Automatic vision system for wheel surface inspection and monitoring

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ABSTRACT
In order to stand out from the competition, the only alternative for automotive industries, including wheels manufacturing industries, is to grant lot of importance to their products quality. In recent years, most of the customer returns of defective products are due to appearance defects, which are associated with the wheel aesthetics. These defects are located on the outside of the wheel and are mainly related to the quality of the painting. In general, the defect detection process is a manual process conducted by operators, which is subjective and difficult due to the complicated wheels surface. This paper proposes to design a fully automatic computer vision system to inspect the whole surface of the wheel. It is proposed to use four cameras placed over the production line. A diffused lighting system is considered in order to illuminate homogeneously the whole surface of the wheel. Each wheel is designed with specific parameters that define its form and geometry. For defect detection, an original adaptive linear parametric model is proposed. This model is sufficiently general to describe any type of wheels. The adaptivity of the proposed model makes it sufficiently accurate to describe the inspected wheel surface while detecting small defects by using an optimal statistical hypothesis test. In addition, the computer vision system monitors in real time the wheel coating intensity. Using a parametric sequential method, this monitoring allows the detection of any abrupt changes, i.e. small decreasing amount of paint, that would reveal a sudden problem in the painting process.

Keywords: Computer vision, wheel inspection, quality control, hypothesis testing, sequential monitoring

INTRODUCTION
The automotive industry has been undergoing a period of growth due to the ever-increasing global demand for automobiles. On average, the production of automobiles has been growing by 2.2% every year since 1975 [1], thus making the automotive industry one of the world's most important economic sectors by revenue. On the other hand, the automotive industry has entered the phase of “globalization”, meaning that today, a company has less and less geographical privileges in the market [1].

With the ongoing competitive pressures, the only alternative for automotive industries, including wheels manufacturing industries, is to grant lot of importance to the quality of their products. As a result, many regulations and standards have been introduced to define the proper control techniques. The ISO standard [2] describes two test methods to evaluate fatigue strength characteristics of wheels used on passenger cars. These inspection techniques fall into the category of destructive testing (DT), in which case a product is forced to reach its failing point by the application of various load factors [3, 4]. These techniques are essentially applied offline on a small sample of the production, and when a defect is detected, the production stops in order to diagnose and find the faulty process or machine. Finding the defects and their potential causes was the first step, which was followed by updating and improving the manufacturing processes to avoid such defects. As a consequence, in recent years, most of the customer returns for defective products were due to appearance defects, which are only associated with the wheel aesthetics. These defects are located on wheels outside surface, are mainly related to painting quality and occur randomly since they are due to product handling errors or to process related faults. Thus, such defects usually affect some products randomly, which means that it is mandatory to inspect every single product and that only non-destructive testing can be used to preserve the future usefulness wheels. Besides, the testing process has to be carried out in real time and fast thus limiting the potential testing techniques that can be used. Eventually, another difficulty to the detection of such defects is that no prior information, such as the size or shape, of the potential defect is available for the inspection process. Till today, this inspection is carried out (fully or partially) manually by operators whose role is to inspect each and every wheel, that is up to several thousand products during a day. The main advantage of human evaluation is its great flexibility with regard to the various types and shapes of appearance defects that can be present on the surface of the wheel. However, human inspection faces major disadvantages, as the decision is usually subjective and sometimes biased [5, 6]. This results in an uncertainty and a lack of precision for the detection of certain appearance defects.

To overcome these difficulties, automated visual inspection (AVI) has been proven to be the best alternative for industries to rely on [7] especially for removing variability and subjectivity in decision-making. Furthermore, the higher precision and resolution that an AVI system can reach enable it to perform better for detecting small defects. At present, there are commercially available systems that can perform inspection of wheels surface using X-ray imaging. Most of these systems use multiple view inspection techniques to overcome the wheel irregularities, and to detect defects with different orientations [8, 9]. In such systems, several images of the wheel with different views are acquired in predefined positions. This leads to an inspection cycle for each wheel of at least 20 seconds, which will only enable to inspect a total of roughly 4000 wheels per day. This number is generally low for a wheel industry, hence limiting its production capabilities. Detailed description of such systems can be found in [10, 11].

