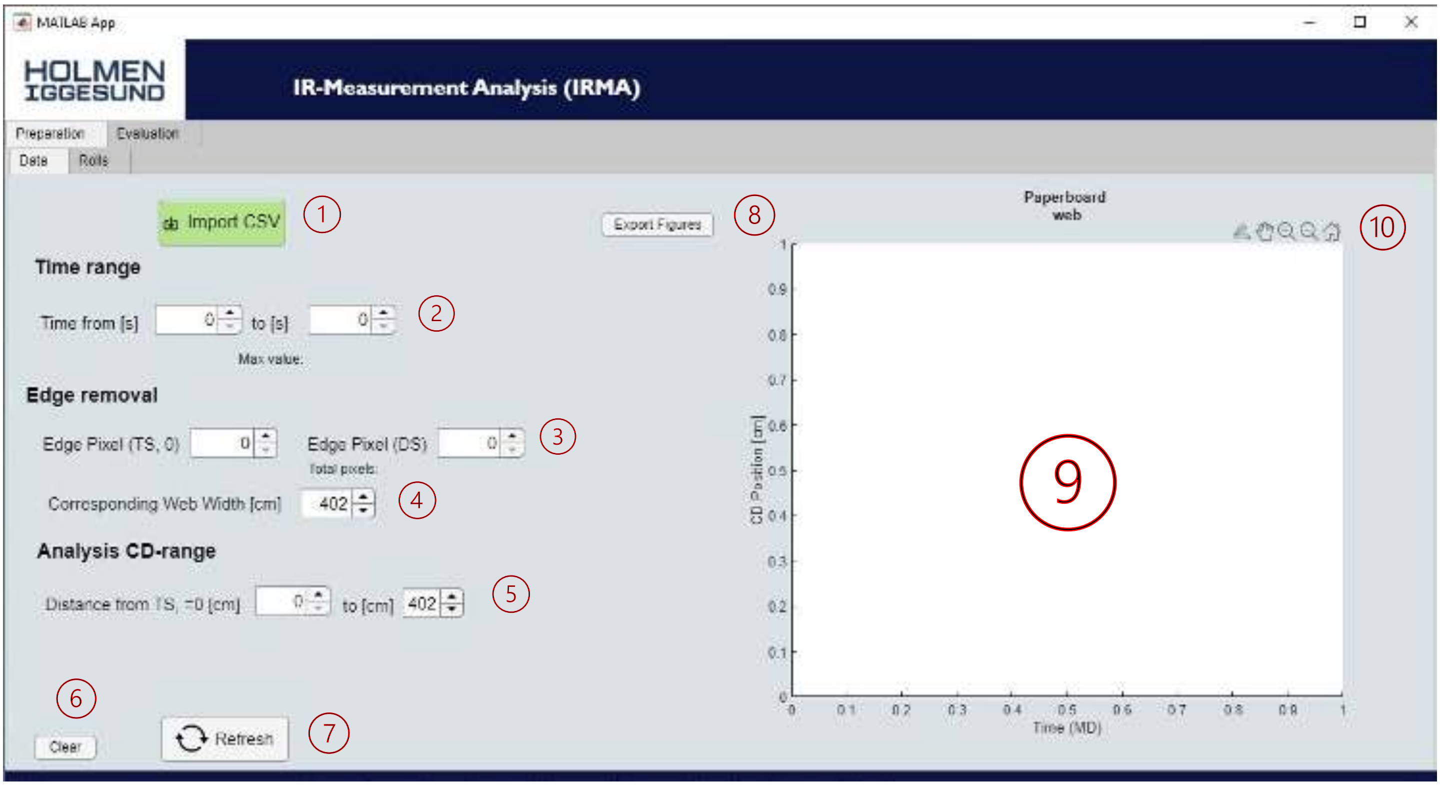
IR-Measurement Analysis (IRMA) is a computer application (app) developed to analyse paperboard quality and variability based on IR-measurement data achieved from cameras. IRMA analyses mean values and frequency through the FFT-algorithm. Furthermore, IRMA also supports scaling of measurement data and inclusion of process parameters. The app was developed through the external software MATLAB but has been compiled to be independent. Hence, IRMA can be used on computers who do not have MATLAB installed.

1.1 Installation

IRMA can be installed by clicking on the file *IR-Measurement Analysis.exe.* Since the app is developed using the software MATLAB, your computer might display warnings when installing an unknown application. These warnings must be disregarded to proceed with the installation. If you have any questions regarding the installation, please contact Hannes Vomhoff (hannes.vomhoff@holmen.com).

