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Machine Vision Based Quality Control and Fault Detection in a Textile Dyeing Machine

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Abstract

Fault detection systems come in a variety of formats and are used in many different types of machines and industries. They can be used to perform fast and accurate detection, classification and analysis. The need for user interaction can be decreased and by that the general level of automation can be increased.

This project has been conducted together with B&R Automation and Imogo. B&R specializes in knowledge and products for the automation industry, including programmable logical controllers, vision sensors and vision solutions. Imogo develops new, more environmental friendly textile dyeing machines. In these machines the current fault detection system require more manual work and in order to further automate the system, one possibility could be to use machine vision. The purpose of this thesis is to investigate whether a B&R vision system could be used for fault detection and quality control in Imogo's textile dyeing machine.

A literature review has been undertaken, where the general topics of fault detection and machine vision have been investigated, as well as a more specific review of different potential solutions for the problem at hand. Different tests, where all key parameters, such as sensor configurations, lighting and resolution, have been performed in order to evaluate the system.

The vision sensor along with the program have been tested and evaluated on the real machine and the result shows both advantages and disadvantages. The program is based on comparisons of mean grayscale and grayscale deviation values between an acquired image and an image of a correctly dyed piece. The system performs well on static fabric and manages to detect faults of different degrees. The main focus of the system is to detect if a fault has a occurred or not, especially large faults, but the program can also provide some additional information about the cause or location of the fault. For further development, a number of tests and different configurations can be done. With more knowledge and more testing this detection method has the potential to be both robust and dynamic, while still being sensitive enough.

The project contributes to the field of machine vision and fault detection. This application differs in many ways from the common use cases for machine vision, which perhaps shows how versatile vision systems are.

Sammanfattning

Feldetekteringssystem finns i flera olika varianter och används inom många olika typer av industrier och maskiner. De kan användas för att utföra snabb och noggrann detektering, klassificering och analys. De kan även bidra till en högre grad av automatisering, eftersom behovet av operatörer som utför mätningarna minskar.

Det här projektet har utförts tillsammans med B&R Automation och Imogo. B&R specialiserar sig på kunskap och produkter för automationsindustrin och tillhandahåller bland annat vision sensorer och vision system. Imogo är ett företag som tillverkar nya, mer miljövänliga textilfärgningsmaskiner. Det nuvarande feldetekteringssystemet kräver mer manuellt arbete och för att vidare automatisera systemet skulle en möjlig lösning kunna vara ett vision system. Syftet med det här projektet är att undersöka om ett B&R vision system skulle kunna användas för feldetektering och kvlitetskontroll på Imogos textilfärgningsmaskiner.

Vision sensorn tillsammans med programmet har testats och utvärderats på den riktiga maskinen och resultatet visar på både fördelar och nackdelar. Programmet är baserat på jämförelser av medel gråskala och gråskaleavvikelse mellan en tagen bild och en bild av ett korrekt färgat tyg. Systemet fungerar bra på statiskt tyg och kan detektera fel av olika grad. Systemets huvudsakliga syfte är att detektera om ett fel har skett eller ej, i synnerhet stora fel, men programmet kan även ge viss information om orsaken till felet, samt var felet har uppstått. För framtida utveckling kan flera tester och konfigurationer göras. Med mer kunskap och mer testning har denna metod potential att både vara robust och dynamisk, samtidigt som känsligheten bevaras.

Det här projektet bidrar till ämnesområdena machine vision och feldetektering. Den framtagna applikationen skiljer sig på många sätt från machine visions vanliga användningsområde, vilket kanske kan visa hur mångsidigt ett sådant system är.

Acknowledgement

We would like to thank B&R Automation and Imogo for giving us the opportunity to work on this exciting project. A special thanks goes to our industrial supervisors, Erik Ottosson and Daniel Bengtsson, for helping us throughout the project, giving us the tools we needed and valuable feedback.

We would also like to thank our academic supervisor Gunnar Lindstedt and our examiner Ulf Jeppsson at Lund University for supporting us throughout this project.

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Acronyms

HMI - Human Machine Interface

PLC - Programmable Logical Controller

FOV - Field Of View

ROI - Region Of Interest

SVM - Support Vector Machines

ML - Machine Learning

AI - Artificial Intelligence

RGB - Red Green Blue

I/O - Input/Output

DOF - Depth Of Field

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1 Introduction

This section introduces the background to this thesis project. The objective and limitations are presented as well as the division of labour.

1.1 Background

Fault detection systems are a common and perhaps even necessary feature in many machines and industries, in order to ensure good quality and reliability. Automatic fault detection systems possess many advantages, since they can operate very fast when detecting, analyzing and classifying different faults. They can help increase the general level of automation and perform swift and accurate measurements and actions, as well as reducing the need for user interaction.

Traditional fault detection has mostly been based on readings from different sensors, such as flow and pressure sensors, but the technology available on the market today offers many other potential methods. This includes machine vision, which by the means of a sensor, acquires images and extract relevant data to perform fault detection and analysis.

Imogo is a company that develops new, more efficient and environmental friendly textile dyeing machines. Imogo's machines use a technology where the dye is sprayed onto the fabric by several small nozzles, located on both sides of the passing fabric. In Imogo's textile dyeing machines a potential fault could for example be an unevenly dyed piece of fabric, due to clogged nozzles or pressure drop. To detect such errors in the dyed fabric, a vision based system could be a possible solution. It would present a higher level of automation and require less user interaction, compared to the currently used fault detection system, based on manual readings of colour values across the fabric, using a photospectrometer.

B&R Automation is a company that develops, manufactures and sells solutions for the automation industry. It has a wide range of products, such as Human Machine Interface (HMI), programmable logical controllers (PLC) and vision sensors that can fit different types of applications.

1.2 Objectives

The objective of this project was to create a machine vision based quality control and fault detection system for Imogo's textile dyeing machine using a B&R smart vision sensor. Additionally, other potential solutions were investigated and evaluated.

The main approach was to use a B&R smart sensor to detect faults. A working solution could be extended to also determine and locate the cause of the fault. If time allowed, a different detection method could be tested and compared to the B&R smart sensor based solution.

1.3 Limitations

The project has been developed off-line, meaning that tests will be performed using non-moving samples rather than the real dyeing machine in operating mode. These samples have different degrees of faults but still do not cover all possible faults, colours or patterns.

The work took place in an office environment at B&R which could lead to some differences when tested on the real system due to the surrounding environment. On top of this, a limited number of sensor/camera configurations were available. Therefore the practical equipment used might not be the one that is theoretically optimal.

1.4 Division of labour

The labour has been divided equally in order for all participants to have equal insight and equal right of decision making in the operations of the programs. At times, the work has been split among the participants in order to make use of time more efficient. The same holds for the writing of this report.

2 Literature review

This section presents theory and literature review of both the individual and combined key topics: Machine Vision and Fault Detection. Other potential solutions to the project, based on the literature review, are presented as well as an evaluation of said solutions.

2.1 Potential solutions

Machine vision is a technology used to automatically inspect and analyze a picture provided by a camera. The picture can be transcribed and read by a computer using applied filters. The general purpose of a machine vision system is to acquire an image, automatically analyze it and extract relevant information. A machine vision system requires two things, a sensor to acquire an image and software to analyze this image. These two parts can either be combined, for example in a smart sensor, or be separate by using a camera in combination with a PC.

A fault detection system is used to monitor machines and identify when a fault occurs. The working way of a general fault detection system can be split up in three steps: detection, classification and diagnosis. The first step is to simply detect that a fault has occurred. The main way of achieving this is to monitor and compare signals from the currently operating application with its known correct operation. The second step is to classify the fault. In other words determine the severity, type and location of the fault. The third step would be to determine the cause of said fault and pinpoint the location of the causing part.

Traditional fault detection systems have been based on sensor readings. By the means of different sensors, fit for the application, data has been collected and compared to known correct data and different thresholds. A fault is detected when readings show that a sensor output exceeds its limits. Another approach would be to base a fault detection system on mathematical models of the system. Recent research present the additional possibility to use machine learning to further analyze gathered data. Machine learning algorithms, for example support vector machines (SVM), can be used on existing datasets, collected from different sensors or models of the system, to detect different faults [1]. Parameter estimation can be used in combination with good models to produce features for diagnosis algorithms [2]. A high quality, modelbased fault detection system requires good knowledge about the system at hand. Since many systems today are quite complex, good models might be hard to accomplish. A third option could be to have a vision based fault detection system [3]. A vision system is based on information extraction from images. It could for example be colour, shape, size or a combination of them all.

Machine vision is frequently used in a variety of applications. In the automation industry, vision systems can serve many purposes, such as detecting faults using a PC and sensor combination [3] or to act as a supervisory controller for different machines [4]. Recent research present many studies where machine vision is used within the agricultural industry. The purpose could for example be to detect fruit maturity [5] or to differentiate between plants and weeds [6]. In many applications, machine vision is also accompanied by machine learning algorithms. This means that a machine learning model is trained with different data from the application. The trained model can then be used together with the application to perform classification and regression. Such algorithms can achieve both fast and accurate performance [6], but on the other hand they require quite extensive datasets. In order to train a model properly, large datasets, containing data of the object of interest in different variations, is needed. Depending on the application, such extensive datasets might be hard to acquire.

As mentioned earlier, a vision system requires two things: a sensor to acquire an image and software to analyze this image. These two things can either be performed by separate units or by one combined unit, e.g. a smart sensor. A number of different vision software libraries exist, e.g. HALCON, AVL and openCV [16]. While most companies turn to the more commercial libraries like AVL and HALCON, a large amount of vision research has been made using the open source library openCV. openCV performs well in detecting colours, edges and shapes in a variety of applications, such as detection of lane-lines [7] and differentiating between healthy and unhealthy parts of plants [8]. Since openCV is not dependant on any specific hardware, image acquisition can be performed by any type of camera.

Also relevant for this project is colour detection. It can be performed using machine vision but also using dedicated colour sensors. Taking a picture using a camera brings with it much more complexity. When recreating an object and analyzing the picture the camera is trying to copy more than the colour patterns of the object. The camera is more sensitive to configuration choices and limitations such as focus and distance between camera and object, while colour sensors only give one output, based on the colour of the object. Colour sensors are easy to use, since they only extract colour data from decided points of the fabric, rather than recreate an entire image.

Colour sensors are of the type photoelectric sensors. Colour sensor work by transmitting light and then receive the reflected light. The reflected light is then analyzed to determine the colour of the object. Colour determination can be based on the intensity or the wavelength of the reflected light. The use of colour sensors is well documented in the agricultural field, where colour is measured to estimate ripeness of fruits and vegetables, quality of soil and in determination of a plants well-being, [12], [14], [10]. Colour sensors come in a wide range, from very basic ones, used to differentiate between red, blue and green, to advanced industrial ones with high accuracy. Two popular solutions that have been used in many different academic projects are the TCS3200 and TCS230 colour sensors. The TCS3200 and TCS230 colour sensors are cheap and the output is a voltage value which means that it can be used in connection with a micro controller, for example an Arduino [15]. Another sensor that is used in multiple agricultural studies are the sensors from nix color sensors [12], [13]. Nix color sensor is a portable wireless colour sensor that has been used in multiple articles, for example to determine soil type and differentiate between plants based on leaf colour. The market for colour sensors is big and many industrial ones with high accuracy and precision exists. However, these tend to come at a higher price as well.

2.2 Other possible solutions

The possible solutions presented below are researched to present more precise possible solutions.

2.2.1 Other vision systems & vision systems in general

The market for vision systems is big and many companies specialized towards the automation industry have vision systems in their product catalog. In order to get an overview of how vision systems most commonly are used and if there might be one better suited for the problem at hand, a market survey has been made and any potential candidates will be presented below.

In general, the use cases for vision sensors, similar to the B&R sensor used in this project, present online fault detection in production lines, where an image of a moving object is captured by a stationary sensor. Whether the object is a manufactured machine part or an object with a text or barcode on it, or if the fault detection is based on shape, colour or alignment, the common thing is that the field of view is relatively small. This in turn means that the distance between sensor and object can be relatively small and the sensor can most likely be mounted in such a way that it is part of the machine. On top of this, the sensors are most commonly used to perform pass/fail inspections, without any further diagnostics.

This perhaps shows what kind of applications vision sensors are most commonly used for in the industry, but it does not mean that they are limited to perform such tasks. Vision systems have the advantage of actually looking at the result and in this project, the result tells quite a bit about the causing parts as well.

Keyence IV3-600 smart camera

The IV3-600 smart camera series from Keyence offers a total of 65 tools to use for detection and classification [18]. Some examples of tools are learning, brightness average and colour average. A smart camera, compared to a smart sensor, can use a combination of multiple tools to make up the final detection algorithm, which makes it possible to further extend the functionality of a detection program. The sensor uses machine learning (ML)/artificial intelligence (AI) to extract colours or detect objects or edges based on manually taught models of correct and/or incorrect images. The smart sensors from Keyence can also be trained using image data where different faults have occurred, together with the cause of the fault, to make online detection and fault diagnostics. It could potentially make it possible to create a fault detection system based on ML/AI, where models are trained using different data. The Keyence smart camera can have both colour and monochrome sensors. A colour sensor would make it possible to distinguish between fabrics of different colour, which is not necessarily the case with a monochrome sensor. The perceived colour is still dependant on the lighting, but with the correct lighting it could potentially be more straight forward to tell if a piece of fabric is incorrectly dyed if the exact colour can actually be determined. In the IV3 Navigator, which is the HMI for the camera, acquired images are visible and different settings and parameters can be set. The camera outputs are the result of the logical operation of each tool and the total judgement in the form of pass or fail. Histograms of degree of similarity, number of passes and fails, as well as the processing time and counts for different values can also be accessed. Keyence sensors are compatible with different PLC manufacturers and three different communication protocols: EtherNet/IP, PROFINET and TCP/IP are available. At an installation distance of 2000 mm the field of view is 1822 (H) x 1364 (W) mm [18].

2.2.2 Sensor based solution

A camera based solution uses images and performs information extraction from these images. This means that many different parameters, such as colour, shape and size, can be used to analyze the extracted information. However, for this project it could potentially be enough to only analyze the colour parameter. Therefore, the following potential solutions presented below are sensors that do not include any vision part.

For this project the main use of the camera is to analyze the colour of the fabric and therefore a colour sensor could be another option. A colour sensor would be a more specific and less dynamic solution to this project but the same way the B&R smart sensor looks at the grayscale value of an image, a colour sensor could look at the colour values, in the form of Red-Green-Blue

(RGB) values for example. By placing colour sensors to cover different areas of the fabric, the same way models are placed for the smart sensor, errors could be detected by registering colour deviations. Two different colour sensors have been researched, the CSS High Resolution from SICK and the OFP401P0189 Color Sensor from Wenglor. For the colour sensor from SICK the diameter of the light spot size is 32mm [22] and for the colour sensor from Wenglor the working range is 30-40mm [23].