Besides, X-ray testing is not convenient for the inspection of the wheel defects related to aesthetics. This is mainly due to the specific characteristics of the aesthetic defects, like painting drops and smear marks, which have a negligible, or even nonexistent, impact on the amount of X-ray radiation passing through as compared to the impact of the wheel material. For aesthetic defects, their density compared to the density of the wheel metal is insignificant. Thus the X-ray radiation will be greatly affected by a slight metal irregularity on the wheel surface, but not sufficiently affected by the presence of an aesthetic defect. As a result, the contrast introduced by the presence of such defects in the X-ray image of the wheel will not be relevant.

In this work, it is proposed to design a fully automatic visual inspection system to inspect the whole surface of the wheel using a multi-camera installation. The imaging system is placed over the production line of a wheel industry to test its efficiency. A diffused lighting system is considered in order to illuminate homogeneously the whole surface of the wheel. A parametric detection method is developed to inspect the wheel surface, along with a sequential method to monitor in real time the wheel coating intensity.

INSPECTION REQUIREMENTS AND SPECIFICATIONS

Real-time surface inspection of finished wheels faces a number of challenges. Some are imposed by the specific characteristics of wheel surface inspection, while others are imposed by the industry:

- The surface of the wheel has a complex geometrical design, with irregularities in different directions. Those irregularities may sometimes hide defects when inspecting the wheel from a single direction.
- The variability in wheel designs and defect types is a major challenge to address. The AVI image acquisition system should be designed in a way that enables the inspection of the whole surface regardless wheel design. Besides, the detection method used within the AVI should also be able to adapt to this variability.
- Most of the finished wheels are coated with a glossy paint layer that renders the wheel surface more reflective. That makes it difficult to design a proper lighting system that minimizes the possible light reflection artifacts in the wheel image that could result in false alarms during the detection procedure.
- In order to increase the productivity and maintain it above a certain limit imposed by the industry, the wheels do not stop under the AVI system, but are rather moving at a constant speed of about 1m/s. Consequently, the AVI system must be able to capture the image of the moving wheel without any distortions or blurring that may decrease the image quality, thus the inspection efficiency.

Table 1: List of the main potential defects with their characteristics

Type	Cause	Acceptance Limits	Frequency (ppm)	Examples
Imprint	Stamping process	Area ≤ 30 mm²	~ 2000	
Painting Drops	Painting process	Area ≤ 20 mm²	~ 5000	
Black Dots	Cataphoresis process	Area ≤ 30 mm²	~ 2000	
Scratch	Product handling	Width ≤ 2 mm Length ≤ 15 mm	~ 1500	

Defect Types

Given a set of product specifications, any deviation from what is standard, or normal, to the product is considered an anomaly. Furthermore, if the anomaly surpasses certain acceptance limits, which are usually defined by the customer, it is then referred to as a defect. Appearance defects can be divided into two different types whose origin, impact and relevant method of detection differ widely:

- Local appearance defects:

Local defects are defined as a local heterogeneity or distortion from the reference texture of a surface. They represent a sudden variation on a limited area of the inspected surface. Such defects stand out on the surface of the wheel and represent the most frequent type of defects detected during final inspection. These defects can take different shapes and sizes, different origins whether they are scratches, marks, geometrical deformation, etc. and new local defects can occurs upon changes in production process. In this work, the smallest defects that are wished to be detected have a size of about 2 mm in a single direction. Table 1 highlights the most frequent types of local appearance defects that can be found on the surface of the wheel. For each type of defects, Table 1 provides common information, defined according to the customer criteria or acquired during the inspection process, such as the usual cause of the defect, acceptance limits in terms of average size, occurring frequency and few real examples.