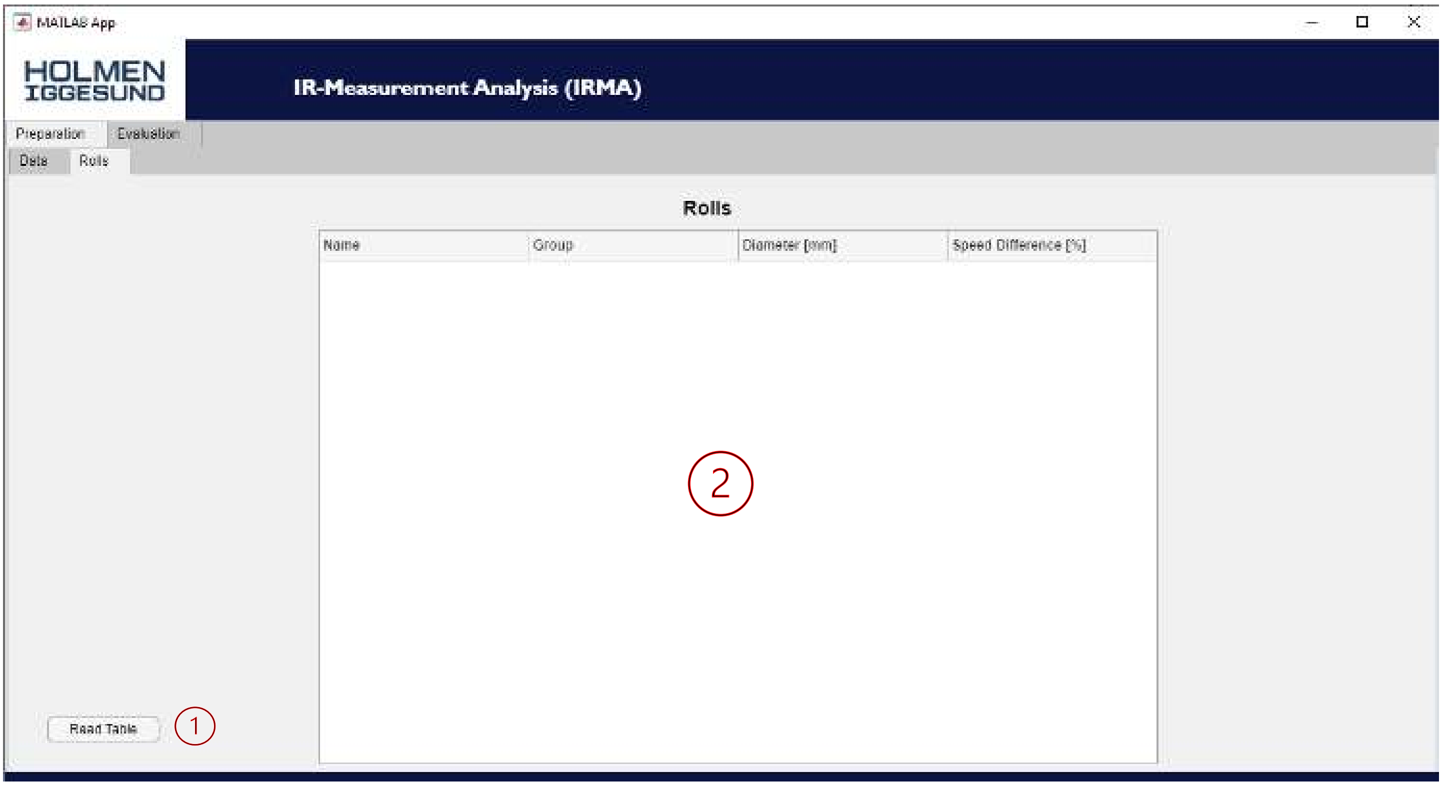
2. Overview

This section explains the various functionalities of IRMA. The app is structured in two main tabs, *Preparation* and *Evaluation.* Each tab has two subtabs, *Data/Rolls* and *Mean/FFT* respectively. Below, images of the user interface are shown together with an overview of each page. The next section of the manual will provide more detailed descriptions of IRMAs functionalities.