Stemmer Line-Scan-Bar

Another potential sensor is the Line-Scan-Bar from Stemmer Imaging produced by Mitsubishi Electric. While sensors like the B&R smart sensor and the IV3-600 from Keyence are small and most commonly used to look at small areas, the Line-Scan-Bar is specifically made to look at wide, flat areas, such as paper or textiles [19]. It has a small working distance of 27 mm, which makes it less sensitive to external lighting and disturbances. With such a short working distance, the Line-Scan-Bars, as a fault detection system, can be considered part of the machine and the fault detection system will not require any bigger area than the one already occupied by the machine. The maximum scanning width is 1688 mm, but more sensors could be added to cover a wider piece. The Line-Scan-Bars have LEDs distributed along it, which makes it possible to have uniform lighting across the fabric. The maximum scanning speed is 309 m/min.

Configurations, settings and parameters are selected by writing to different registers. Different image processing functions, such as dark and white correction and interpolation, as well as the sensor mode and output format, are also set using these register. The sensor can give both colour and monochrome results and different options for resolution, datasize, bitrate and number of output channels are available. The default setting gives a 24 bit RGB colour output. The output data is captured using a Frame Grabber, which in most cases comes with built-in I/O for communication with different systems. The communication interfaces available are CameraLink and CoaXPress.

PLEVA Material Moisture AF.RF.MP 120

The two possible solutions stated above (Keyence IV3-600 smart camera, Stemmer Line-Scan-Bar) are both related to vision, although the Stemmer Line-Scan-Bar does not use images. For both solutions inconsistencies in lighting, shadows, creases will have an effect on the result. Another approach that is entirely disengaged from these problems is using a moisture measuring sensor.

One way to determine how the paint has been applied to the fabric is by measuring the moisture at different parts of the fabric. If the paint is applied equally over the entire fabric then the moisture of the fabric should be equal all over the fabric.

The moisture measurement sensors from PLEVA can approximate the wetness of a fabric by measuring the microwave absorption of the water in the fabric. By transmitting microwave energy through the fabric and measuring the energy on the other side of the fabric with a receiver, the absorption of microwaves in the fabric can give an estimate on the amount of moisture in the fabric [20].

The Material moisture sensors can be used in two ways, either mounted static, AF and RF120, or traversing, MP120. The difference between the AF and RF120 is the precision of the measurements. Values measuring moisture of fabrics is given in gH_2O/m^2, where the measuring range for the AF120 is $0..2000gH_2O/m^2$ and for RF120 is $0..200gH_2O/m^2$, the measuring range for MP120 is the same as for AF120.

Both MP120 and AF120 are very accurate in measurements. The measurement accuracy for the static sensor is $\pm1\%$ and not better than $\pm0.3gH_2O/m^2$ while for the traversing the measurement accuracy is $\pm1\%$ and not better than $\pm0.8gH_2O/m^2$.

Both microwave sensors would be connected to the microwave evaluation electronic MW 120, used to connect the sensors and to translate sensor values into humidity values [20]. MW 120 uses PLEVA's own protocol for PLEVA systems, but optionally CAN-Bus can be used. Both sensor setups require a frame that the sensors are connected to, the fabric is then flowing through the frame with one sensor on either side of the fabric, for AF120 the frame depth is 250mm and for MP120 the depth is 520mm. This means that for it to be able to be integrated in the Imogo machine there would have to be space in the mechanical design to fit the frame so that fabric can flow freely through it.

The static measuring heads are usually used in combination with a system where fabrics are lowered into paint and a padder applies pressure to the fabric to control the amount of paint in the fabric, called padder control. This means that the configuration consists of three static measuring heads, one placed at each edge of the fabric and one in the center. The center sensor is used as reference and the edge sensors are used to calculate the difference between the edges and the center. In combination with padder control, this would be used to decide how the pressure of the padder is applied across the fabric [21]. The traversing sensors can cover the entire fabric and can instead be used to automatically adjust to the fabric width. The traversing heads will however not give single point measurements but give information of the entire fabric.

3 Theory

The section below describes the theory of all the hardware and software configurations, together with different settings, relevant for this project. The dyeing machine and its constraints on the application are also presented.

3.1 B&R smart sensor/camera

When it comes to vision systems, both sensors and cameras can be used. In this project, the B&R smart sensor has been used. The word "smart" means that image processing software is built into the hardware and no additional image processing is needed. The difference between a camera and a sensor lies in its ability to multitask. The sensor can only run one VisionApplication at a time. It can switch between different VisionApplications, but only if they contain the same type of VisionFunction. A camera on the other hand can run multiple types of functions and applications. VisionApplications and VisionFunctions are covered in section 3.2.

Figure 1 shows what the sensors looks like, together with the different light segments. The figure also shows the orientation of the sensor resulting in an upright image in the HMI.

Figure 1: The different lighting segments of the sensor

The quality and features of an image are dependant on a variety of configurations that can be made to the camera. These will be described below.

3.1.1 Lighting

To obtain an image a camera captures the reflected rays of light from an object, thus the lighting is of highest importance. The lighting is also crucial when it comes to detection of surfaces and contours. For the B&R smart sensor/camera, the lighting can either be the internally built in LED segments, an external lighting or both.

The camera has four built in LED flash segments, which can obtain green, red, blue, white, lime and IR light. The number of segments, as well as which segments that are used, are optional. The choice of segment colour is important, since it affects which colours the camera can detect. Different light colours can be used to highlight or hide objects of different colours. A red object will not be visible through the eyes of a sensor, if the light colour too is red. Any other colours will however still be visible. White light can be used to detect all colours, which makes it the optimal choice for an application where the colour to be detected might not be known. External lighting can be used if necessary, for example if there is a need to have more evenly illuminated object or stronger lighting. The light intensity as well as the distance between the external lighting and the object of interest affects the result.

Exposure time is the time during which the shutter is open, allowing light to reach the sensor. The exposure time is closely related to the lighting, since less lighting requires a higher exposure time and vice versa. This time can be changed automatically or manually in the HMI application in order to fit the application.

3.1.2 Lens

A lens is used to alter incoming light by either focusing or dispersing the rays. Depending on the shape of the lens, the light can be focused on one point, using a convex lens, or dispersed, using a concave lens. The characteristics of the light will be depending on the properties of the lens.

The lens can affect the properties of the camera in a variety of ways, but for this project only two aspects are of interest. These are the field of view (FOV), which depends on the focal length, and the depth of field (DOF), that depends on the aperture of the camera. For a camera to get a clear picture, a convex lens can be used to focus the reflected light from an object to a single point, the focal point. The focal length, the distance between the lens and the focal point, indicates how strongly the lens converge light. A shorter focal length means that the lens will bend the incoming rays to a point closer to the camera while a longer focal length means that the lens will converge light less effectively, see Figure 2. This means that the focal length will affect the FOV of the camera since a shorter focal length means that incoming light from an angle less perpendicular to the lens will still be focused on the focal point.

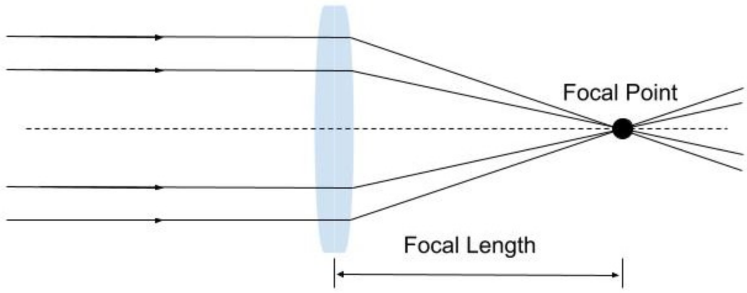


Figure 2: Focal length and focal point related to the incoming light and lens

Aperture is the opening through which light can travel into the lens and is annotated with an f-number, the larger the f-number the smaller the aperture. The size of the lens opening can be altered and will have different effects on the picture depending on size. A larger aperture means that more light will travel through the lens and the DOF will decrease. A smaller aperture will increase the DOF.

3.1.3 Sensor

An image sensor consists of multiple pixels that can register how much light that falls upon them. The pixels will convert the amount of light to electrons which can then be converted to a voltage and read as a signal. There are two main sensors that differ from each other, the CMOS and CCD sensors. For the B&R cameras CMOS sensors are used. The main difference between the sensors are that for the CCD sensor the voltage from multiple pixels are transferred from the chip to output nodes, while for the CMOS sensor the voltage is being read from every single pixel [11]. Both sensors can only read values from dark to bright and therefore unable to read colours, further colour filters can be added to translate to colour values.

The resolution of an image is measured in how many pixels that are used, where the number of pixels are dependant on the size of the sensor. For the B&R camera/sensors the possible sensors are 1.3, 3.5, and 5.3 megapixels. A larger amount of pixels means a higher resolution, which in turn means better precision when processing the picture. However, there are also downsides to a higher resolution. More pixels also means more data and therefore a higher demand to process the picture. A larger amount of pixels requires a larger sensor. This means that the lens has to be able to fill the whole sensor with the image, which creates restraints on the options for the lens. A short focal length might lead to that only smaller sensors can be used.

3.2 Sensor software

3.2.1 VisionApplications, VisionFunctions & models

The three parts VisionApplication, VisionFunction and models will be referenced throughout this report. Therefore a description of these parts and their functionality is presented below.

Figure 3 shows how the three parts are related to each other. A VisionApplication can be considered as a shell, holding both the image processing program and the image settings. The VisionApplication holds all the functions and commands related to image acquisition, as well as different settings for an acquired image, such as width and height. However, in order to extract any information from an acquired image, an image processing program, a VisionFunction, is needed. A number of different VisionFunctions exist, each providing a different functionality, that can be used to fit different applications. The different functionalities could for example be to detect objects of a certain shape or to present the mean grayscale of an image or part of an image. Most of the VisionFunctions available for the sensor are model based. This means that they require a model to be defined in order to work. The purpose of the model is to set the region of interest (ROI) in the image. Such a model is defined manually in the HMI application, once the first image is acquired. When a new image is acquired, any extracted information will simply be extracted from the region defined in the model. This makes it possible to exclude potential irrelevant backgrounds or other irrelevant patterns in an image. Up to twenty models can be defined for each VisionFunction. Information can therefore be extracted from both an entire image and different sections of an image.

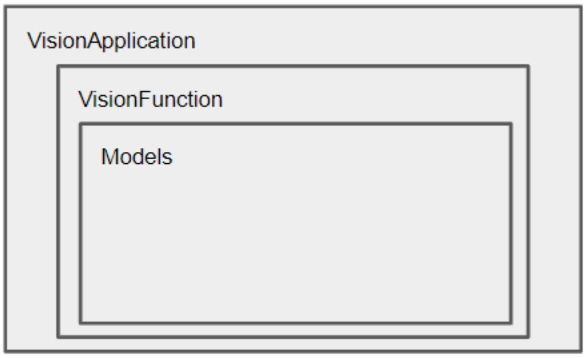


Figure 3: VisionApplications, VisionFunctions & Models

The camera and sensor from B&R Automation is compatible with a variety of different functions. However, for this project two different functions, PixelCounter and Measurement, has been used and therefore only they will be further explained.

The PixelCounter VisionFunction counts the pixels in a predefined region of interest and can display pixel information. Two values are used in the fault detection application: Mean grayscale and grayscale deviation. The mean grayscale value compiles the mean of the gray value of all the pixels in the picture. The range of grayscale is 0 to 255, where 0 means pitch black and 255 completely white. The grayscale deviation shows how large the difference is between the darkest and brightest pixel in the picture.

Measurement is used to determine distances and radii of objects in an image. By using a predefined region of interest and tuning parameters to specify expected characteristics of the wanted object in the picture, the measurement function can find objects and provide information about distance and dimensions.

3.2.2 HMI application

The B&R smart sensor comes with a webb based HMI application, where different sensor settings, such as focus and exposure time, can be changed manually. The models for the VisionFunctions are also defined in the HMI application. On top of this, the HMI application displays the acquired image, as well as the corresponding function values, such as mean grayscale. An image of the HMI can be seen in Figure 4.

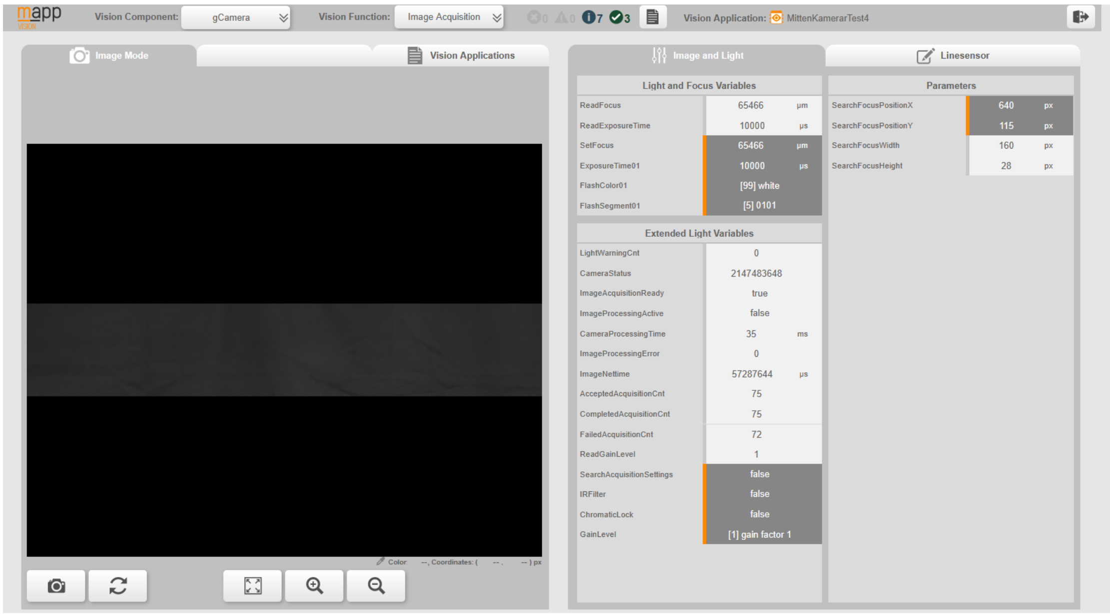


Figure 4: The B&R sensors web based HMI

The functions and the displayed values can be accessed from Automation Studio as well. Automation Studio is the software from B&R used to program the PLC, HMI, and handle the communication for the system. In this way, the created application can be automated in such a way that image acquisition and information extraction is performed automatically and cyclically. The model(s) defined for the VisionFunction must however be created manually in the HMI.

A simple, webb based HMI has also been developed for this project specifically, in which the operator can choose between different programs and see the alarm history. This was made during this project to make testing and gather data easier. A full description of the developed HMI can be seen in section 5.

3.3 Imogo's textile dyeing machines

Imogo's textile dyeing machine has two different configurations, one for woven fabrics and one for knitted fabrics, see figure 5. Due to the characteristics of knitted fabrics, it can not be as freely flowing to prevent the sides of the fabric from curling. The dye is applied onto the fabric using two arrays of spray valves, one on each side of the fabric. Each array has a number of spray valves, that can be turned on or off to fit the width of the fabric. The spray valves spray at a certain angle, which means that the paint from two valves will overlap at the edges.