- Global appearance defects:

Global defects affect the entire surface of the wheel in a uniform manner. In this case, it is difficult to judge the wheel by itself as the defect is only visible if compared to previous wheels. Detecting this heterogeneity between different products of the same type is a challenging task since differences always exist between produces. Almost all of these defects are caused by the final manufacturing process, the painting process of topcoat layer. This is the last layer of coating applied over the surface of the wheel and it maintains the aesthetic appearance characteristics of the wheel surface. Any increase or decrease in the amount of paint used for this layer will lead to an excess or shortage of color on the wheel surface, thus generating a global defect. In general, a faulty painting process will lead to a decrease in the amount of paint. This happens when a paint spray gun nozzle partially clogs, or gets blocked.

SYSTEM DESIGN

The typical configuration of an AVI system generally consists of the following four basic components: the camera, the lens, the lighting, and the processing platform. In what follows, we will discuss the choice of each component to design an AVI system that meets the defined specifications.

Camera

Without a doubt, the key component of an AVI system is the camera. Depending on the size and shape of the inspected object, several cameras may be required to perform properly the inspection of the whole region of interest

(ROI). In this work, the ROI is defined as the wheel surface, which has a very complex geometrical design. Indeed, using one camera located directly above the wheel is not sufficient to “see” the whole inspected surface. Hence, it is proposed to install three additional cameras at different locations around the wheel to enable the inspection of the whole surface. The installation setup will be detailed in a later section.

The camera has the purpose of creating the image from the observed scene projected on its sensor. The two main sensor technologies available for industrial cameras are the charge-coupled device (CCD) and the complementary metal-oxide-semiconductor (CMOS) image sensor technology. Both have the same task of transforming light (photons) into electrical signals (electrons). This information is, however, transmitted by both sensor types using different ways and means and the design of each is also fundamentally different [12]. In light of the many technological improvements in recent years, the trend on the sensor market is increasingly pointed toward CMOS technology due to their low cost, low power consumption, integration capability, etc. [12].

Shutter type

There are two shutter type options: global or rolling shutters. While global shutters expose the whole sensor from scene light at once, rolling shutters instead scan vertically the scene, exposing lines one after the other. Because stopping the wheel under the camera, even briefly, to take its photo decreases the productivity, it has been decided to use a CMOS sensor with the global shutter technique as they are more suitable for moving objects. Indeed, only recently high quality global shutter CMOS sensors became available, as it was only supported by CCD sensors.

Scan technique

There are two subdivisions of scan techniques within the world of industrial cameras: line scan cameras and area scan cameras. Since line scan systems require parts in motion to build the image, they are often well suited for products in continuous motion, or high-speed applications. They are thus best employed to inspect rolled or sheet objects, including fabric inspection [13], conveyor belts inspection [14], and steel surface inspection [15]. However, for our specific application, the use of an area scan camera is more suitable. In fact, the inspected wheels arrive one by one and the inspection of each wheel is carried out individually. When the whole ROI can be captured on a single image it is preferable to use an area scan camera; the benefit of using a line scan camera for the continuous objects inspection is not applicable while its complexity, in terms of images merging, remains.

Resolution

One of the most important features to consider when selecting the camera is the required resolution to perform the inspection [16]. For a specific detail to be available for inspection, the resolution must be better than the size of the detail itself. Thus, the resolution will be defined partially in correspondence with the order of magnitude of the smallest defects that are intended to be detected on the wheel surface. As mentioned in the system specifications, the smallest defects that are wished to be detected have a size of about 2 mm in a single direction. At this point, there is no general rule that defines the number of pixels necessary to represent the smallest defect, to be able to distinguish it in the image. This number heavily depends on the wheel texture, or the background of the area surrounding the defect. In this work, the vision system is intended to inspect several different designs of wheels, with different textures. In this case, it is mandatory to consider the roughest wheel texture to define the necessary number of pixels for the smallest defect. An additional consideration to take into account when making the choice is the quantity of information needed to be gathered about the defect. The goal of the designed inspection system is not only limited to the detection of the defect, but also to characterize this defect according to various variables, such as its size and shape, in order to create a record of all the possible defects with their category. With these considerations in mind, the number of pixels per defect is set to a large value of 8 pixels in a single direction.

