Machine vision system for the inspection of reflective parts in the automotive industry

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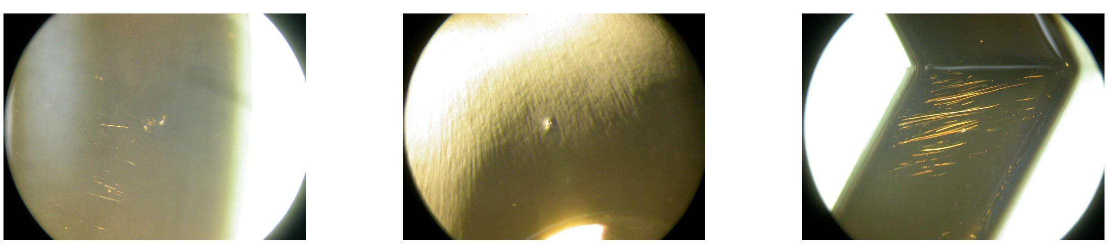
ABSTRACT

Specular surfaces inspection remains a delicate task within the automatic control of products made by plastic plating. These objects are of very varied shape and their surface is highly reflective acting like a mirror. This paper presents steps to follow in order to detect geometric aspect surface defects on objects made by plastic plating. The projection of a binary fringes pattern is used and enables to reveal the defects near the transition between a dark fringe and a bright fringe. Indeed, the surface imperfections provoke important light rays deviations. By moving this dynamic lighting, and thanks to a saturated camera, the system brings an aspect image where the defects appear very contrasted on a dark background. A simple image processing algorithm is then applied leading to a very efficient segmentation. To obtain such resulting images, the translation step, the duty cycle and also the number of images are constraint. This article finally shows how to adjust these parameters according to the various sizes of defect and to the objects shape.

Keywords: specular surfaces, industrial inspection, machine vision, quality control, structured lighting

1. INTRODUCTION

Highly reflective surfaces inspection is a problem met frequently within the automatic control of industrial parts.[1–3] This inspection is generally done manually. It implies subjectivity and tiredness influence on classification results. A machine vision system offers objectivity, better reliability and repeatability and is able to carry out defects measurement to classify the industrial parts quality. This work aims at detecting surface defects on reflecting industrial parts. The objects to be controlled are made by plastic plating, and their surfaces are highly reflective, acting as perfect mirrors. As shown on Figure 1, surface defects are dents, bumps and scratches. The defects areas have the same reflective properties as the flawless area of the surface: they reflect incident light only in the specular direction.



(a) (b) (c)

Figure 1. Example of surface defects: (a) dents, (b) bumps and (c) scratches.

In order to detect geometric aspect surface defects on objects made by plastic plating, the projection of a binary fringes pattern is used.[4] It enables to reveal the defects near the transition between a dark fringe and a bright fringe. By moving this dynamic lighting, the system brings an aspect image where the defects appear

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very contrasted on a dark background. From this aspect image, the defects are automatically detected thanks to an image processing algorithm.

The outline of the paper is as follows: the dynamic lighting system is presented in section 2. In section 3, the algorithms to detect the defects are described, and in section 4, influence of the fringes design is studied in depth.

2. DYNAMIC LIGHTING

2.1. Lighting principle

Imaging of reflective surfaces is not easy. We observe the entire object environment through its surface. In order to capture images without unwanted information, we need to completely master the environment of the surface. By choosing an adapted lighting system, the imaging of defects is possible. The lighting principle used in our system enables to ensure to separate the defects from the flawless area. A tried technique to reveal the aspect defects is the imaging of the reflection of a structured lighting through the surface.[1–3] The surface imperfections provoke important light rays' deviations. This property is used to detect defects with a particular lighting system. This lighting is binary type. It is composed of a succession of zones of null luminous intensity and zones of maximal luminous intensity. In these conditions, a defect appears in the captured image as a set of luminous pixels among a dark zone or a set of dark pixels among a luminous zone. Figure 2 illustrates the lighting principle and shows a typical image acquired with the lighting device. In the first case, without defect, the surface reflects a dark zone of the lighting. In the second case, the defect deflects luminous rays coming from the luminous zone and so, the defect appears as a clear spot in a dark zone. We choose to saturate the camera in order to obtain images where defects appear very contrasted on a dark background and so to enable a simple image processing for detection (see 3 Defects segmentation and measurements). In these illumination and imaging conditions, defects only appear as high gray level pixels in dark zones.