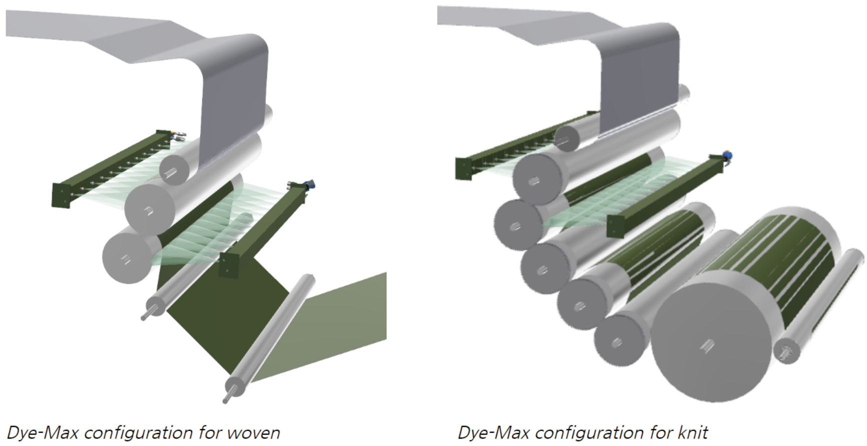


Figure 5: Imogo's textile dyeing machines (imogo.com)

The configuration for the knitted fabric put restraints on the possible ways of mounting a potential vision system, as well as the area, which can be captured by the sensor. The arched shape under the fabric, due to the cylinders, will cause different shadows to appear when an image is acquired. In order to avoid potential problems with different colour appearance over the cylinders, it has been chosen to only look at the area given by a 120 degree angle of the cylinder. Equation (1) shows how the restriction on how many pictures the sensor has to be able to take every second is calculated.

$$\begin{aligned} \frac{\pi r_{cylinder}}{3} x &\geq v_{machine} \\ \rightarrow x &\geq \frac{3 v_{machine}}{\pi r_{cylinder}} \end{aligned} \tag{1}$$

$r_{cylinder}(m)$ is the radius of the cylinder the fabric is placed on, $x(pictures/s)$ is the number of pictures the sensor can take per second, $v_{machine}(m/s)$ is the speed of the Imogo machine i.e. the amount of fabric passing per second. From equation (1) the processing time can be calculated according to equation (2)

$$t_{processing} \leq \frac{\pi r_{cylinder}}{3 v_{machine}} \tag{2}$$

where $t_{processing}(s/picture)$ is the processing time of the sensor to take one picture.

Fabrics of different widths, ranging from 1.6 m to 3.6 m, can be processed in the machine. The max width of 3.6 m will be the lower limit of the field of view. The potential ways of mounting a vision system is also limited, due to the construction of the machine. Therefore, the distance between the sensor and the fabric can not exceed 1 m.

4 Method

In this section all steps taken to develop the application are explained. The section starts with a description of the equipment and setup used. Next follows a detailed description of all the performed tests.

4.1 Equipment and setup

The list below shows the hardware, software and other external equipment used in this project to perform and evaluate different tests.

- B&R Smart Sensor
  - 1.3 MP Sensor
  - Focal length 12 mm
  - F-number 4
  - 2/3 inch sensor size
- Seven different textile samples
- Automation Studio
- Vision function Pixel Counter

All tests are performed in an office environment which means that the external lighting used consists of ceiling lights and no light disturbances are present. There are no other machines or equipment that interferes with the camera. The camera used for the tests is not configured the same way as the final camera, but will be used to try to replicate how the final camera will behave with regard to aspects such as resolution of the picture.

4.2 Preparatory work

Before any development could be undertaken, a number of preparations had to be made. The purpose of the preparatory work was to gain both general knowledge about the field of study and its possible usages relevant for this project, and specific knowledge about the tools and programs needed. The preparatory work also includes setting up a plan for how the final system should be created, based on the gathered information. All parts of the preparatory work will be described below.

4.2.1 Literature review

A literature review was done in order to gain some general knowledge about the key topics machine vision and fault detection. The literature review puts in perspective how these topics have been used and configured in other projects and serves as good background knowledge when making decisions and stating facts.

Information for the literature review has mainly been acquired through the LUBsearch database, but also through different websites.

4.2.2 Pre-study of available B&R material

Different B&R specific exercises were gone through, in order to acquire some basic, necessary knowledge about the specific tools needed for this project. This involves learning about the main program Automation Studio, how to create and run programs and how to configure the correct settings for communication between different parts of the system. It also involves more specific knowledge about the sensor, its settings and available functionality and how it potentially could be used in this project.

To determine what functionalities of the camera are relevant for this project, tests and research were put into the pre-defined vision functions of the camera. Table 1 shows a short description of the functions available on the B&R smart sensor. Both Code Reader and OCR are used to read codes and characters only, and are therefore not relevant for this project. Matching and Blob could be used to detect patterns on the fabric, since the fabric is supposed to be one colour there should not be any patterns. However, both functions require some training, meaning that a person has to select the area or the object that is used to find patterns.

Measurement is used to calculate position, distance, and dimensions of chosen objects. By using beforehand taught-in shapes such as circles and edges measurement can detect different objects in an image. To further optimize the search for objects, parameters can be tuned such as edge transition or edge contrast. Measurement is further discussed as a solution to further improve the error detection as the chosen function to find errors was Pixel Counter.

Pixel Counter is a vision function that can calculate information based on the grayscale value of pixels in an area. By selecting an area of the image, called a model, Pixel Counter can calculate the mean grayscale value of the pixels in the selected model, the deviation of the grayscale values, max and min grayscale value, number of pixels in the area.

Function	Description
Code Reader	Read QR codes and bar codes.
Blob	A Blob is an area where the grayvalue of the pixels are similar. Can find Blobs within a picture.
Matching	By selecting one object in an image, similar objects can be found in the same image. Can either be based on grayscale value or contours.
OCR	Trained data to recognise characters.
Measurement	Calculates position, distances, and dimensions of chosen object in an image.
Pixel Counter	Calculates information about pixels in a chosen area of the image.

Table 1: Description of the available functions of the smart sensor

4.3 Development

The development of the final solution can be split up into three parts. Initially, a draft of how the program should work, which functions to use and how these had to be configured was done. Different potential questions, problems and requirements were stated and all the different tests required to answer said questions were planned. Once the main idea was set, all the tests were performed and evaluated. The program was continuously updated, based on the test results. The final step was to test the program and setup on the real machine and evaluate and improve its performance. Below all the parts of the development phase will be further described.

4.3.1 Program overview

As mentioned in section 4.2, the vision function PixelCounter was determined to be the one best suited for this project, since it can be used to extract grayscale data from an entire image. The general program idea was to create a fault detection program based on comparisons of mean grayscale values and grayscale deviation between currently acquired images and an image of a correctly dyed fabric. An image of a correctly dyed piece will have a specific mean grayscale and a low deviation. An incorrectly dyed piece will then either have the wrong mean grayscale value, if the colour is different, or a larger deviation, due to white spots. To further extend the program, more models, covering specific areas, could be added to make further analysis of what kind of fault that had occurred. On top of this the system should be robust, require as little operator interaction as possible and meet the timing requirements set by the machine.

A number of factors, such as accuracy, lens, resolution and lighting, affect the system. The measured grayscale values must be accurate and reliable in order for the system to be able to differentiate between different samples. The lens affect both the FOV and the resolution and it had to be determined what specific lens to use and to make sure that this lens does not result in a too poor resolution. Lighting is perhaps the most important factor, since it affects numerous things. The number of light segments to use had to be determined, as well as how different ambient lighting and light disturbances affect the system.

4.3.2 Tests

Reliability and accuracy of mean grayscale value and grayscale deviation The PixelCounter vision function provides the possibility to determine the mean grayscale of an image, as well as the deviation in grayscale. In order for the solution to be reliable, the grayscale measurements must be consistent between measurements and accurate in such a way that they match the appearance of the fabric. Textile samples with different faults must result in different mean grayscales and deviations in order for the application to be able to differentiate between them.

The grayscale measurements make up the base for all tests. The measurements will differ depending on aspects such as lighting and lens configuration. This will be described below, but as a starting point tests were performed to see the overall accuracy and consistency between measurements on the same piece of fabric. These tests were performed using different variations of the built in LED segments as lighting.

Effect of ambient light and light disturbances Lighting is a key factor when it comes to image acquisition. In our case, different lighting will result in different measured grayscales. The importance of lighting in this project does not necessarily lie in the exact illuminance or type of lighting used, but rather in the use of consistent lighting. Whether a light is consistent, even in the presence of a disturbance, might however be affected by the original ambient lighting, which in this case is considered to be normal ceiling lights. In order to determine the effect of ambient lighting, light disturbances and the combination of the two, tests were performed using two different ambient lightings and a flashlight as disturbance. The effect of a disturbance is also affected by the distance between the disturbance and the sensor. A distance of 30 cm was chosen for the tests. In a real factory it is assumed that potential light disturbances would be located at a distance further away than 30 cm and therefore the test would consider the worst case scenario. Different angles of the disturbing lighting were also tested. On top of this, it was investigated if a disturbance would affect the image even if the disturbance was cropped out.

Different lens and sensor configurations A number of different parameters interact with each other and affect the final solution. Two key parameters are the field of view and the image resolution. These parameters are affected by the choice of sensor, lens and the distance between sensor and object of interest.

The design of the real machine limits the amount of options to mount the sensor(s) and therefore the max distance between sensor and object is considered at 1 m due to space limitations. Fabrics of different widths can be processed in the machine, but the widest one of 3.6 m sets the lower limit of the field of view (FOV).

An external, interactive Excel document from B&R Automation, containing information and calculations of different lens and sensor configurations, was used to determine the optimal setup. Based on the limited distance between sensor and object, the lens providing a field of view as big as possible was chosen to minimize the number of cameras required to cover the entire width of the fabric. This also affected the resolution. The camera available for testing did not have the correct lens. In order to test the resolution resulting from another lens, the distance between the sensor and object was changed to simulate the same resolution and width of the image.

Increasing the number of models The models used by the VisionFunction are manually tuned but can then be saved and used on all pictures taken with the sensor. For more simple evaluations of the fabric, such as determining the colour shade, one model is used to cover the whole visible fabric. However, when making more complex diagnostics on the incorrect dyed fabrics, a higher number of models are used on the picture. Tests were performed, where a number of equally sized models covering the entire image, were defined. Three models are used to cover the spray-area of one nozzle, one each for the left, middle and right side. Since the spray-areas of the nozzles overlap with each other, the right side of one nozzle will also be used to analyze the left side of the nozzle next to it. Figure 6 shows what the models look like. All models are named, based on which part of each nozzle the look at. Model L1 looks at the left part of nozzle 1. The three models used to cover one nozzle will be called a segment in this report.

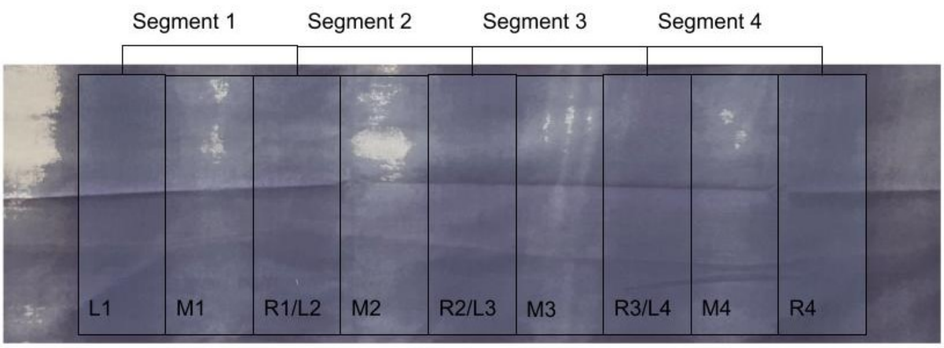


Figure 6: Models to analyze 4 segments. For segment 1, L1 is the left part of the first segments, M1 the middle part, and R1 the right part which also will be used to analyze the left part of the second segment

Parameter tuning To be able to analyze new images of the fabric, the values read by the camera have to be compared in order to evaluate if they indicate an error or not. In the sensor's start up phase the camera will adjust its settings as well as its values that will be used in comparisons to evaluate new pictures of the fabric. Using the function "image acquisition settings", which is a predefined function for the sensor, it will tune both focus and exposure time itself. Further, pictures are taken on a correctly dyed fabric and values are saved. The values are used to compare the grayscale value and the deviation of new pictures of fabrics to determine if they are correctly dyed or not.

The values gathered during the start up phase of the camera will also be used to set the offsets used when comparing values. For every picture the grayscale and deviation values vary even when taking pictures of the same object. Therefore there has to be a region in which small deviations of values are accepted. An offset is chosen which will be added and subtracted to create a margin which the measured grayscale and deviation values may stay inside without signaling that there is an error in the dyeing process.

There are two different offsets that have to be decided, one for the whole fabric to decide if the fabric is the same colour according to the camera or if the colour of the fabric has changed, this could occur if for example the lighting in the room were to change. The second offset is when looking at the different models to decide if there are colour patterns on the fabric, for example spots were the nozzles have not dyed the fabric.

Tests were performed to measure the mean grayscale and grayscale deviation on different fabrics, in order to get information of how small or large the different offsets need to be. Three different methods for setting an offset were evaluated.

Resolution The resolution of the camera will determine how easy it is to detect spots and lines that are incorrectly coloured on the fabric. A lower resolution means that every pixel has to capture a larger area, therefore small errors might be merged with correctly dyed parts of the fabric and hard to detect. Different sensors, lenses and installation distances result in different resolutions and therefore different combinations had to be tested and evaluated. Since only one sensor, with a specific lens, was available, the performance of other configurations could not be properly tested. But by placing the sensor at different distances from the fabric, the different resolutions and their effect on the images could be simulated. Figure 7 shows two different setups corresponding to a 3.5MP and a 1.3MP sensor.

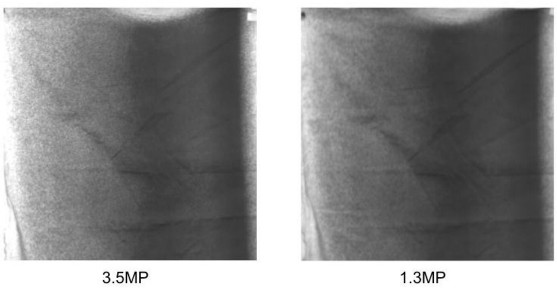


Figure 7: Pictures of the same part of the fabric, corresponding to a 3.5 MP sensor on the left, and a 1.3 MP sensor on the right

4.4 Test subjects

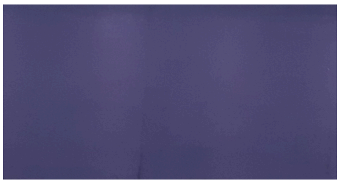
The tests have been carried out on a number of different fabrics. Two samples represent a correctly dyed piece and the rest are incorrectly dyed due to different faults in the machine. The different samples have been analyzed and classified. In order to create an application that can differentiate between the different faults, the characteristics of each fault have been determined in means of grayscale and deviation.

Below the different fabrics are presented as well as the possible errors.

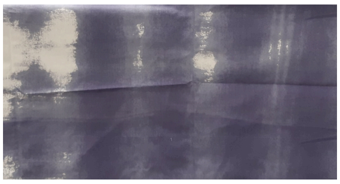
(a) Dark correctly dyed

(b) Light correctly dyed

(c) Fabric 1: The darker colour on the right side indicates that the nozzle is partially clogged and will spray unevenly



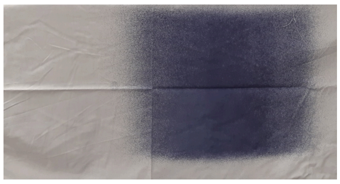
(d) Fabric 2: The colour of the fabric is a different colour shade than the correctly dyed fabric as well as the lines that are lighter.