Another factor that plays a role in calculating the proper resolution is the field of view. It is calculated by summing the maximum dimensions of the area to be inspected (length or width, depending on the case), the range of motion, and a safety factor. In our case, for the wheel inspection application, the dimensions of the wheels defer from one design to another, where the diameter of the biggest manufactured wheel is of 17 inches, which converts to about

432 mm. As for the range of motion, it depends on the position of the wheel under the imaging system. While it is proposed to use adjustable guide rollers on each side of the conveyor belt to center the wheel, a non-negligible displacement could occur and could span up to 15 mm. We finally add a safety factor of a few millimeters to guarantee that the whole wheel is present in the image, which adds up to 450 mm. However, when designing the inspection system, it is important to anticipate some possible modifications in the products. Hence, it is proposed to add an offset of 50 mm around the largest current wheel to ensure the possibility of inspecting wheels with a diameter up to 2 inches more, without any adjustment to the system. Consequently, the field of view for our application can be set to 500 mm. Finally, with all the information above, it is possible to determine the minimal camera resolution required to respect the application specifications. This is done using the following equation:

$$res = \frac{(field\ of\ view\ \times number\ of\ pixels\ for\ smallest\ defect)}{smallest\ defect\ size}$$

where res is the minimal resolution in each direction. Then, applying the calculations will lead to $res = (500 \times 8)/2 = 2000$ pixels. Hence, the most suitable camera resolution is a 4MP camera with 2046×2046 pixels in the horizontal and vertical directions respectively. This is more than sufficient for the intended application, and it ensures that the system will be able to perform even if the system specifications evolve slightly.

Then, knowing the resolution of the camera, it is necessary to calculate the exposure time. As previously mentioned, the wheels do not stop under the imaging system, but they are in continuous movement with a constant speed of about 1 m/s. In order to eliminate the blurring in the acquired image, the wheel must not move more than one pixel during the exposure time. To ensure that with a camera of 2046 pixels in one direction, and a field of view of 500 mm, the exposure time must be set to a value no more than 245 µs. Recent industrial cameras can reach values of exposure time as low as 10 µs for some models. Keep in mind that with such a small value of exposure time, the lesser quantity of light accessing the camera sensor has to be compensated with a bright light source.

Sensor and Pixel Sizes

A trade-off exists between resolution and sensitivity. Larger pixels will allow the camera to be more light-sensitive whereas smaller pixels over the same area will allow the camera to see finer details and smaller objects. Therefore the necessity of a larger sensor, onto which more pixels can fit, which produces a higher resolution, and the individual pixels can still be large enough which ensures a good Signal-to-Noise Ratio (SNR). For our application, it is proposed to use a non-standard camera resolution of 4MP with 2046×2046 pixels. With this resolution in mind, the choice of the sensor and pixel sizes will be limited to the availability in the market. The most suitable camera that can be found has a sensor size of 11.3 mm×11.3 mm and a pixel size of 5.5 µm×5.5 µm. The performance of the camera with these dimensions is considered to be typical in machine vision applications, with a dynamic range of 58.7 dB and an SNR of 40.8 dB, according to the camera's technical sheet.

Lens

The lens is at the front of the optical system. It captures the image and delivers it to the image sensor in the camera. Indeed, choosing the appropriate lens for the vision system is a vital part. In order to get a good and sharp image, you do not only need a good camera, but also the right lens for this specific camera, and for the application as a whole. Many factors play a role when selecting the lens for the application. Some of these factors are directly related to the camera specifications, such as the camera resolution and its sensor size, while other factors depend on the imaging system, ranging from the installation constraints to the lighting conditions.

Resolution

A high-resolution image can only be created if a high-resolution lens is used. The resolution of a lens is given in line pairs per millimeter (lp/mm). For the camera considered in this work, its resolution and the physical measurements of its sensor result in a value of about 182 pixels/mm, which translates to a total of 91 lp/mm. Checking the available lenses resolutions in the market, the choice has been set on a standard lens resolution of 120 lp/mm, which is more than enough for our camera.