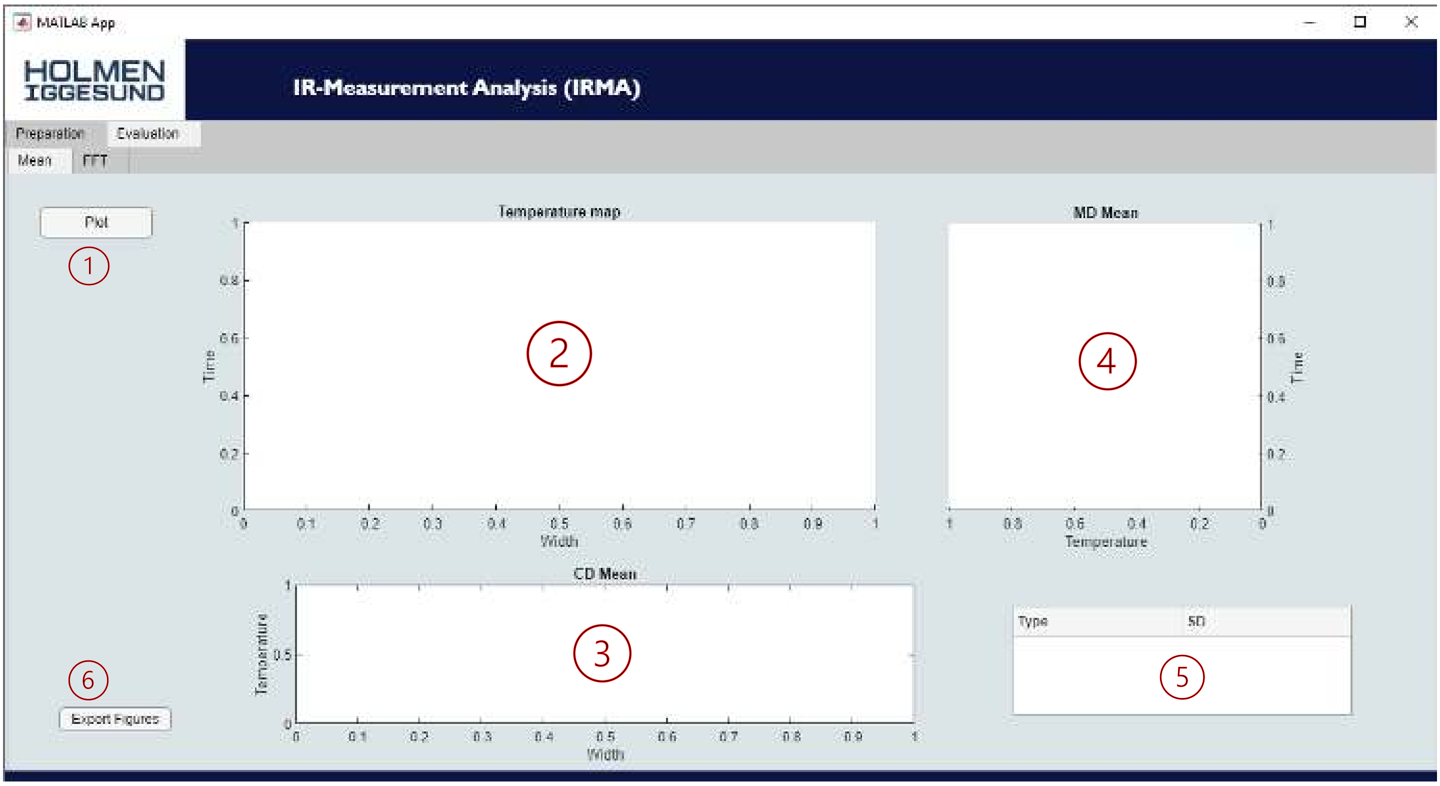
2.1 Data - Overview

1. **Import CSV** – Press button to choose a file containing measurement data (mandatory action).
2. **Time window** – Use input fields to define the desired time interval of the measurements.
3. **Edge Removal** – Set number of pixels to be removed from Tender side and Driver side.
4. **Web Width** – Enter total paperboard web-width in centimetres
5. **Cross-Direction range** – Use input fields to define the desired CD-range
6. **Clear all input fields** – Set all input fields to zero
7. **Refresh** – Use button to refresh plot after changing settings
8. **Export Figure** – Save image of plot
9. **Plot** – Visual representation of the chosen set of measurement data
10. **Plot Navigation Options** – Hoover over plot to see options for navigation. Options for rotation, details, zoom and reset