(e) Fabric 3: The alternating between a lighter and a darker colour indicates that there probably has been a pressure drop in the spraying system.

(f) Fabric 4: Unknown source of error

(g) Fabric 5: The edges are darker than the middle which indicates a pressure drop in the spraying system



(h) Fabric 6: Correct dyeing for one nozzle

Figure 8: Eight different fabrics with explanations of the dyeing

4.5 On site test

To make a final evaluation of the performance of the system the sensor along with the code was tested on the real machine. The plan was to test the system on the machine, while the machine was operating, but that was unfortunately not possible. Different tests that would evaluate the complete system, as well as smaller algorithms, were planned and performed. This includes determining how well the system detects faults on both still and moving fabrics and how well it handles speed requirements and lighting changes. Since the machine was not operating during the test, actions like moving fabric had to be performed manually by pulling a loose piece of fabric. When pulling the fabric through the machine the fabric does not move with a constant velocity and it does not match the speed of the machine. It was only done to see how the sensor can handle objects that are moving. Faults were simulated using a small piece of white fabric that was placed over a darker fabric. The sensor was placed at a distance of 0.5 m from the fabric, which gave a FOV of 258 mm.

The test setup can be seen in Figure 9 and Figure 10 shows how images of non-moving fabric, placed on the cylinder, are acquired.

Figure 9: Camera setup when taking pictures of fabric in the real machine. The fabric is moving through the top cylinder

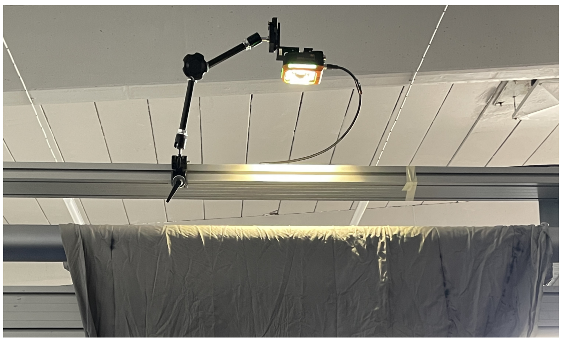


Figure 10: Camera taking picture of fabric lying still. The fabric is lying still on the cylinder to simulate the real machine when standing still

5 Results

In this section the results of all performed tests are presented, as well as the performance of the resulting solution.

For a number of the tests, different light segments on the sensor will be used, see Figure 1 in section 3.1 for a description of the segments. Many tests are based on measurements of mean grayscale and grayscale deviation. These values are dependant on a number of factors, such as distance between sensor and object, lighting, exposure time and focus. The importance of these tests and their result do not necessarily lie in the exact value, but rather in the relation between the value and a certain setting.

5.1 Test and Evaluation

5.1.1 Reliability and accuracy of mean grayscale and grayscale deviation values

Table 2 shows the grayscale measurements for the correctly dyed piece of fabric and table 3 shows the measurements for the similar coloured but incorrectly dyed piece of fabric. Five measurements for each choice of segment were taken in order to provide some information about how consistent the application is.

Segments	0101	1010	0010	1101	1111
Measurement 1	113.24	112.39	62.82	164.60	209.79
Measurement 2	114.39	112.40	62.60	164.32	209.61
Measurement 3	114.26	112.24	62.70	164.40	209.68
Measurement 4	114.35	112.38	62.52	164.34	209.66
Measurement 5	114.09	112.39	62.61	164.53	209.69
Average	**114.066**	**112.36**	**62.65**	**164.438**	**209.686**

Table 2: Grayscale values with different segments active when taking pictures of the correctly dyed fabric

Segments	0101	1010	0010	1101	1111
Measurement 1	153.84	143.33	79.50	212.94	243.54
Measurement 2	153.81	143.13	79.38	212.90	243.51
Measurement 3	153.84	143.25	79.55	212.82	243.52
Measurement 4	153.80	143.11	79.55	212.77	243.48
Measurement 5	153.83	143.19	79.49	212.67	243.46
Average	**153.764**	**143.202**	**79.494**	**212.82**	**243.496**

Table 3: Grayscale values with different segments active taking pictures of the incorrectly dyed fabric Fabric 2

The overall consistency between measurements is good. The values differ between measurements but the deviations are in a value range less than 1. The total range for the measurements is 0-255, therefore the deviation between measurements will not have a significant impact. The grayscale value increases when more segments, i.e more light, is used and decreases when less light is used. A higher grayscale value means a brighter picture. Figure 11 shows the appearance of the correctly dyed piece with different LED segments active.

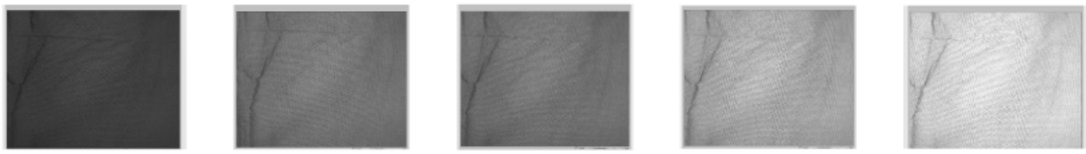


Figure 11: Appearance of correctly dyed sample using different LED segments

To test the colour deviation value within an image, between measurements, different segments were tested on the correctly dyed fabric to see how deviation and segments are correlated. Furthermore, Fabric 5 and Fabric 2 were used to test the deviation values. This since Fabric 5 has large deviation and Fabric 2, although incorrectly dyed, has little deviation.

Table 4 shows the deviation in grayscale when using different light segments together with the correctly dyed piece of fabric. The values are consistent between measurements, but differ a lot depending on how many segments that are used. The deviation will increase when more light segments are used and decrease when less light segments are used.

Segments	0101	1010	0010	1101	1111
Measurement 1	15.05	15.19	8.00	22.72	30.02
Measurement 2	15.10	15.21	8.04	22.75	30.03
Measurement 3	15.08	15.22	8.05	22.74	30.05
Measurement 4	15.12	15.20	8.03	22.78	30.05
Measurement 5	15.14	15.22	8.04	22.78	30.10
Average	**15.098**	**15.208**	**8.032**	**22.754**	**30.05**

Table 4: Deviation values with different segments active when taking pictures of the correctly dyed fabric

In table 5 it can be seen that the deviation is roughly twice as large for Fabric 5 compared to Fabric 2. This means that the sensor successfully manages to detect the deviations in Fabric 2, as well as distinguishing between two fabrics with different levels of coverage.

Fabric	5	2
Measurement 1	43.90	17.90
Measurement 2	43.92	17.86
Measurement 3	43.94	17.86
Measurement 4	43.67	17.87
Measurement 5	43.59	17.86
Average	**43.084**	**17.87**

Table 5: Deviation values with segments 0101 active when taking pictures of the Fabric 5 and Fabric 2 from Figure 8

5.1.2 Effect of light disturbances, ambient lighting and colour of fabric

Two tests were performed with two different ambient lightings and a flashlight as disturbance. The flashlight was located at a distance of 300 mm from the sensor and was tested at four different angles. An illustration of the test can be seen in Figure 12, where the fabric and the sensor are displayed, together with the different positions of the flashlight.

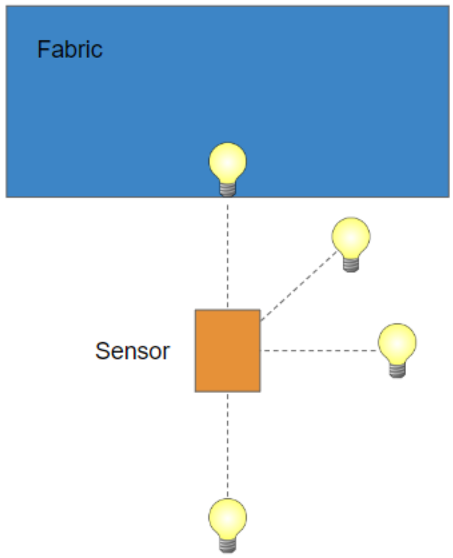


Figure 12: Illustration of disturbance test

Table 6 shows the grayscale measurements when the ceiling lights were turned on and table 7 shows the measurements when the ceiling lights were turned off. The reference case is when ceiling lights are turned on or off and no disturbance is present.

Segments	0101	1010	0010	1101	1111
Ceiling lights - Reference	131.63	144.46	74.43	200.78	237.62
Light from behind	132.58	145.68	74.76	201.59	237.71
Light perpendicular	131.81	145.67	75.30	200.95	235.63
Light facing the sensor at an angle	133.40	146.18	75.51	202.95	235.77
Light from direct backlight	160.05	166.24	87.82	210.87	242.41
Difference between no disturbance and direct backlight	28.42	21.78	13.39	10.09	4.79

Table 6: Grayscale value with ceiling lights on and a flashlight at different positions while taking pictures of the correctly dyed fabric

Segments	0101	1010	0010	1101	1111
No ceiling lights - Reference	122.72	137.04	62.39	194.58	229.25
Light from behind	123.07	137.32	63.04	195.05	229.66
Light perpendicular	122.90	136.98	62.40	194.41	229.11
Light facing the sensor at an angle	122.11	136.43	62.20	193.66	228.52
Light from direct backlight	151.39	168.69	91.55	214.74	238.94
Difference between no disturbance and direct backlight	28.67	31.65	29.16	20.16	9.69

Table 7: Grayscale value with ceiling lights off and a flashlight at different positions while taking pictures of the correctly dyed fabric

It can be seen that a change in ambient lighting, in the form of turning on or off the ceiling lights, results in a value change of around 10. This result is consistent over the measurements for the different segments, even in the presence of a disturbance.

When it comes to the disturbance, only direct backlight has a consistent, visible effect on the measurements. However, the effect varies depending on both how many segments are being used and the ambient lighting. With the ceiling lights turned on, the biggest impact is presented when using two light segments. The resulting difference between no disturbance and a disturbance is of value 28.42. Comparing this with the corresponding value of 4.79 for all four segments, shows that more segments, i.e more light, reduces the impact of a disturbance. The pattern is the same when the ceiling lights are turned off, but the corresponding values are a bit larger, meaning that the impact of a disturbance will be bigger in the presence of less ambient lighting.

Both for light and dark fabrics the surrounding lighting affects the sensor's perception of the colour of the fabric. Table 8 shows the average grayscale value of 80 measurements for four different fabric and light setting combinations. It can be seen that the measured grayscale value differs not only between different coloured fabrics, but also between the same fabric exposed to different lighting. It can also be seen that the lighting has a bigger effect on the light fabric, since the difference in grayscale between the two light settings is 97.62, compared to 16.9 for the dark fabric.

Light fabric		Dark fabric	
Ceiling lights on	Ceiling lights off	Ceiling lights on	Ceiling lights off
213.68	116.06	45.89	28.99

Table 8: Average grayscale values for light and dark fabrics, with ceiling lights on and off

Figure 13 shows the normally distributed mean grayscale values for the four different colour/light-setting combinations. The normal distributions are based on 80 measurements of mean grayscale and grayscale deviation for each setting. It can be seen that the measured grayscale do not differ much between measurements. The standard deviation lies between 0.0430 and 0.1417. The dark fabric, with ceiling lights turned off, give the highest difference between measurements, but the corresponding value of 0.62 is still very small. Since the difference in captured values between measurements are so small, the offset for the mean grayscale can be kept very low, regardless of the colour of the fabric and the external lighting.

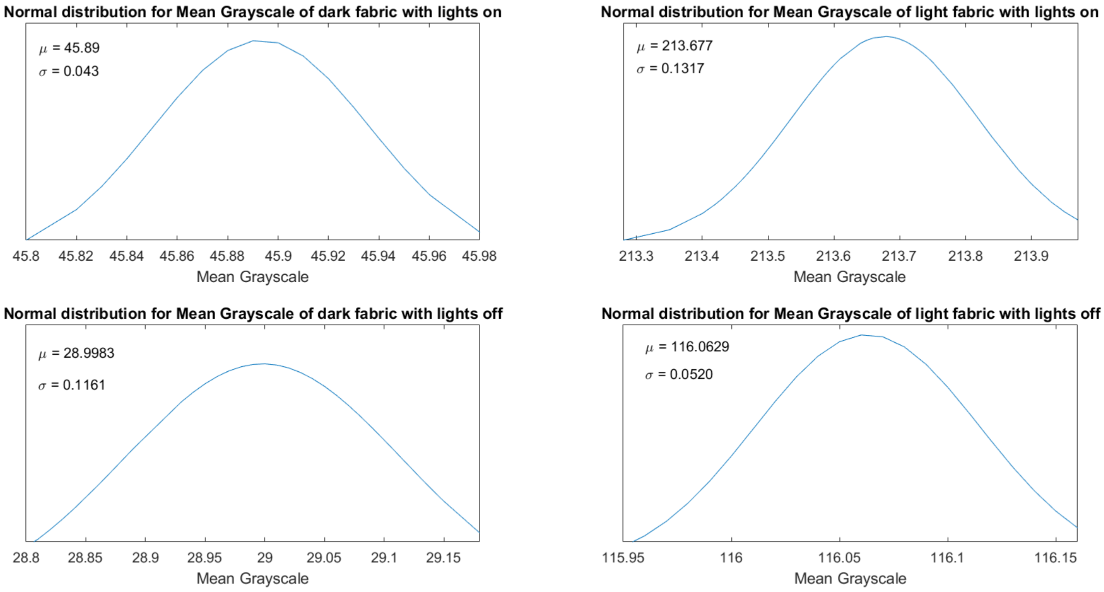


Figure 13: Normal distributions of mean grayscale value for the four cases

Table 9 shows the average deviation in grayscale value, within an image, for the same measurements. It can be seen that the deviation is larger for the light fabric than for the dark. When the external lights are turned on, the deviation within the light fabric increases with 43%. The same number for the dark fabric is 14%, which is small enough to not have an impact on the systems general sensitivity. The large deviation values are due to the fact that the light is not distributed equally across the fabric. This is more visible on the light fabric than on the dark.

Light fabric		Dark fabric	
Ceiling lights on	Ceiling lights off	Ceiling lights on	Ceiling lights off
9.32	6.51	3.33	2.93

Table 9: Average deviation values for light and dark fabrics, with ceiling lights on and off

When looking at smaller parts of the fabric rather than the whole picture there is a greater difference between darker and lighter colours. For a fabric that is one solid colour the grayscale value of each model vary significantly for a lighter fabric. Creases on the fabric will create shadows on the fabric which will be more prominent for lighter coloured fabrics. The flash of the sensor is not able to evenly light up the fabric, which creates darker shadows at the edges of the picture than in the center, and this will affect the grayscale values for lighter fabrics. This can be seen in Table 10.

Model	Dark fabric	Light fabric
Left01	40.22	206.08
Middle01	44.10	207.78
Right01	45.52	215.52
Middle02	46.89	217.09
Right02	46.62	217.68
Middle03	47.67	213.48
Right03	46.57	209.23
Middle04	46.87	204.78
Right04	44.15	197.29

Table 10: Grayscale values for each model. For model-placement, see Figure 6

Table 10 shows grayscale values for the different models, both for light and dark fabrics. For the dark fabric, the maximum difference between two models is 6.67, while it is 20.39 for the light fabric. Once again, the numbers are much larger for light fabric. Since the models are used to determine which kind of fault that has occurred, the offsets need to be large enough to not classify a light fabric as incorrect.