Focal length

When selecting the suitable focal length, it is necessary to consider the sensor size, the field of view wished to capture, and approximately how far from the inspected object the lens is located, also known as the working distance. Then the calculation of the focal length f will be straightforward using the approximate form equation:

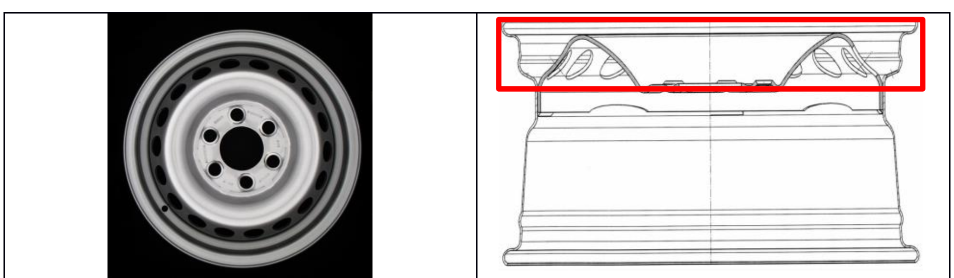
$$f = \frac{(sensor\ size\ \times working\ distance)}{field\ of\ view}$$

It would be impossible to provide a lens for each focal length there is, so there exist some standard values that all manufacturers provide. These are called "fixed focal length" lenses. The most commonly found lenses fall between 8 mm and 25 mm. When the calculated focal length has a non-standard value, two options exist: either choose the first lower standard focal length, where the camera views a larger area, or choose the first higher standard focal length, where cropping of the sides may occur. The general tendency in such a case would be to select the lower value option, as the field of view is generally important to maintain for an application.

In our application, the imaging system has to be installed over the conveyor belt, where the space is restricted. Accordingly, the allowed distance between the camera and the inspected wheel ranges between 550 mm and 600 mm. This will lead to the first focal length of $f_1 = (11{,}3 \times 550)/500 = 12.43$ mm and the second focal length of $f_2 = (11{,}3 \times 600)/500 = 13.56$ mm. Following the discussion above, it is better to choose a focal length of 12.5 mm, which is near the value of f_1 to avoid losing the defined field of view. Although this focal length is a little bit higher than the value of f_1, but the resulting cropped surface of the image is much lower than the offset that we included in the field of view. Thus the wheel is guaranteed to be visible in its totality in the acquired image.

Aperture

The value of the aperture of the lens being used determines the depth of field. Other parameters also affect the depth of field, such as the object distance and the focal length. However, these parameters are fixed in our application. The relationship between the aperture and the depth of field is easy: large aperture means a small f-number which results in a shallow (small) depth of field. Vice versa, small aperture means a larger f-number which results in a deeper (larger) depth of field. Choosing the proper aperture for an AVI system depends heavily on the inspected object shape. The surface of the wheel has a complex geometrical design, with elements on different distance levels from the camera. Figure 1(a) represents an image of the surface of a wheel intended to be inspected. The largest part of the wheel surface is the disc, while only the upper part of the rim surface is visible on surroundings. Figure 1(b) shows an illustration of the side view cross section of the same wheel highlighting that this visible surface consists of several layers located at different heights.



(a) **(b)**

Figure 1: (a) An example of a wheel to be inspected with (b) an illustration of its design.

To properly perform the inspection of the wheel surface, it is necessary that the whole zone located in the red rectangle to be in focus. The aperture should then be set to a value small enough to enable the depth of field to be larger than the width of the red rectangle. Note that this width will be larger for the cameras on the side. The more the depth of field is larger, the better for the inspection, considering that the focus will be higher in the depth of field zone, at its maximum at the plane of optimal focus, and will decrease going further from it. But this will come at a cost, because as the aperture is getting smaller, the light reaching the camera sensor reduces. For our application, it is suitable to choose a lens with a manual iris to control the aperture level that ranges between f1.4 and f22.

Lighting

One of the most important aspects of a computer vision application is the correct choice of lighting. Nowadays, a variety of lighting sources are used in computer vision applications, including fluorescent, quartz halogen, metal halide (mercury), or xenon to cite few. However, the most widely used and rapidly growing illumination source over the past years has been the light-emitting diodes (LEDs) to significant benefits: long service life, low energy consumption, and consistent output without flicker which produces a very bright light. But the best feature for LED lighting is that, unlike conventional light sources, LED modules do not die instantly; instead their light output slowly degrades over time [17]. This ensures a well-functioning of the AVI system for a long period of time, and helps avoid a sudden failure in illumination that could cause the system to break.