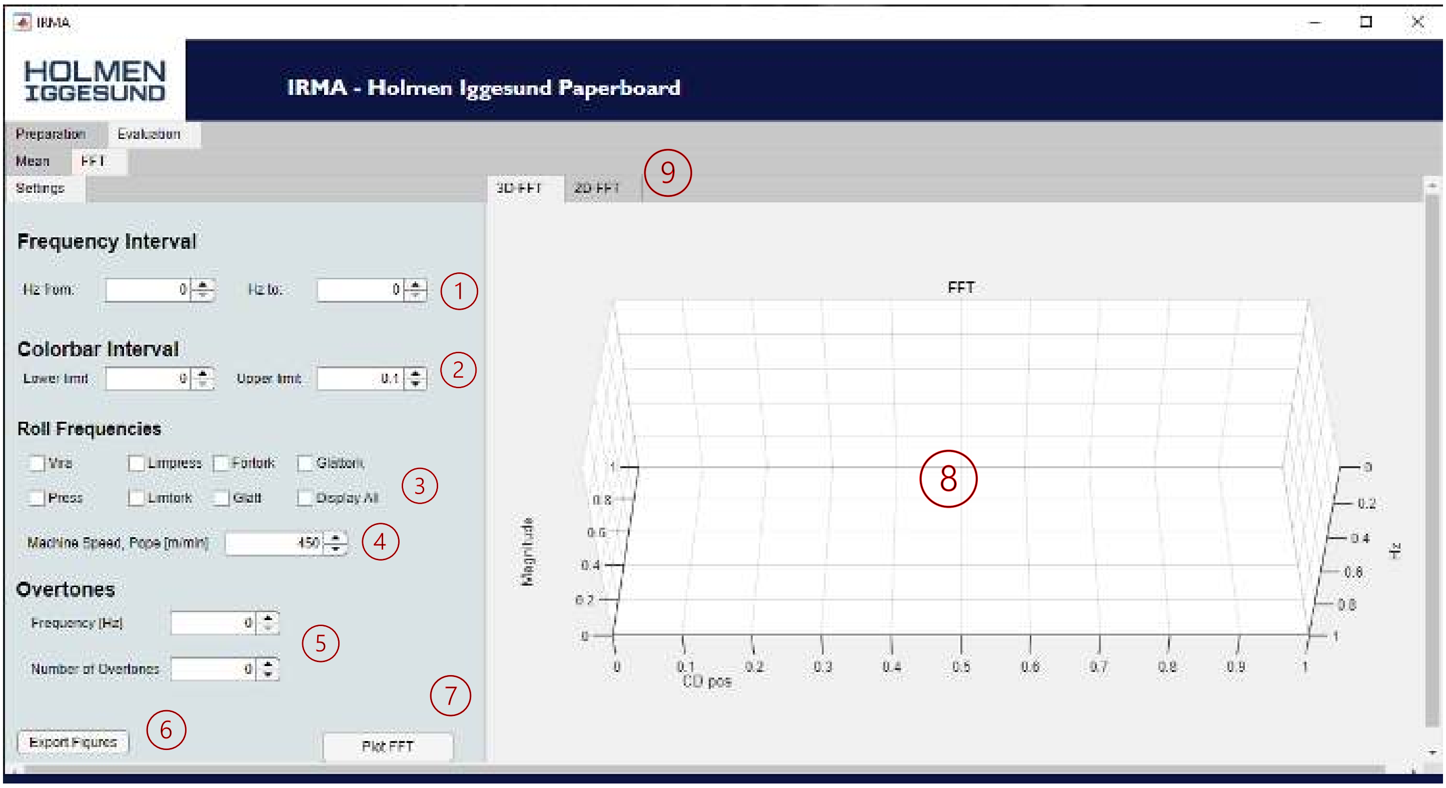
2.2 Rolls - Overview

1. **Read Table** – Press button to choose a file containing roll information
2. **Table**– Table displays the imported file. Temporary changes are possible.



2.3 Mean- Overview

1. **Plot data –** Press button to plot the previously chosen dataset.
2. **Temperature Plot** – Visual representation of temperature of raw data.
3. **CD-mean** – Graph visualising the mean values in cross direction.
4. **MD-mean –** Graph visualising the mean values in machine direction.
5. **Standard Deviation Table –** Table displaying total, CD- and MD-standard deviations.
6. **Export Figures –** Save images of plots



2.4 FFT- Overview

1. **Frequency Interval** – Set interval for frequency axes in plot (8) and (9)
2. **Colorbar settings** – Set limits for color range in colorbar
3. **Roll Groups** – Choose which roll groups to display in plot (9)
4. **Machine Speed –** Enter the speed of the paperboard machine corresponding with time of measurement.
5. **Overtones –** Set frequency of first overtone and how many overtones that should be displayed
6. **Export Figure –** Save images of plots
7. **Plot FFT –** Press button to display the FFT analyses
8. **FFT –** Visual 3D representation of FFT analysis
9. **2D FFT –** Tab for displaying the visual representation of the mean of (8). Also displays rolls and overtones.