5.1.3 Offset values

The lighting and samples used throughout all tests are not continuously controllable, which means that only discrete patterns can be seen and used to draw any conclusions. In order to determine good offsets, based on the samples and results at hand, different methods were discussed, tested and evaluated. Early on the offsets were simply set as a static value, that would leave enough room to handle the deviation between measurements, but still be small enough to not cover a fault. This value was used regardless of which light setting or fabric colour that was used. But since it was determined that the measured values, even for a correct sample, will vary greatly, see Figure 14 and Figure 15 , this approach had to be reconsidered.

Although it is not possible to determine a mathematical relation between grayscale and different settings, all approaches have been to adapt a linear relation in the form of a percentage of the measured values. Based on how much the measured values of grayscale and deviation differ between measurements, margins of $\pm$ 10% of the average values were determined to make a good fit. If the average deviation would be 3, the margins would give the range 2.7-3.3, which is small enough to not fit a fault and at the same time provide the system with good sensitivity.

When making comparisons between models, the mean grayscale value between different models for light fabrics can be quite large. A third offset is used that is based on the grayscale value difference between models. By comparing each model with the models closest, i.e. model M1 is compared with L1 and R1 from Figure 6 the largest difference is registered and used to set an offset.

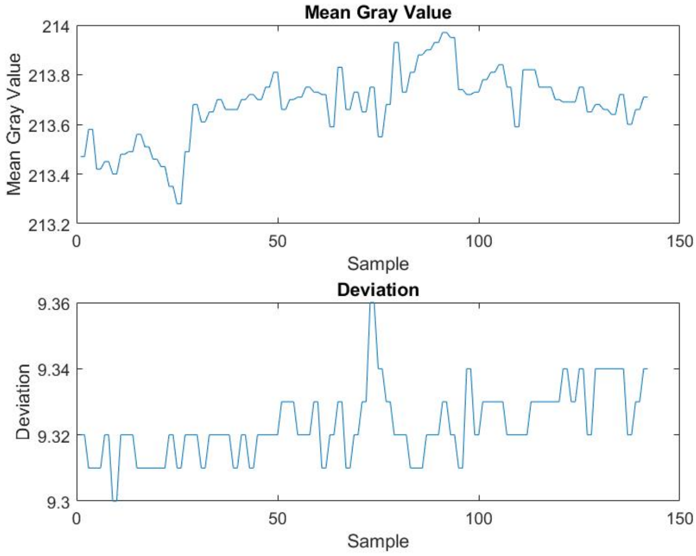


Figure 14: Mean gray value and deviation for a light fabric

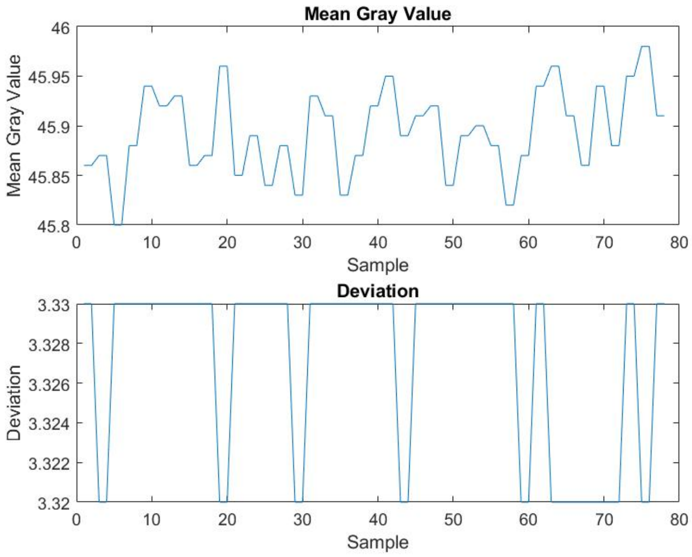


Figure 15: Mean gray value and deviation for a dark fabric

5.1.4 Image acquisition

The fabric in the machine will constantly be moving, therefore it is preferable to use the image acquisition setting function of the sensor as few times as possible. Since it requires a constant stream of correctly dyed fabrics to attain a correct exposure time and focus from the image acquisition setting function, the duration of the function will affect how much correctly dyed fabric is needed. The duration of the function is in the range of seconds, but less than a minute. This is considered a long time for this application. It would additionally require a person overseeing the process every time a new exposure time and focus were to be determined. As long as the sensor is stationary and at the same distance from the fabric, the exposure time and focus will not vary greatly, see Table 11. Therefore, it is assumed that as long as the sensor is not moved, the same exposure time and focus can be used for different colours on the fabric, and thus decrease the amount of times the image acquisition setting function has to be used.

	Exposure time (μs)	Focus
Dark Fabric	10000	65466
Light Fabric	9989	65466
Whiteboard	7065	65466

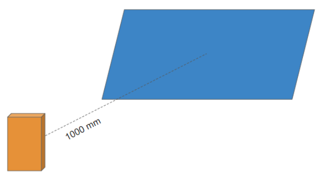
Table 11: Exposure time and focus using the sensor function image acquisition setting

The focus is related to the distance from the sensor to the object, therefore the colour of the fabric will not affect the focus. The sensor is at a distance such that the focus will reach its maximal value. The exposure time will change depending on the colour of the fabric, however the max value of the exposure time is 16.8 seconds, meaning that an exposure time of 0.01 seconds or 0.007 seconds should not affect the results considerably.

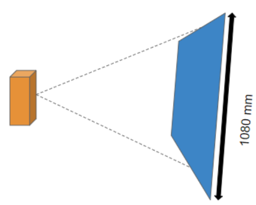
5.1.5 Lens configuration & resolution

The 1.3 MP sensors, with a focal length of 12 mm, would require a distance between sensor and object of 7100 mm, in order to capture the full width of 3.6 m. This is not possible, since the distance between sensor and object is limited to approximately 1000 mm for the real machine. In the case of a 1000 mm distance, the current sensor would be able to see a width of about 500 mm. This means that 8 sensors, on both sides, are required to capture the full width.

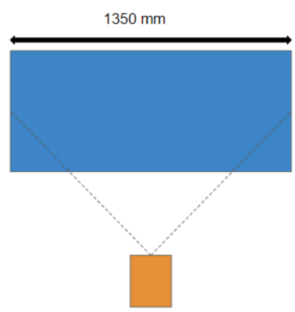
Other lenses exists and the most appropriate one would be the smallest one, with a focal length of 4.6 mm. At a distance of 1000 mm it captures a width of 1350 mm and a height of 1080 mm. This means that a total of 6 sensors are needed to capture the full width, 3 on each side.



(a) Distance between sensor and fabric



(b) Height of Field Of View



(c) Width of Field Of View

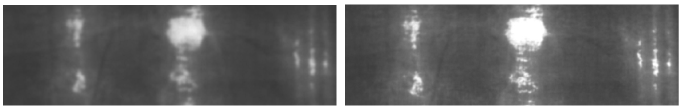
Figure 16: Illustration of sensor setup showing installation distance and FOV

Different lenses have different resolutions at different distances. At a distance of 1 m, the 12 mm lens have a resolution of 0.400 mm/pixel, compared to 1.054 mm/pixel resolution of the 4.6 mm lens.

The test below have been made using a 1.3 MP sensor with a 12 mm lens, but the distances between sensor and object have been chosen so that it simulates the resolution of either using a 1.3 MP or 3.5 MP sensor, both using a 4.6 mm lens.

Figure 17 shows images with two different resolutions. The sensor was placed at a distance of 2400 mm from the fabric to simulate the resolution of a 1.3 MP sensor, with a 4.6 mm lens, and at a distance of 1600 mm to simulate a 3.5 MP sensor, with a 4.6 mm lens. The resulting resolutions are 0.96 mm/pixel and 0.64 mm/pixel, respectively.

The images are quite similar and hard to distinguish from each other by simple visual inspection. The program manages to detect the three faults regardless of the sensor, which suggests that the 4.6 mm lens and a 1.3 MP sensor would fit the application.



(a) 1.3 MP sensor (b) 3.5 MP sensor

Figure 17: Resolution of a 1.3 vs 3.5 MP sensor

5.2 Program structure

5.2.1 State machine

Figure 18 shows a state diagram of how the program behaves. The program runs cyclically every 50 ms.

Initially the program performs a predefined function on the sensor which searches for the optimal image settings. Different focus and exposure times are tested and the optimal ones are chosen. A calibration algorithm is then performed, where twenty images of a correctly dyed piece of fabric are acquired and stored in an array. The values are used to calculate the offsets according to Section 5.1.3 as well as calculating average values for the deviation and mean grayscale value, which are used when comparing new fabrics with the correctly dyed one.

To detect faults, there are three possible cases that the program will determine. The fabric is correctly dyed, the fabric is one solid colour but wrong colour, the fabric is unevenly dyed.

To determine if the fabric is unevenly dyed, which would consist of spots or stripes in a different colour, the sensor will look at the colour deviation in the fabric. There are two cases that has to be true for the sensor to be able to determine that the fabric is unevenly dyed: the deviation has to be larger than the deviation added with the deviation offset, and the large deviation has to be caused by an unevenly dyed fabric rather than lighting problems related to Table 10. Determining whether the deviation is too large or not is done by checking whether the currently measured deviation lies within the limits set during the initial calibration. If this criterion alone was used, a change in lighting from dark to bright would also result in a fault.

If the sensor has been calibrated and calculated its offset values based on a correctly dyed dark fabric, the deviation offset will be quite low. The deviation for a light fabric, however, is much higher, even for a correctly dyed one, since light fabrics are more sensitive to shadows when the light is not distributed evenly. Therefore, when transitioning from a dark to a light fabric, the sensor will classify the light fabric as unevenly dyed, due to the large deviation, even if it is in fact correctly dyed. This is solved by having the second criterion, where it is first determined if the large deviation is caused by either a fault or how the light hits the fabric, before any further fault analysis takes place. The second criterion consists of an algorithm that compares models within the image. The light hits the fabric with more intensity in the center and then decreases further away from the center. The grayscale value of the two models at the edges of the fabric are compared with each other, then the second model from the left is compared to the second model from the right. This patterns continues until the middle model has been reached. Since these comparisons follow the pattern of the light from the flash of the sensor when taking a picture, more light in the middle and decreasing light intensity towards the edges of the fabric, it is possible to distinguish between deviation caused by the lighting and caused by dyeing errors. If the difference between models is larger than a predefined value decided through experiments, then the fabric is determined to be unevenly dyed.

If the fabric is evenly dyed, meaning that the deviation lies within its limits, the sensors instead checks the mean grayscale value of the entire fabric to decide whether the fabric is the correct colour or not. If the current mean grayscale does not lie within the limits set by the offset parameters during calibration, then the fabric is deemed to be the wrong colour. This could either be due to that the colour of the fabric has changed or that a change in lighting has occurred, resulting in the fabric being perceived as a different colour. If 100 consecutive images, which corresponds to 10 seconds, are deemed to be of wrong colour, the sensor will recalibrate. The number 100 is chosen so that small, temporary changes will not result in a recalibration, but instead be classified according to the other presented rules. If none of the cases above are true than the fabric will be considered as correctly dyed.

When an uneven dyed fabric is registered, additional analysis is made to determine what the source of error is. This is done by analyzing each segment that covers the area of one nozzle. Every segment consists of three models covering the right, middle and left area of one nozzle. The possible errors and how they are detected are presented in Table 12. When a fault is registered, an alarm is set and the program then starts over. Three models to cover each nozzle are chosen since the nozzles overlap each other at the ends and the models should observe the two overlapping parts as well as the middle of the segment that is only dyed by one nozzle. A fault due to pressure drop will result in a dark-bright-dark pattern for each nozzle. The nozzles are also connected in series from left to right, which means that a potential pressure drop will result in the pattern growing more visible the further right it goes. Therefore the models must be configured from left to right and a final comparison between the left half side of the fabric and the right half side must be made, in order to properly classify it as a fault due to pressure drop, otherwise it registers as unevely dyed for some other reason.

Error	Description
No error	The left, middle, and right model are all a similar colour, meaning that the grayscale value for each model is equal to the average grayscale value of the correctly dyed fabric as well as each other.
Unevenly dyed - pressure drop	The three models of one segment are compared with each other. The left and right models are a darker colour than the middle model.
Evenly dyed but wrong colour	The grayscale values of the left middle and right models are all equal to each other. However, they are not the same colour as the correctly dyed fabric.
Unevenly dyed - Other reason	None of the stated errors above are registered.

Table 12: Description of errors

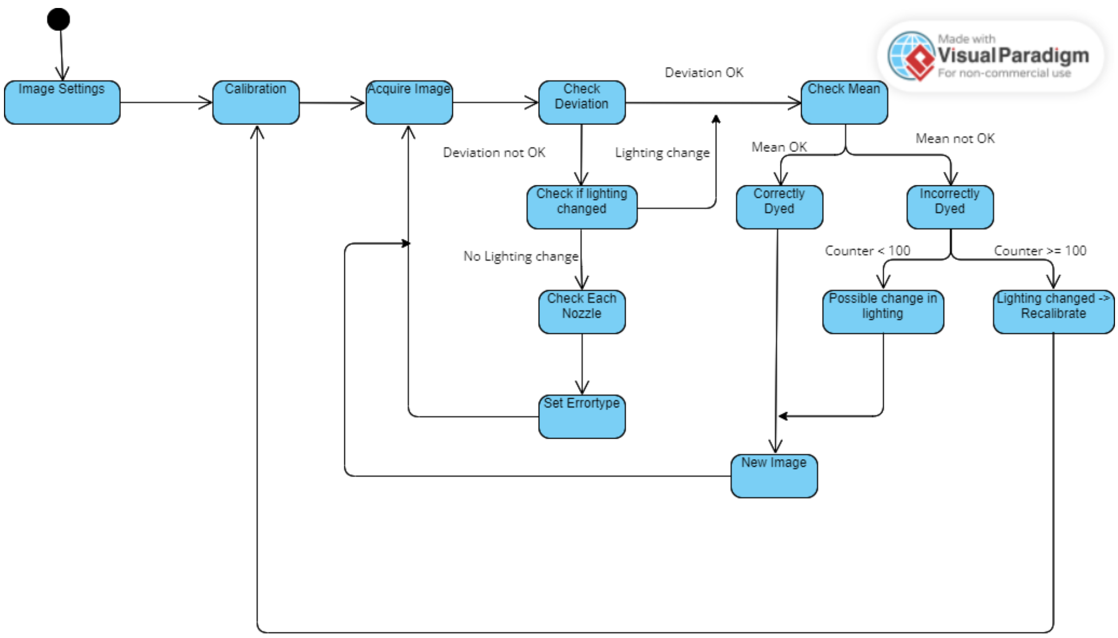


Figure 18: Program state diagram

5.2.2 HMI

In order to make testing easier, as well as making the application more user friendly, an HMI has been created. A description of the HMI and its functionality will be presented here. Images of the HMI can be seen in Figure 19 - 22.