Lighting Technique

Two main features of the wheel surface intended to be inspected will be crucial for the choice of the suitable lighting technique. First, as seen in Figure 1, the wheel does not have a flat surface. On the contrary, the shape of the surface is complex with various irregularities in different directions. This should be taken into account when illuminating the wheel to make sure that the light will reach all the sides of the surface in a uniform manner. Secondly, the surface of the wheel is usually coated with a reflective layer of paint to create a smooth and glossy surface. In this particular case, direct lighting cannot be used as it will create light reflections on the surface that will be considered as potential defects during the inspection.

With these features in mind, diffused lighting is the most appropriate technique to use. It ensures uniform illumination in every direction, and can greatly reduce the effect of light reflections on glossy surfaces.

Platform

The last step when designing an AVI system is the choice of the processing unit. In our case, we have used a high-speed workstation with a Dual Intel Xeon Processor, each with 10 cores and 25MB cache, working with 32GB of RAM. The processing is done using C/C++ programing language with the OpenCV library, while the user interface was developed in Delphi.

Installation

The imaging system is installed over the production line of a wheel industry. Figure 2(a) shows an illustration of the installation setup. Camera n°1 is installed directly above the inspected wheel, while cameras n°2-3-4, referred to as side cameras, will be installed on the side at an angle of 120° apart. Only camera n°2 is shown in Figure 2(a). Each of those side cameras is installed on a curved track with a slider that enables to modify the angle between the camera and the wheel, which goes from 30° to 75°, along with the distance to the wheel. Hence, the camera can be positioned to adapt to the inspected wheel type. A single trigger is used to control the 4 cameras to record the 4 images at the same moment. The lighting diffuse system cannot be presented on Figure 2(a) for confidentially reasons. Finally, Figure 2(b) shows 2 images of the same wheel, the first acquired using camera n°1, while the second was shot with one of the side cameras. As it can be seen, the side camera enables to better view some regions of the wheel surface that are not visible for camera n°1.