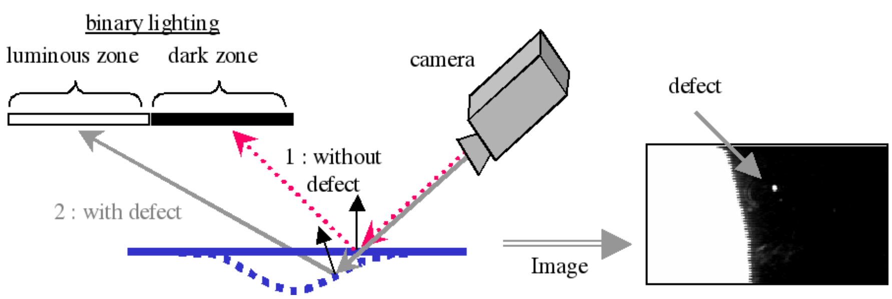


Figure 2. Lighting principle.

2.2. Implementation

In order to inspect the whole part surface, an element of the lighting structure has to scan every part of the surface. During experiments, we noticed that the size of the defect signature on the image depends on the distance between the light transition and the defect. It can be schematically explained as shown in Figure 3.

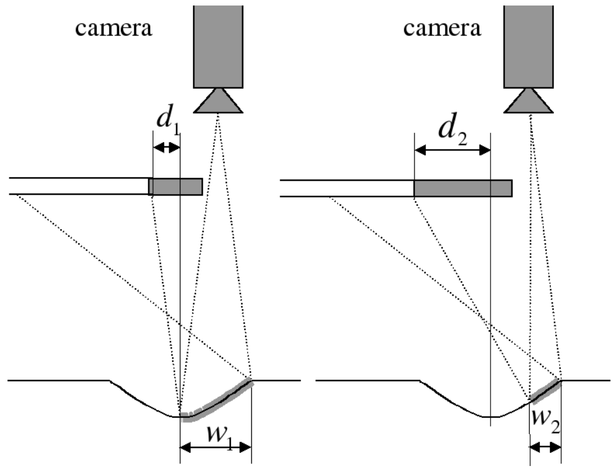


Figure 3. Defect size variation.

If the light transition, projected on the surface, is close to the defect, the defect size on the image is close to its real size. But if the distance between the defect and the light transition increases, the defect size decreases and can even be null for an important distance. This particular property can be measured by computing the defect size from images acquired during experiments. Figure 4 represents a defect size (percentage of real size) versus the distance between two light transitions and the center of the defect (normalized by the defect dimensions) and the corresponding images.

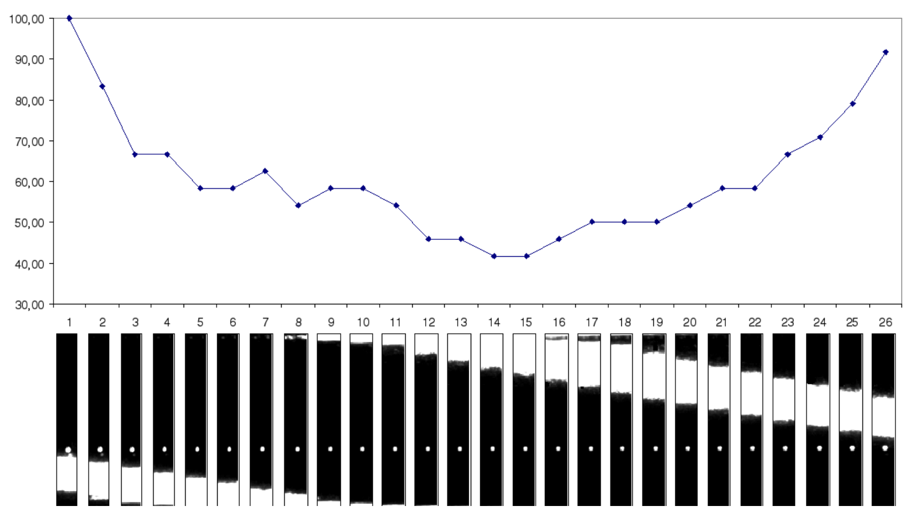


Figure 4. Defect size variation versus distance to the first light transition.