The HMI consists of three pages: MainPage, ServicePage and AlarmPage. If multiple VisionApplications exists, the appropriate one can be chosen and loaded to the PLC on the MainPage. Since the sensor flash can be a bit disturbing, the sensor can be started or stopped from this page as well. In the ServicePage different parameters, such as offsets, focus and exposure time can be set and the sensor can also be recalibrated and/or acquire new settings. On top of this it is possible to start and stop a recording. When a recording is started, a number of parameter values and states are being logged. Once the recording is stopped, all values are saved in an csv file and can be accessed through different programs. In the AlarmPage the different alarms appear. Currently the following three alarms can be displayed: LightChange, WrongColour and EmptyArray. A description of each alarm can be seen in Table 13.

LightChange	The alarm states that a change in lighting has been detected and the sensor will simply recalibrate
WrongColour	A fault has been detected where the fabric has been incorrectly dyed
EmptyArray	No models have been defined and therefore the parameters can not be set. The user needs to define models

Table 13: Description of HMI alarms

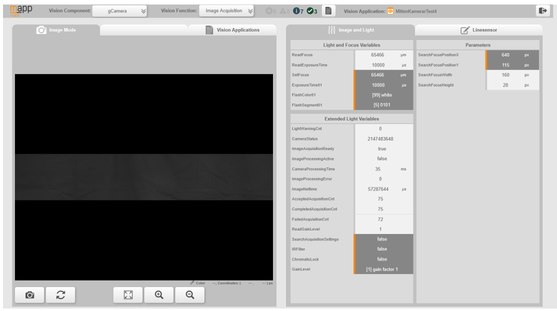


Figure 19: B&R's web based HMI for vision sensors

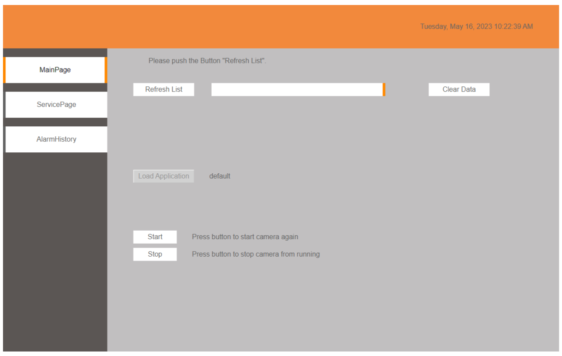


Figure 20: HMI - MainPage

Figure 21: HMI - ServicePage

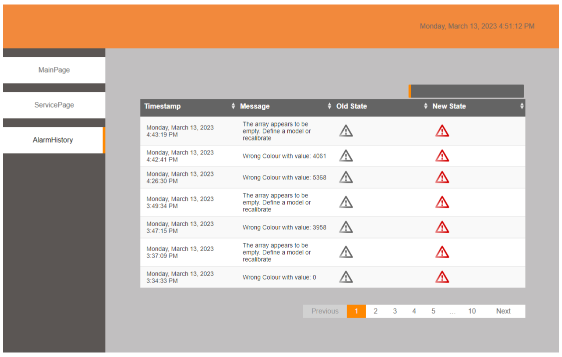


Figure 22: HMI - AlarmPage

5.2.3 Data & timing results

When a recording is stopped, the resulting csv-file will be saved on the PLC. For this project, all parameters and states, that are to be recorded, will result in two files: one file covering the entire fabric and one file that has details about each nozzle. All parameters are logged based on value changes, which means that if one parameter value changes, all parameters will be logged. This could potentially result in quite large amounts of data, especially if the recording is to be done for a long time, if not always, and might potentially require an external storage medium.

To test which datasizes the resulting files would have, the recording was kept on during five minutes of operation. The two files were of 24.2kB and 24.5 kB, respectively. If it is assumed that logging will be done with the same pace, an hour of recording will have a size of around 585 kB and a full 24 hour recording will have a size of less 15000 kB (= 14MB).

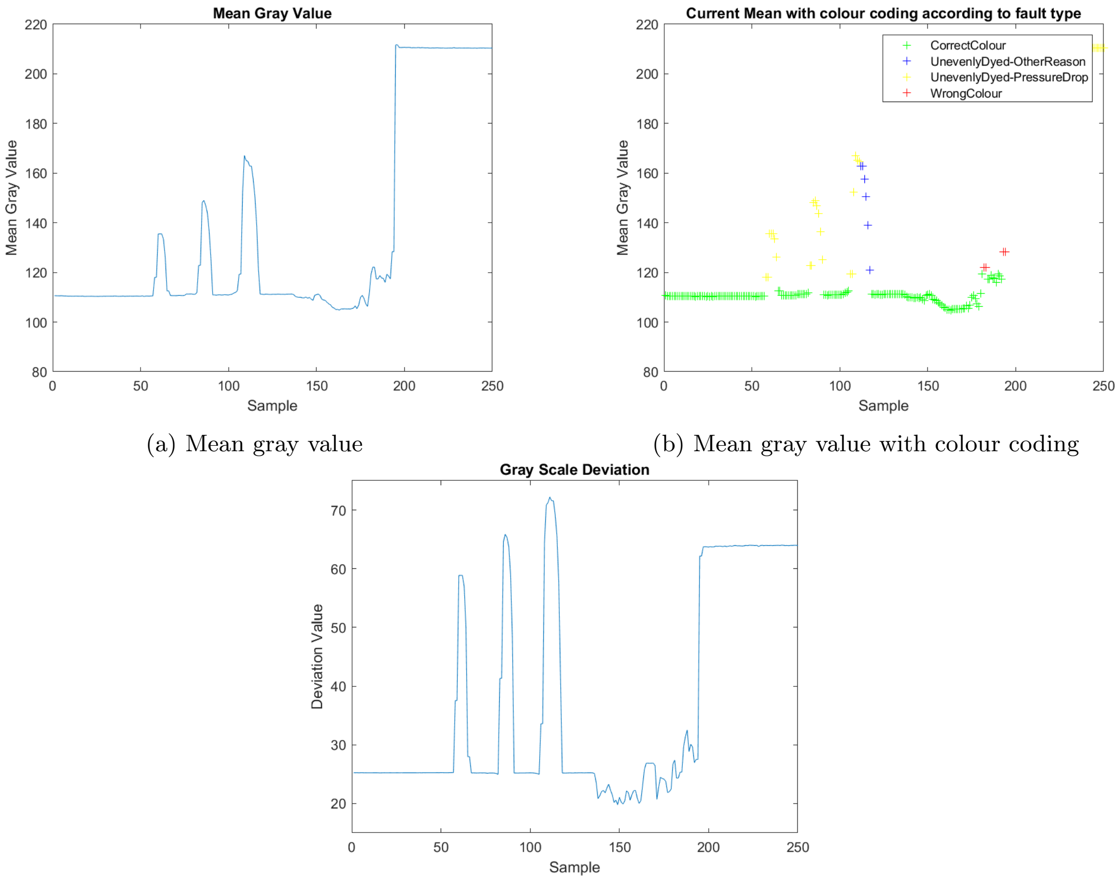
The application is also subject to time constraints. The machine operates at a certain speed and the fault detection system needs to be at least as fast as the machine. A timer function, in combination with the code being run cyclically every 50 ms, is used to make sure that images are acquired fast enough. Tests were performed where 100 images were acquired and the average image processing time was calculated. The resulting number was 75.5 ms per image. The program is structured so that image acquisitions and fault detection can not happen at the same time. This is done to be sure that there are no concurrency problems in the program. This means that it takes one cycle to take a picture, then an additional cycle to process that picture and a third cycle to determine the fault, which means that it takes approximately 150 ms between image acquisition and potential fault classification. When comparing the speed of the Imogo machine and how much fabric that passes the sensor every second with the speed and area that the sensor covers, 150 ms is considered sufficient, see section 3.3, for further explanation.

5.3 Testing on site

Tests were performed on site to see how well the program and setup works on the real application. All information about the setup can be seen in section 4.5.

Figure 23 shows the mean grayscale and deviation captured during the tests. Three spikes can be seen in Figure 23a and Figure 23c approximately around samples 60, 85 and 110. These are all due to that a small white piece of fabric was put in the line of sight. In Figure 23b the mean grayscale, together with a colour coding according to error message is presented and it can be seen that the spikes are classified as faults, where the fabric is unevenly dyed. Since this was the expected outcome, it means that the program successfully manages to detect and classify these faults and changes.

Around sample 150, the fabric starts moving. From this point, it can be seen that the values for both mean grayscale and grayscale deviation starts oscillating, but they are still considered correctly dyed. Towards the end of the recording it can be seen that the samples show a mean value of more than 200. This is due to the fact that the images acquired at this point are of the cylinder and not the fabric.



(a) Mean gray value

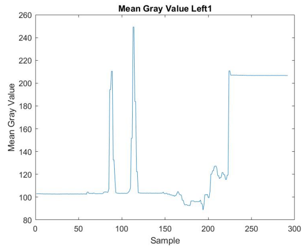
(b) Mean gray value with colour coding

(c) Grayscale deviation

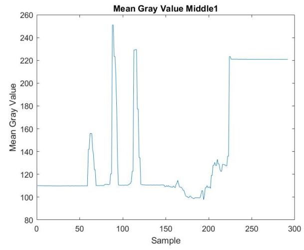
Figure 23: Captured mean and deviation, together with error message, during on site test, with moving fabric.

Tests were also performed where the lighting was changed, or simulated by using different coloured fabric. The program manages to detect changes in lighting going from bright to dark, and then performs a recalibration. In the opposite direction, from dark to bright, the program does not always manage to classify it as a lighting change and not a fault.

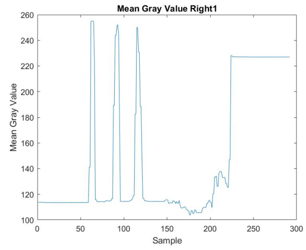
Accompanying Figure 23 further values where logged for each individual model to further analyze the source of errors. Figure 24 shows the grayscale value for each of the models, which were recorded at the same time as the values in Figures 23. All of the models show an increase in grayscale value when the light fabric was placed over the darker fabric. The light fabric is not wide enough to cover the entire image and therefore at different times different models show an increase in grayscale value. Comparing Figure 24a with Figure 24e shows that the mean grayscale value is lower at the start for 24a than for 24e. This is because more light from the sensor flash hits the middle of the fabric than the corners and therefore the corners of the fabric is constantly darker. This can also be seen in Figure 24i, where the grayscale value is lower than in the middle models, for example Figure 24e.



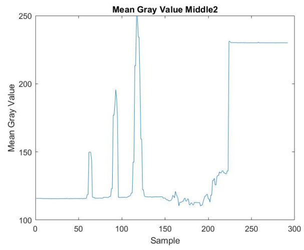
(a) Mean gray value for Left1 model



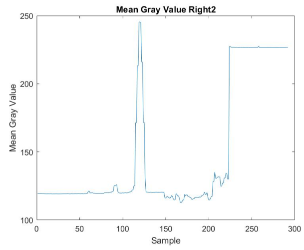
(b) Mean gray value for Middle1 model



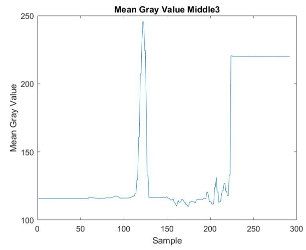
(c) Mean gray value for Right1 model



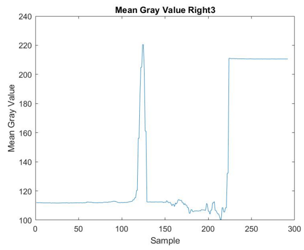
(d) Mean gray value for Middle2 model



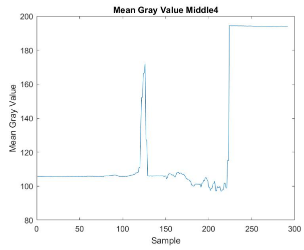
(e) Mean gray value for Right2 model



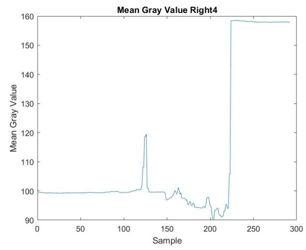
(f) Mean gray value for Middle3 model



(g) Mean gray value for Right3 model



(h) Mean gray value for Middle4 model



(i) Mean gray value for Right4 model

Figure 24: Gray scale values for each of the models

6 Discussion & conclusions

This chapter covers the discussion about the different test results and the on site test, as well as an evaluation of the program in general. Other potential solutions and improvements are also presented, together with the final conclusions.

6.1 Camera & setup

6.1.1 Accuracy & lighting

The mean grayscale and deviation tests show high consistency. Different fabrics result in different measurements, where these differences provide enough information to distinguish one pattern or colour from another. Most tests have been performed in combination with different light segments active and as can be seen in the tables, fewer light segments result in a darker image and more segments result in a brighter image. This means that different baselines can be achieved by using different number of segments. The correctly dyed textile sample used in many tests has a dark blue colour. When using all four light segments, the corresponding gray value is approximately 210, see Table 2. The range of grayscale values is 0-255, which means that if all four segments are used, it causes a dark piece to appear as bright and thus limits the potential range of grayscale values to approximately 45 (210 - 255). On top of this, all colour shades above a a certain limit will result in a grayscale value of 255, which means that they are all classified as completely white. Correspondingly, if zero or one segment is used it will result in a dark image, even if the true colour might be brighter. In the same way as for the light fabric, all values under a certain grayscale value will be classified as completely black if the lighting is too dark. In order to maintain a decent range of values and at the same time providing an image appearance similar to the real test object, it was chosen to use two light segments. Further tuning of appearance can be made by changing the exposure time, if necessary.

The measurement results when testing different ambient lightings, together with a light disturbance, show that lighting has a big impact on the acquired image. A change in ambient lighting can result in significant differences in overall mean grayscale and a light disturbance from direct backlight will cause even larger differences. In general the change of lighting and light disturbances can be split into three cases that require an action.

The first case would be if the external lighting changes in such a way that the entire area visible to the sensor, homogeneously appears brighter or darker. Since it is assumed that the colour or colour shade can not change in the middle of the process, this scenario can be solved by simply recalibrating the sensor. This feature has been implemented in the program. Another approach could perhaps be to use some kind of light compensation, but that would require an external light sensor. This external sensor would then have to be integrated in the system to be able to communicate with the B&R sensor and that might not be possible for all sensors. On top of this, it would require a controllable lighting that could be set to compensate for the ambient lighting. However, in our case, only the number of light segments used can be changed and not the light intensity itself. The lighting is therefore not continuous and would most likely not be able to compensate in a good way. The lighting would then have to be changed using an external light-rig. B&R has external lighting products which can easily be integrated and synchronized with the sensor.

The second case would be if a light change would affect only a part of the visible area. This would result in a too large deviation and considered as a fault by the program. One way of solving this is by using more light to illuminate the fabric. However, this will also make the fabric appear lighter, which has additional problems as stated above. Another way of solving this problem is to prevent it from happening at all. That would require some kind of barrier or alternatively a very controlled environment, where a light disturbance can not reach the visible object. In addition with a barrier to prevent light disturbances, an external rig could be used to light the fabric evenly rather than using the segments of the camera. This would especially prevent the large difference in deviation between dark and light fabrics due to the light intensity being lower at the edges of the fabric than the middle.