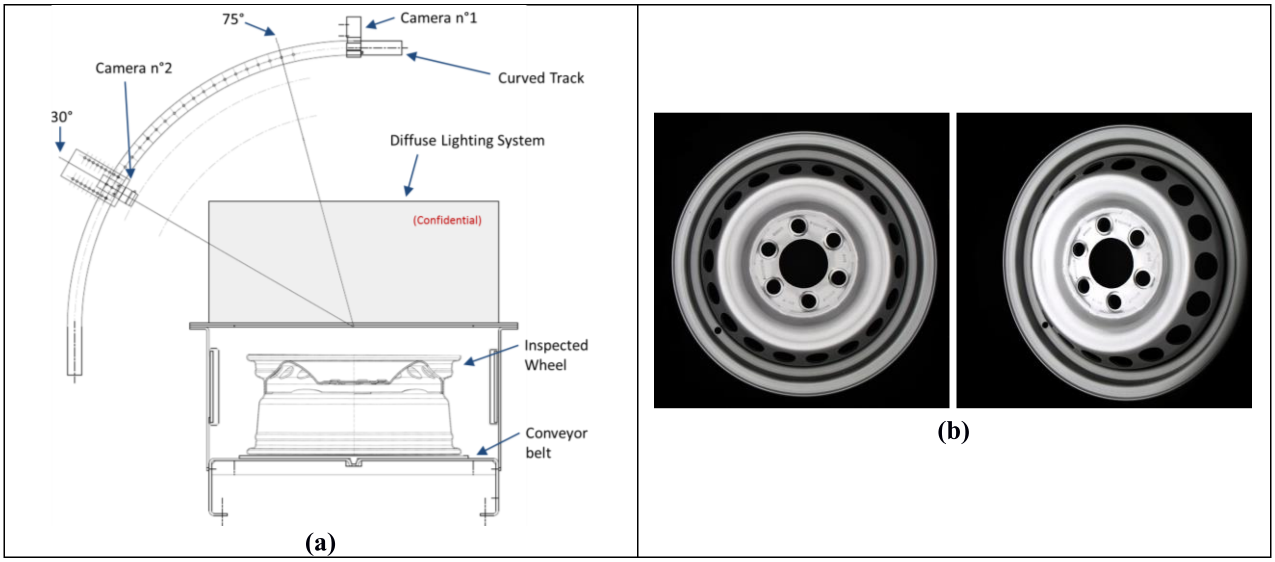


Figure 2: a) Illustration of the AVI prototype installation, b) example of acquired images with two cameras.

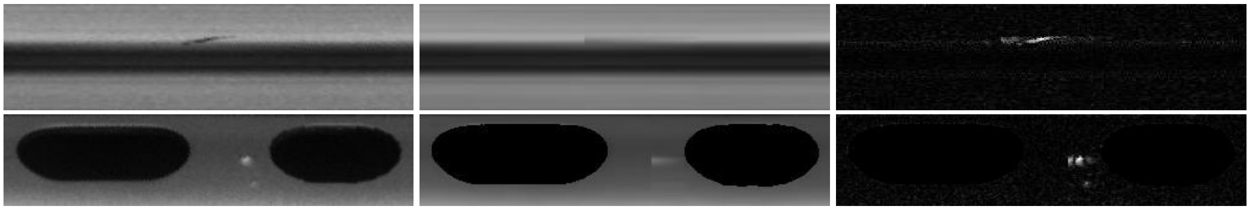
INSPECTION PROCESS

The inspection process consists of two main parts: the defect detection method developed to detect local defects on the wheel surface, and the sequential method developed to monitor the topcoat intensity of the wheel. But beforehand, an essential pre-processing step is required, in which it is proposed to locate all the key elements that figure on the wheel surface, such as the wheel center, the valve hole, and the lug holes, in order not to consider their presence as a defect. Another benefit of this localization is that, on the one hand, it will enable to identify the wheel type, and on the other hand, it can be used to split the wheel into different parts, and then unfold each individual circular part to create a rectangular area on which the detection method will be applied. The pre-processing steps are detailed in the following papers [18, 19].

Surface Defect Detection Method

The method to detect local defects is based on a parametric approach which consists in considering the image of the wheel to be inspected as the combination of a non-anomalous part, an acquisition noise and an anomalous part, the potential defects. In fact, the non-anomalous content of the image that represents the wheel, referred to as the background, acts here as a nuisance parameter as it has no interest for anomaly detection while it must be carefully taken into account. Hence, an original adaptive linear model is designed to model the anomaly-free background, and enable its rejection. The proposed model is accurate, to ensure high detection performance, and computationally simple, for real-time applications. In addition, it is sufficiently flexible to allow the inspection of a wide range of wheels, and is linear enabling it to be used within the well-founded statistical theory of invariance to design a statistical test to perform the anomaly detection process. After the rejection of the background, it is possible to obtain a residual map composed mainly of image acquisition noises and potential local defects. Finally, a model of the noise characterizing its heteroscedasticity is considered to normalize the residuals. This method allows to adapt to a potential variation in the lighting conditions of the wheel (for example, a slight change in the color of the wheel), as well as to control the statistical properties of the detection test to answer the industry requirements.

Figure 3 presents two examples depicting the detection procedure for two different types of defects present on two different parts of the wheel surface. Figure 3(a) shows the unfolded images containing the defect. We choose on purpose two defects that are present on complex areas of the wheel surface to demonstrate the potentials of the detection method. Figure 3(b) presents the adaptive linear models for the non-anomalous background. It can be seen that the models are very accurate, and preserve most of the anomaly within the residual images, which are shown in Figure 3(c). A detailed description of the detection method and more results can be found in [18, 19].