3.Functionalities

In this chapter of the manual, all functionalities of IRMA will be further explained. The sections are divided as to represent the structure of the app. If any questions remain after reading this chapter, contact information can be found at the end of the manual.

3.1 Preparation

The *Preparation* tab handles all necessary preparation of data and process parameters (rolls). The tab consists of two sub-tabs, namely *Data* and *Rolls*. Below, the functionality of each tab is further explained.

Data

In this tab, all preparation of measurement data is performed. First, a *.csv*-file containing measurement data must be imported. This is indicated by the green color of the Import CSV-button. There are some pre-set values to the input fields when importing the data. These can be changed at any time. After data has been imported, IRMA will visualise it in the plot (Data – Overview (9)). The app will also display the total time of the sample in seconds and the total number of measurement points, from now on referred to as pixels.

You may choose which time-interval you want to analyse by inputting values in the fields for time range. You can also remove pixels from the ends (CD-position) of the data since the IR-camera measures slightly outside the paperboard web. Removing edge-pixels will be beneficial for the accuracy of the analyses. Furthermore, you can also define the exact web-width in the input field, which can be helpful when interpreting the visualisations in all tabs. The web-width is pre-set to 402 cm but can be changed if needed. Lastly, you can specify the CD-position interval by entering values in the fields for CD-position. Only data within all set intervals will be evaluated in the upcoming analyses. By pressing the refresh-button, you apply the changes that have been made. By pressing the clear button, you clear all values in the input fields of the tab. The visualisations can be saved by pressing the export figures-button. An additional window will appear and here, you chose where you want to save the images and enter a temporary filename (this name will be automatically overwritten).

Rolls

In this tab, you will import an excel-file containing information about the rolls of the paperboard machine. There are limitations to the formatting of the file that can be imported. It must be four columns long and contain roll-name, group, diameter (in mm) and speed difference, in that specific order. The order is important since it is these values that are later used to calculate the frequencies of rolls for comparison with the FFT-analysis. Values in the roll-name-, diameter-, and speed difference-columns can be changed if needed. However, these changes will not be saved in the original file.

3.2 Evaluation

This tab is primarily designed to handle the analyses in terms of mean and FFT. The tab consists of two sub-tabs, namely *Mean* and *FFT*. The sub-tabs focus on different kinds of analyses. Below, the functionality of each tab is further explained.

Mean

This tab serves to perform IRMAs statistical evaluations. By pressing the plot-button, the data set specified during preparation will be visualised in terms of a flat temperature map, the MD-mean and the CD-mean. A small table displaying total standard deviations are placed in the bottom-right corner of the tab. The figures can be saved through the procedure described above.

FFT

The *FFT* tab performs all analyses concerning frequencies- Here, you can also compare the measurements with roll-groups. You can choose to press the plot FFT-button without inputting any values in the input fields. As previously mentioned, the machine speed is pre-set to 450 m/min. The upper limit of both frequency interval and colorbar interval is also pre-set. However, you can specify a frequency interval by entering upper and lower Hz limits into the input fields. You can also specify the limits for the colorbar, which will change the color in the FFT visualisation. The checkboxes let you choose which roll-groups to display in the MD-FFT visualisation, you may choose several groups if desired. You can switch between the visualisations by clicking on the tab above the visualisations. The machine-speed can also be adjusted to match the speed of the paperboard machine when the measurement data was collected.

You can also use the input fields for overtones to display overtones in the MD-FFT visualisation. First, you choose at what frequency the first overtone should have by entering it in the first input field. Then, you choose how many overtones you want to display. To choose the frequency of the first overtone, you can click on a frequency peak in the visualisation. A square containing X- and Y-coordinates will appear. The X coordinate represents the frequency in Hz and the Y coordinate represents the magnitude. By entering the approximate X coordinate of the peak as the first overtone, you can see if that specific peak has any overtones. Press the plot FFT-button to update the visualisation based on the settings. The export-figures button has the same functionality as the other pages.

4. Error messages

IRMA is designed to indicate errors for faulty input values. If an error occurs, it will be displayed in a popup-window. You can close the window and adjust your settings. If the error is persistent and you want help with solving it, please contact:

Hannes.vomhoff@holmen.com