The image signature equals the physical size if the defect is close to a light transition and it decreases if the distance increases. In our industrial application, we have to obtain image signatures proportional to the defects physical size. So, the light transition has to scan all over the surface to ensure each defect to be close to a light transition in the image sequence. To carry out surface inspection, one can imagine that the object is moving in front of the camera and the lighting system.[5] In the case of important surface curvature gradients, the projection of the luminous and dark fringes on the complex geometry surface varies a lot between two consecutive images. So, entire scanning is not ensured if the object is moving in front of the static lighting. To overcome this limitation, an inverse process is proposed: the lighting structure is dynamic while the object is static.

Having static object during the inspection presents numerous advantages:

- the fringes projections and the position of the fringes between two images are completely mastered,
- an a priori knowledge of the object to be controlled can enable definition of region of interest in the surface inspection (see 3.2 Post Processing),
- shape defect detection can be computed by inspecting the silhouette.

In order to reduce the number of necessary images to perform the scanning of industrial parts, the lighting system is composed of juxtaposed luminous and dark fringes. It enables a large number of light transitions to scan the surface. The lighting devices have to be diffuse and homogeneous. So, the lighting system is realized by luminous surfaces made of diffusers placed in front of fluorescent tubes. The luminous panels are then shaded by an opaque mask.

The surface aspect imaging is performed by different lighting system positions. The lighting system is translated along the main object axis. For each regular spatial position, an image is captured. We finally obtain an image sequence as seen in Figure 5.

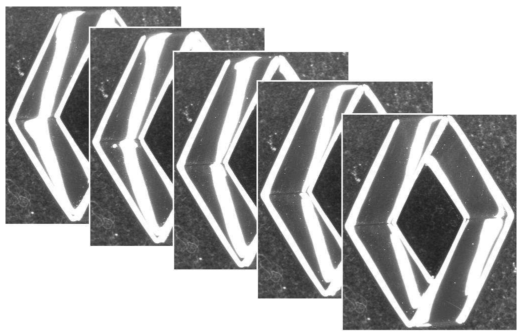
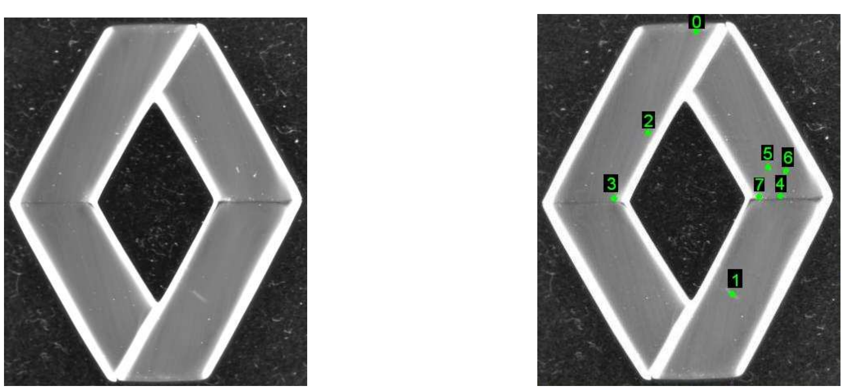


Figure 5. Part of image sequence.

3. DEFECTS SEGMENTATION AND MEASUREMENTS

3.1. Image sequence processing

In the sequence, defects always appear as high gray level pixels because of the saturation of the CCD matrix. By computing the mean image of the sequence, we obtain a synthetic image called "aspect" image. In this image defects appear as high gray level pixels and the entire flawless area of the image appear with medium gray level (see Figure 6(a)).



(a) (b)

Figure 6. (a) "Aspect" image, (b) result of the post processing.