The third case would be a light disturbance in the form of direct backlight. This case can basically fit into the two other cases. If the light disturbance causes the entire visible area to homogeneously appear as a different shade, the program will eventually recalibrate. If it on the other hand only affects a part of the visible area, the same applies as for the second case.

6.1.2 Sensor setup

The optimal sensor setup and configuration could not be tested, due to the fact that only the 1.3 MP sensor with a 12 mm lens was available. However, it was simulated, using the sensor at hand, positioned at different distances from the fabric. Although the tests show that the system would work, it still comes with a few disadvantages.

The maximum distance available between the machine and a potential mounting place is 1000 mm. The sensors could be mounted closer, but that would reduce the FOV and therefore require more sensors. In order to keep the amount of sensors required at a minimum, the installation distance will therefore be that of 1000 mm. This will, however, increase the area required by the machine, together with the additional fault detection system, since no person or object can be allowed to block the line of sight. If a person or object were to stand in the line of sight, it would most likely result in the fault detection system classifying it as a fault and depending on the nature of the fault, the system could potentially start to recalibrate itself incorrectly.

The sensor flashes every time an image is acquired. Images are acquired every 100 ms, which means that there will be a new flash every 100 ms. The camera flash can be quite disturbing and it will most likely affect its environment in an unpleasant way. A possible solution would be to have some kind of barrier or enclosure around the entire sensor system. This would be beneficial considering other aspects as well, such as keeping the lighting consistent, as mentioned earlier. Another potential solution would be to simply reduce the amount of light segments used. There is no exact right answer to which or how many segments to use. Every choice comes with both advantages and disadvantages and those have to be weighed and prioritized.

6.2 Program evaluation

6.2.1 Offset values

For the program to be able to operate correctly, values from a correctly dyed fabric need to be collected and used. This requires that an operator can ensure that the fabric is correctly dyed at the start of the program. The program requires 20 pictures of a correctly dyed fabric, which takes approximately 2 seconds to acquire, so the operator is not required to be present for a very long time. From those 20 pictures variables such as average grayscale, deviation and offset values are calculated. The offsets for deviation and grayscale values across the whole fabric are based on the average deviation and grayscale value. The main characteristics of these offsets are to increase the margin in which a fabric can vary in deviation and grayscale value and still be considered correctly dyed.

The offset values, or thresholds, are somewhat difficult to determine and evaluate. The methods to calculate the offsets are based on different measurements of grayscale and deviation of the different textile samples available, which means that they are based on a fairly small amount of colours and colour patterns. Although these values provide a working solution, they could also cause some problems and they most definitely leave room for improvements. It would most likely be more beneficial and accurate to base these values on mathematical or statistical patterns, based on collected data from different lightings and colour shades, rather then very limited tests. However, since the amount of samples available are limited and the lighting is not continuous, it is difficult to draw any such conclusions.

The light reaching the fabric is not uniformly distributed across the entire fabric. For dark fabrics, it does not have much of an impact, which means that the grayscale remains approximately the same over the entire fabric. Any offsets used for dark fabrics, can be kept small and thus minimizes the risk of a fault being able to fit within these offsets. For light fabrics however, the impact is quite big and the difference in grayscale between different models can be as much as 20, which can be seen in Table 10. Such large offsets could potentially fit a fault as well, meaning that a fault could go unnoticed if it does not lead to that the deviation across the entire fabric is greater than the offset. The test setup uses one sensor, while the optimal setup would use three. Using three sensors would result in more light and perhaps together they would create a more uniformly distributed light. But since it can not be tested, it is not possible to know if it would result in an improvement. An alternative solution would be to use an external lighting instead of the built in LED segments.

The camera will be supervising a machine in a factory setting. This means that the lighting in the room will most likely change now and then. The ceiling lights might be turned on or off for example or if there are windows the outside lighting will have an impact. These changes in lighting will result in the fabric having a different appearance and in order for the application to be able to manage changes in lighting, a lightchange detection algorithm has been implemented in the program. This algorithm uses experimentally determined offset values. Due to the fact that light fabrics has a large deviation, even though it is correctly dyed, the limits used when determining whether a light change has occurred or not, could also fit a fault. If the program assumes that a light change has occurred, even though it in fact is a fault, the system would then base its calibration on an incorrectly dyed piece of fabric. This could potentially mean that any forthcoming faults will pass by undetected.

In general it can be seen as a compromise between sensitivity and how dynamic the system is. Having a system that automatically detects changes in lighting, or a complete colour change, since it results in the same behavior, makes the system dynamic. If a light is turned on or off or if an operator starts dyeing the fabric a different colour, nothing needs to be done by the operators themselves in order for the system to be on the right track. But having the system behave in such a way makes it less sensitive to changes and faults. The program could require the operator to always restart the program when fabric of a different colour is coming or if a potential change in lighting is detected. But since it was requested to make it as easy to use as possible and to require as little operator interaction as possible, it was determined that a dynamic, self managing program was better even though it would be less sensitive.

6.2.2 Models drawn in camera HMI

The models used to define the ROIs within an image must be defined manually in the sensors' HMI. They must be hand drawn in the image, which means that it is difficult to place them in the exact right position and having them the exact same size. In this project one model is used to cover the entire image and then three models are used for each nozzle. The model for the entire image is used to determine if a fault has occurred or not and the models for the nozzles are used to make further diagnostics. The nozzle models are the ones that are difficult to get exactly correct. It does not necessarily affect the systems' ability to detect faults, but it does affect its ability to correctly analyze and diagnose these faults. However, the main purpose of this system is to simply detect if a fault has occurred or not, and any further diagnostics can be considered an unnecessary, but helpful feature. All models can be saved and reused as well, which means that if the sensor remain in the same position, the models will only have to be made once.

The final function of the program was expected to be able to locate errors connected to specific nozzles, and through that be able to make conclusions about the system. This makes the sensor very sensitive to how it is mounted. The model placement has to be very precise and correspond to the right area of the nozzle. Another approach would be to use the models to give an estimation on where on the fabric the error has occurred. This requires more of a human interaction with the system to determine the source of the error but it would mean that the sensor would work independent of its placement.

For knitted fabrics, the machine has a different configuration, see Figure 5. In order to avoid potential shadows that can affect the fabric, due to the arched shape of the cylinders, the height of the FOV needs to be limited. This in turn means that only a part of the image make up the ROI. There are two ways of handling this. The first way is to simply draw the models in such a way that only the relevant parts of the image are used as ROIs. However, it makes the placing of each model a bit more difficult and time consuming, since it requires both horizontal and vertical pixel coordinates. The other way is to use the pixel coordinates to determine the size of the relevant area and then crop the image according to these coordinates. Each model then require the horizontal coordinates only. The downside with this solution is that image cropping can not be done during runtime, it must be done manually when the sensor is offline. On the other hand, it only has to be done once, when the sensor is started for the first time.

6.2.3 Edge detection

There are two different cases where some sort of edge detection is needed. The dyeing machine from Imogo can handle fabrics with different widths and therefore the overall width of the fabric will vary. Also, fabrics are less static in its shape than for example paper, meaning that the edges of a fabric will vary instead of being one straight line. For both of these cases, if parts of the cylinder, that the fabric is placed on, is visible in the models, the grayscale and deviation values of the cylinder will have a large impact on the error detection. This was seen during the on site tests where the deviation and grayscale values increased greatly when the sensor was taking pictures of the cylinder, seen from Figure 23. Therefore, some edge detection algorithm is needed.

One way to detect the edges of the fabric is by using the vision function Measurement. Measurement is able to detect objects based on predefined shapes, lines and circles, and based on variables related to the grayscale value, such as contrast and grayscale transition, see section 4.3.3 for further explanation. This function can be used to detect an edge and output the corresponding pixel coordinates. A second method to determine the edges of the fabric is by having an operator manually input the width of the fabric every time it would change.

Once the width of the fabric is determined the models covering the edges of the fabric could be altered so that the edge of the model lines up with the edge of the fabric. However, the models can not be changed during runtime via Automation Studio. Instead the image could be cropped. To change the image the vision application would have to be uploaded again. This procedure takes some time, in the range of seconds, which means that there would be some time where the camera would not be able to take new pictures. If the width is changed due to that a new fabric is being dyed with a new overall width this would be acceptable. The new vision application would only have to be uploaded once in the beginning of the program. However, to detect the edge variations that occur due to the fact that fabric, as a material, does not have a static edge, would not be possible. It is possible that the edge would vary between each picture taken and therefore a new vision application would have to be uploaded every time the camera takes a picture, which is too time consuming. Therefore there would have to be some margin so that the models do not cover the fabric all the way to the edges. Since the models can not cover the fabric all the way out to the edges there is no way to ensure that the fabric is correctly dyed at the edges.

An operator would not be able to manually enter the small variations that occurs within the same width of the fabric. The variations are too small and the operator would have to be engaged the whole time. This would be the main purpose of using the VisionFunction *Measurement*. If some margin would be used instead so that the models would not cover all the way to the edges of the fabric, edge detection would only have to take place at the start of the program, to determine the overall width of the fabric. If an operator is present too, for example overseeing the calibration of the camera to gather values of a correctly dyed fabric, then the operator might also be able to manually input the width of the fabric. If this is possible the usage of Measurement could be excessive. If Measurement is used a B&R smart camera would have to be used to be able to handle multiple vision functions. It would bring with it more complex code, where the edges first would have to be detected, then altered and uploaded to the camera, and then the rest of the code can run.

6.2.4 Limited number of test samples

The program is based on the fabric samples available, therefore there is a large amount of scenarios that has not been tested. The colours used for testing are limited to two different shades of blue and one white fabric. There is a possibility that there are shade differences that are visible to the human eye, but not to the camera. If the errors are very small they might potentially not be registered. In the fabrics in Figures 8c and 8e the errors are very specific and visible. Figure 8e shows an error caused by pressure drop in the system. In this textile sample, the white and blue lines across the fabric are clearly visible to the sensor, but that might not always be the case. It is possible that a fault due to pressure drop will be less significant and the lines not as clearly visible. On top of this, these lines might not appear across the entire fabric. For Figure 8c the source of the error is a clogged nozzle, for this example the darker line on the right is distinct and there is a white line in the middle. If the clogged nozzle were not as affected then these colour differences might be less clear. To be able to detect small variations in colour, increased lighting might be one solution. However, this comes with other potential difficulties as stated above. There are a number of errors that have not been identified, since they are not present in the fabric samples used for this project, but they still need to be classified as faults, even though the cause can not be stated. If none of the states "pressure drop", "correct colour" or "wrong colour but correctly dyed" is registered, the state is simply registered as "other error".

This is also what a clogged nozzle is registered as. An error caused by a clogged nozzle can have many different colour patterns and is therefore redeemed to be categorised as an unspecified error. Still, it can be located to a certain position on the fabric.

6.2.5 Error analysis

The main purpose of the camera is to register if an error has occurred. However, if possible, it is preferred to further locate and analyse the error. When an unevenly dyed fabric is registered, further analysis could be made about the error. Two different errors were looked into, errors due to pressure drop and other errors, assumed to be caused by a clogged nozzle. The characteristics of an error caused by pressure drop is that the fabric is darker where the nozzles overlap and brighter in the middle. For the models used in all images, this corresponds to the segment, covering one nozzle, being darker at the edges and brighter in the middle. This due to the fact that the amount of paint coming from one nozzle is not enough to correctly dye the fabric. The overlapping parts get paint from two nozzles, which means that although they will not be correctly dyed, they still get a darker colour. The nozzles are connected in series from left to right, which means that if a pressure drop has occurred, the amount of paint that is applied should decrease the further right the nozzles are. The program will give an estimation about the error for each nozzle, see Table 12, which could be used to make estimations about the entire system. If an error for one nozzle is registered as Unevenly dyed-Other and the rest is registered as No error, then the error for the system is probably related to one nozzle being clogged. If multiple nozzles register Unevenly dyed-pressure drop, the cause is most likely pressure drop, especially if the nozzles that register this error are in series. Additionally, when a pressure drop occur, the mean gray value should decrease the further to the right the nozzles are since less paint reaches those nozzles. Therefore, by comparing the grayscale values of the left half side of the fabric with the right half side, it is possibly to conclude that it is in fact an error caused by pressure drop in the system.

6.2.6 Dynamic system

Throughout the project there has been an evaluation on how much an operator has to be involved in the system. If the width of the fabric should be automatically registered or if it should be decided through human interaction? If an error is registered should a human conclude the source of error or should the program be able to do that? Can it be guaranteed that the fabric initially is correctly dyed so that the camera can calibrate correctly?

The way this program operates is by calibrating itself, based on a correct sample, and then perform comparisons between measurements and different thresholds. This means that the program is highly dependant on the fact that a calibration is done on a correct piece. If that is not the case, the system will most likely fail its mission to detect other faults. It is not a difficult thing to ensure, that only correct pieces are used for calibration, but it does require more of an operator interaction. The initial calibration requires the sensor to take 20 pictures and therefore it has to be guaranteed that the fabric is correctly dyed for 2 seconds. This would perhaps be considered an acceptable amount of time to supervise the system. Although the goal has been to minimize the need for human interaction, it can not be removed completely, but it has been limited to the initial installation only. The position of the sensor has to be at the right distance and the models have to be drawn to cover the different segments. When the sensor is installed it is considered sufficient if an operator is involved each time the width or colour is changed.

6.3 On site test

Multiple tests were carried out on site with different fabrics and lighting in the room. The following is mainly describing one test carried out since it included many functionalities of the program and camera.

The camera managed to detect when a lighter coloured fabric was used to simulate an error caused by a nozzle fault. This results in lighter lines on the fabric, which can be seen in the form of spikes in Figures 23a and 23c. In Figure 23b it can also be seen that the error message switches from CorrectColour to UnevenlyDyed and then back to CorrectColour again, which corresponds to the light fabric being placed over the main fabric and then removed again. By looking at the grayscale value and the deviation of the entire image it is also clear that a lighter fabric is placed on top of the main fabric. The average grayscale value is 110.58 and when the fabric is lying still and only the main fabric is in picture the grayscale value is close to the average value. When the ErrorMessage changes value to UnevenlyDyed the grayscale value rises to a value around 135.00, which indicates that a lighter fabric is in the picture. The deviation changes value too, which indicates that a different coloured fabric enters the picture. The average deviation value is 25.22 and when only the main fabric is in the picture the deviation has similar values. However, when the ErrorMessage changes value to UnevenlyDyed the deviation increases to values around 58.80.

By looking at the grayscale values for each model, the error from the lighter fabric can be specified to a certain area of the fabric. When ErrorMessage changes value to Unevenly Dyed the first time, the grayscale value of model M1, R1, and M2 which corresponds to models covering the middle and right of segment 1 as well as left of segment two, see Figure 6 for explanation on model placements. This indicates that the disturbance fabric covers the left side of the fabric. However, not all the way to the left edge. The fact that different models show different grayscale values, depending on whether the disturbance fabric or the main fabric is in the models ROI, shows that it would be possible to pinpoint errors to certain areas of the fabric. This functionality makes it possible to further analyze different faults, compared to simply stating that a fault has occurred.