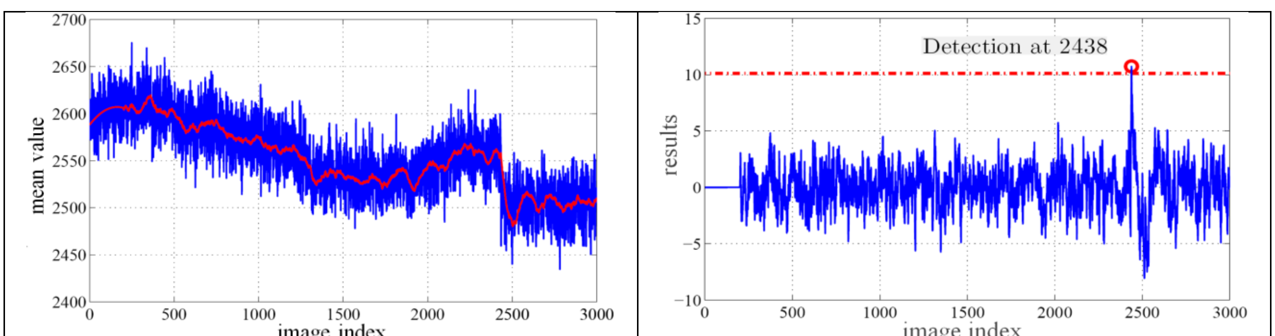
(a) (b) (c)

Figure 3: a) Unfolded image with its corresponding b) model image and c) residual image.

Real-time Topcoat Monitoring Method

In order to detect global defects, it is necessary to monitor in real-time the wheel's topcoat intensity, and signal an abnormal change as soon as it happens. To do so, we consider a small area in the wheel image over which the mean value of pixels is calculated, whose variations depict the variations in the topcoat intensity. In this work, the change occurs in an abrupt manner when a paint spray gun nozzle partially clogs, or gets blocked, causing the paint intensity to suddenly drop. However, as the monitored topcoat intensity is a non-stationary process in the mean, it may generate some changes that are considered as normal behavior to the process. Hence, it is necessary to distinguish between these normal variations, and the significant changes intended to be detected. To this purpose, a two fixed windows sequential method based on the well-known CUSUM procedure [20] is proposed to model the non-stationary process and perform the detection. The linear model parameters are estimated over the first window, and the second window is the one used for the sequential detection procedure. In this context, and unlike the CUSUM method that aims to minimize the detection delay, the proposed sequential procedure operates under the non-classical criteria of minimizing the worst-case probability of missed detection under the constraint of a maximal detection delay (the second window), while controlling the false alarm probability for a given number of wheels.

Figure 4(a) portrays a real case of observations (pixels mean value) when the spray gun nozzle got partially clogged. As a consequence, a sudden shift in the observations can be seen at exactly the image index 2434. The blue plot represents the real observations, while the red plot represents estimated values using the parametric model. Then, Figure 4(b) illustrates the results of the proposed sequential method with a maximal detection delay set to 5. It can be seen that the change point is detected at the index 2438, which means a delay of exactly 5 defective wheels. Again, a detailed description of the sequential detection method and more results can be found in [21].



(a) (b)

Figure 4: a) Real example of the variation of mean value with a change point at index 2434 and b) the detection result with the proposed sequential method for a maximal detection delay of 5 wheels.

CONCLUSION

This paper presents the design of a fully automatic visual inspection system dedicated to the surface of wheels. The first step is to define the desired inspection requirements as well as the specifications of the potential types of defect that it is aimed at detecting. Following those specifications, the choice of all the components of the inspection system is discussed. The resulting system consists of four cameras properly distributed around the wheel to enable the inspection of its whole surface. A diffused lighting source is associated in order to ensure a sufficient and homogeneous illumination of inspected surface. Then, the installation setup over the production line of a wheel factory is described. The designed inspection system is finally used to detect both local and global defects on the wheel surface. For local defects, an original adaptive linear parametric model is proposed. The flexibility of this adaptive model offers highest accuracy for the inspection of a wide range of wheels, while ensuring the detection of small defects by using an optimal statistical hypothesis test. As for global defects, a parametric sequential method is proposed to monitor in real-time the topcoat intensity of finished wheels. This monitoring allows the detection of any abrupt change in the paint intensity, caused by a partially clogged, or even blocked, paint spray gun nozzle.

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