Once the fabric starts to move, which means that the fabric is pulled through the machine, the grayscale value starts to vary. Similar tests were made multiple times, for all tests the grayscale value started to oscillate once the fabric started moving. During the test presented, there were some variations in grayscale value, however the camera was still able to make correct evaluations about the fabric. Figure 25 shows an image of the fabric, acquired by the sensors. This is the picture that grayscale values is retrieved from. There are two aspects of this picture that could have an effect on the variation in grayscale values. Firstly, there are creases on the fabric. During the test the fabric was dry, which makes it easier for creases to appear. If the fabric had actually been dyed, it would be wet from the paint. On top of this, if the machine had been running correctly, the fabric would be have been kept stretched, which would reduce the amount of creases. When the fabric is pulled rather then rolled through the cylinder, it could potentially create creases. Since creases creates shadows, the grayscale values across the fabric will change depending on the creases. Secondly, fabrics have small gaps between the threads, compared to paper for example that has a more smooth surface. These gaps will create a colour difference, which can be visible if the camera is placed close to the fabric. The image quality is not known when the machine is running and pictures should be taken on the fabric when moving. There is a possibility that when the fabric starts moving and the image becomes increasingly blurry, the gaps between the threads becomes harder to detect and will therefore change the image and through that change the grayscale value. This will not necessarily be a large problem, if the fabric is moving with a constant speed, the calibration will also be performed on a moving fabric. However, errors might be harder to detect if the image quality becomes worse when the fabric starts moving. The exposure time for this project has been fixed on a certain value since most tests have been performed on a static fabric. The fabric will move from the time that the shutters open to that they close. By lowering the exposure time the fabric will have moved less and more details in the fabric will be visible but this would require more light when taking a picture.

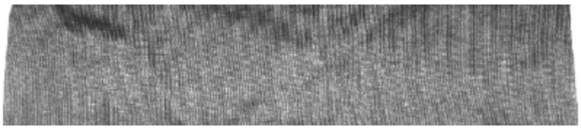


Figure 25: Picture of fabric from the smart sensor

The tests carried out on site, tested the main functions of the sensor and there are multiple tests that should be carried out before the sensors can be used on real machines, see Section 7. However, the test do show that it is possible to detect errors using the camera in an industry factory as well as in an office environment.

6.4 Other possible solutions

In section 2.2 other possible solution were presented. With the B&R smart sensor as reference, the other solutions have been evaluated and compared based on the following criteria: Available Functionality, Sensor Configurations, Integration Complexity and Potential Cost. It would be beneficial to also evaluate the performance of these sensors, but since there are few or none scientific papers about specific vision sensors, their performance in different applications can not be determined, only speculations can be made.

6.4.1 Other vision systems & vision systems in general

Most vision systems available on the market are most commonly used for detection of faults of a smaller nature than this project. Their purpose is to perform simple pass/fail operations, based on different parameters, such as shape, size and colour. Vision systems are perhaps not limited to perform such tasks, but this suggests that maybe a different type of fault detection system could be more beneficial and better suited for this specific problem.

Keyence IV3-600 smart camera

The relevant tools of the Keyence IV3-600 smart cameras are similar to the ones offered by the B&R sensor. The advantage of this sensor is the possibility to use ML, together with training data, to fit models of correctly and incorrectly dyed pieces of fabric. This would mean that an acquired image is compared to different models, rather than more uncertain thresholds or offsets, which in turn would make the system more robust and less based on experimental data. The machine from Imogo is based on B&R products, which makes the B&R sensor optimal from an integration point of view, but the Keyence sensor would most likely also be possible to integrate in the current system, since compatible communication protocols exists.

The Keyence camera might offer an improvement regarding the software part of the detection method, but the hardware setup would remain the same. In order to get as big FOV as possible, while using as few sensors as possible, the installation distance has to be 2000 mm, which is worse than for the B&R sensor. Three cameras on each side of the fabric are still required to fit the full width of 3600 mm. The fairly large distance between camera and object would also make the system more sensitive to light changes and light disturbances and it would mean that a larger area will have to be occupied by the machine.

6.4.2 Sensor based solution

A camera comes with many advantages and makes it possible to make more advanced analysis of the pictures. However, the complexity of using a camera also brings more configuration choices and a greater sensitivity to disturbances. This means that a colour sensor would be a more simple and straight forward solution. However, when looking at different colour sensors, such as the CSS High Resolution from SICK or the OFP401P0189 Color Sensor from Wenglor, there is one common disadvantage. The light spot has such a small diameter of a couple of millimeters only, which means that it is very difficult to cover the entire width of the fabric with colour sensors. If the whole fabric were to be covered, a great amount of colour sensors would be needed which would be an expensive solution. Especially unevenly dyed patterns that are caused by partially clogged nozzle would be very hard to detect. The errors could occur at random places, which would make it hard to place colour sensors in such a way that it could be guaranteed that no errors had occurred, without covering the entire width.

Stemmer Line-Scan-Bar

The Line-Scan-Bar from Stemmer offers many improvements. The working distance of 27 mm is very small, which means that the system would be less sensitive to disturbances. The LEDs distributed along the bar would create a uniform light across the fabric, which would most likely reduce the differences between fabrics of different colours and by that reduce the need for large offsets. However, the system would still have to be based on offsets, which means that all the requirements needed to determine good offsets still remain. Since the widest bar is 1688 mm, three sensors would be needed on each side. However, the width of the bar is 1755 mm, which could potentially mean that there is an area between the three bars that will simply not be visible to either of them. Therefore there would have to be some overlap between the sensors to cover the entire fabric.

Both the B&R sensors and the sensor from Keyence come with a user friendly interface, which makes it quite simple for the user to change different settings and test different configurations and parameters. The Stemmer Line-Scan-Bar is perhaps a bit more complex in comparison, since all settings and parameters are altered using register values.

PLEVA Material Moisture AF.RF.MP 120

It would be possible to use the sensors from PLEVA in combination with the rest of the PLC system from B&R, since compatible communication protocols exists. An advantage that comes with moisture sensors is that the lighting parameter and different disturbances, in the form of creases and shadows, do not have an impact. This means that the system would be less sensitive to complications regarding these kinds of parameters.

The sensors from PLEVA are sensitive and likely to be able to register small variances in applied paint. An accuracy of ± 1 is sufficient for this project, and the best cases of $0.3gH_2O/m^2$ or $0.8gH_2O/m^2$ are both very accurate when compared to the measuring range. However, the amount of paint used in the machines from Imogo vary greatly and there are cases where the paint used exceeds $200gH_2O/m^2$ and therefore the RF120 is not a possible option.

One constraint is the size of the setup. Especially when dyeing knitted fabrics, the space where the sensor can be placed is small, see Figure 5. The frame would have to be placed between to cylinders for the fabric to be able to flow freely through the sensor frame. For both sensors but especially for the traversing heads, the frame depth is large enough to require an alteration in the mechanical design for the Imogo machine.

A problem with the PLEVA sensors is that they are made for a different kind of dyeing machine. The padder control solution is based on the more traditional kind of dyeing machines, where the fabric goes through a colour bath. Besides the fact that this results in a more wet fabric, this also give rise to a set of completely different faults, compared to the spray nozzle technique in Imogo's machines. When using spray-nozzles there is a greater risk of getting spots or lines that are not dyed. These spots and lines are connected to specific nozzle areas, but could still occur in different parts of the fabric. Using only three sensors is therefore not enough for Imogo's machine. It does not provide enough information to tell whether the entire fabric is correctly or incorrectly dyed, since there is a possibility that an error appears between the areas covered by two sensors heads. One measuring head covers an area of 250mm while the maximum width of the fabric is 3600mm, which means that there is a large area between two measuring heads that is not covered.

To be able to use the traversing sensor MP120 there is a need to make alternations to the Imogo dyeing machines because of the size of the frame. It could be used to gather information about the entire fabric and maybe separate between correct and faulty dyed fabrics. If used under supervision on a correct fabric, the values from a correct fabric could be used as reference value for further measurements, the same way the B&R camera calibrates at the start of the program. Since the traversing sensor would only be able to differ between right and wrong, rather than make further analysis on the errors, like error placement, it might not be worth the alterations needed to the mechanical design to be able to fit the frame. The static sensors AF120 are well suited for a dyeing system using padder control, but for a system using spray-nozzles there is no way to ensure that there are no errors between the sensors. To be sure that the fabric is correctly dyed the whole area of the fabric would have to be covered, which could be done by increasing the amount of static sensors. To be able to cover a fabric width of 3600mm wide, 15 sensors would have to be used. This could be a very expensive solution.

6.4.3 Evaluation of other solutions

Figure 26 shows an evaluation of all the possible solutions presented above. The different solutions have been evaluated and compared to the B&R sensors based on the four criteria seen in the figure.

As can be seen in the figure, the Stemmer Line-Scan-Bar is considered the best alternative, mainly due to its short working distance and large FOV. Still, no solution is considered a perfect fit, since they all come with both advantages and disadvantages. Since the Imogo machines are based on B&R systems all other solutions are considered to have a greater integration complexity.

	Concept variants			
Selection Criteria	A IV3-600 - Keyence	REF: B&R Smart sensor	B PLEVA AF310	C Line Scan bar - Stemmer Imaging
Functionality	0	0	+	0
Configurations	-	0	-	+
Integration Complexity	-	0	-	-
Expected Performance	-	0	-	+
PLUSES	0	-	1	2
SAMES	1	-	0	1
MINUSES	3	-	3	1
POINTS	-3	-	-2	1
RANK	3	-	2	1

Figure 26: Screening matrix

6.5 Conclusion

The solution has both advantages and disadvantages. It performs well when it comes to detecting faults on static pieces of fabric and could potentially do the same on moving fabric if the fabric is free from shadows and creases. By using a vision sensor it is possible to actually look at the visible result, but at the same time a vision system is an interaction between so many different parameters and settings that it becomes difficult to find the optimal configuration.

Lighting is the most important parameter, but also the hardest one to control. In order for the system to present a high level of sensitivity and robustness and still be dynamic enough, the environment around the system should preferably be controllable in terms of light and disturbances. If it is possible to make alterations to the machine design so that the camera is isolated from surrounding light and adding an external light source then the performance of the camera would increase. This would most likely remove the big differences between dark and light fabrics, which in return would make it possible to have more sensitive offsets.

Vision based solutions are sensitive, differences in light has a big impact on the results, it requires a certain distance between camera and object, and the fabric preferably has to be straight with no creases. However, it is a solution that is possible to apply to multiple settings. The dyeing machine from Imogo requires some flexibility from the fault detection system. Different machine configurations are used depending on if the fabrics are woven or knitted. Certain errors, related to clogged nozzles for example, can appear anywhere on the fabric and therefore the colour patterns are hard to determine beforehand. A solution such as the sensor used in this project does have a benefit regarding these aspects, since it can be mounted in many different ways to fit the different machine configurations. Other solutions have been looked into and some provide similar adjustable configurations, while others are very dependant on that the Imogo machine works in a certain way. To be able to use the vision sensor on a real machine however, further testing should be made. A camera with the right sensor configurations should be used in combination with an external light rig. Further testing on fabric samples should also be made to both make sure that it works on a larger variety of fabric colours and to get a clear sense of how sensitive the camera is to colour differences. With further testing and development in a controllable environment, an optimal system could be determined and different parameters could be set. Controllable lighting and a continuous spectrum of colour shades could potentially make it possible to detect certain mathematical and statistical patterns, which in turn could be used to set the different offsets.

Other solutions has been looked into and evaluated and there are both benefits and downsides with each solution. The IV3-600 smart camera from Keyence does have a benefit when it comes to training the camera using machine learning to detect errors. However, since the field of view is worse than for the B&R smart sensors, it would serve as no improvement regarding the sensor setup. The material moisture sensors from PLEVA are unrelated to vision, which would mean that all of the complications that comes with lighting and creases on the fabric could be ignored. It would, however, not be possible to use it in a way that would ensure that the entire fabric is error free, since there would be areas on the fabric that would be unchecked. The possible solution that most likely could be used instead of the smart sensor from B&R is the Line-Scan-Bar from Stemmer. Since the distance between the sensor and the fabric is much shorter than for the smart sensor, any disturbances from inconsistent lighting would have less of an impact. The distance between the Line-Scan-Bar and the fabric would be 27mm and provide a FOV of 1688mm. The sensor would require a distance of 1250mm to be able to reach the same FOV. The same problems with edge detection for the smart sensors will remain for the line scan bar. Since the edge will vary for the fabric, the edge would have to be manually decided. Further testing would have to be made in order to be sure that the line scan bar would be a better solution than the smart sensor. The sensitivity of the line scan bar has to be tested to see how well it can differentiate between colours and how small the errors can be and still be noticed. Creases and shadows that can occur due to the characteristics of fabrics will most likely still have an impact, even if it would be a smaller one.

It has been proven that it is possible to detect faults using the B&R machine vision sensor. How well it can perform has to be further elaborated. Large errors can be detected and it is a first step towards a solution that can be used for fault detection in a real machine. There are improvements that can be made to the software, mainly to the offset selection and error classification when more samples of different colours and errors are analyzed. With small alterations to the machine design, such as an external light rig and a barrier that reduces surrounding light disturbances, the performance of the camera could improve greatly.

7 Future work

This sections presents future work that can be made in order to improve the solution.

In order to create a fully functioning and well optimized fault detection system, more testing has to be made. Optimally in a different environment, where things such as lighting, disturbances and samples are continuous and controllable. This would make it possible to draw more mathematical conclusions on what kind of offsets or thresholds to use and to make sure that the system is robust and can fit many different types of colours and patterns.

The setup used in this project is limited by a number of factors and even though a setup, that is believed to fit the application well, has been determined, it has not been tested. If the system should be further developed, it should be tested with the 4.6 mm lens and the correct amount of sensors. On top of this, it should be tested with sensors on both sides of the fabric, since a proper system is required to look at both sides. It should be fairly easy to use multiple sensors, since they are easy to integrate and synchronize, but still it is hard to predict how the system would behave. More cameras in use means more light coming from the sensors, which might have an impact. The flash from one sensor is very likely to reach the sensor next to it, therefore testing with multiple sensors should be done. On top of this, the fabric can be quite thin, which means that if there are sensors on both sides of the fabric, the light coming from the flash will most likely shine through the fabric. Sensors on different sides could potentially serve as disturbances for each other, which means that this case needs to be properly tested and evaluated. One possible way to solve this is by having each side do a different task for each cycle. Since the program is structured in such a way that image acquisition is performed in one cycle and image processing in the next, sensors on one side could acquire images when the other side is processing their image and then switch for the next cycle. This means that in one cycle, only one side will take a picture. The parameters set for this project might have to be re-tuned when multiple cameras are in use. If an external light rig is used instead of the flash of the camera then further testing with the new setup should be made. More sensors would most likely also require software changes, since more models will be used. The line up between these and how to extract the correct data from the correct place might not be as straight forward as it is for the one sensor case. A multiple sensor based system would also need more features and functionalities, such as edge detection in order to detect where the fabric ends.

Only one test has been done on the real machine, which has not covered all of the errors that could occur when it is running. In order to create a truly good fault detection system, it would have to be further tested on the real machine, when it is operating correctly. It would also be interesting to test and evaluate the effect of different additional equipment, such as an external backlight and/or a barrier. Lighting plays a key role in how well a vision system works, therefore such additional equipment have the potential of improving the system and making it more robust and reliable.

8 References

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