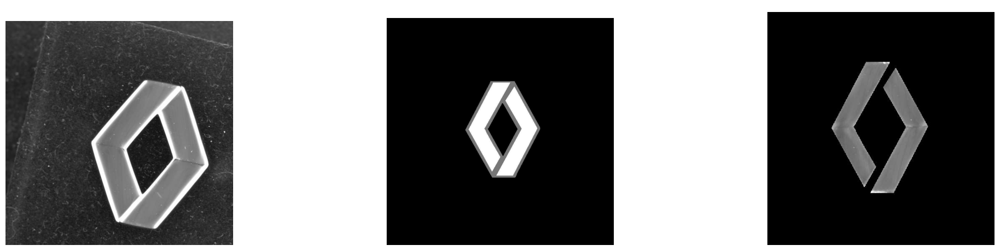
The segmentation of defects zones is then easy to compute because of the very contrasted “aspect” images. The segmentation processing consists in filtering the “aspect” image by a local (9×9 pixels) gaussian filter and to subtract the resulting image to the initial one. With this filter, segmentation of pixels belonging to clear thin areas (defects) from zones of homogeneous gray levels (flawless area) is performed.

3.2. Post Processing

The lighting principle used here is designed to reveal small geometrical surface imperfections. In the case of objects composed of smooth surfaces, edges will be detected as pertaining to defects. So if we do not define Regions Of Interest (ROI) for the defect detection, lots of false detection will perturb the classification of parts. A method is so proposed to define ROI on the industrial parts. This method consists in positioning a predefined mask on the object to be controlled. The first phase is to compute the silhouette of the object from the image sequence. The silhouette is reconstructed from the image sequence. The image sequence represents the lighting scanning through the entire object surface. Then, by computing the sum of the N images and by applying a flood fill method on the external reconstructed shape, the reconstruction of the object silhouette is effective. Once the silhouette obtained, we are able to match a predefined binary mask on the shape. The matching is realized by fitting the equivalent ellipse of the shape to be controlled on the equivalent ellipse of the reference shape on witch the binary mask is defined. The equivalent ellipse of a shape is an ellipse which have the same geometrical moments as the shape. In our case, the shape fitting is realized by matching the center of mass and the orientation of the two shapes. The orientation α is computed from the three second order central moments μ_{20}, μ_{11} and μ_{02}:

$$\tan 2\alpha = \frac{2\mu_{11}}{\mu_{02} - \mu_{20}} \tag{1}$$

The fitting is computed by scaling, translating and rotating the reference shape to make it matching the current shape (Figure 7).



(a) (b) (c)

Figure 7. Definition of ROI by equivalent ellipse matching: (a) Object, (b) Predefined mask and (c) Region of Interest.

This method is applied in our case to perform the defect detection only in smooth surface areas. The main advantages of this method is the translation, rotation and scale invariance. The position and orientation of the objects can be approximate. It simplifies consequently the parts manipulation and positioning on the production line. Figure 6(b) presents the segmentation result of the object.

3.3. Summary of the method

The specular surface inspection method can be summarized as shown on Figure 8.

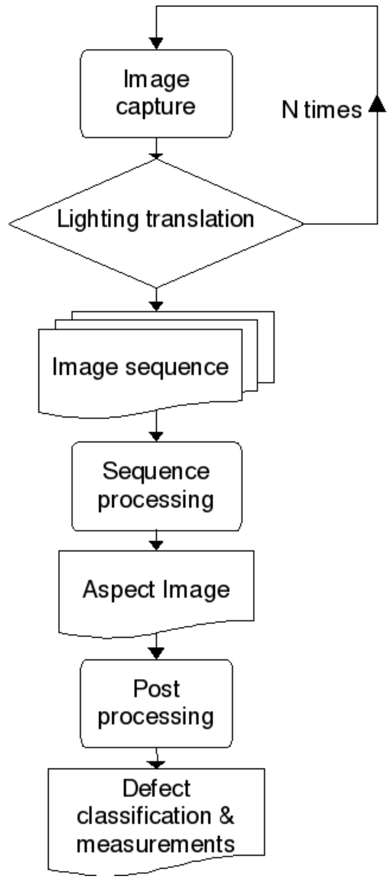


Figure 8. Specular surface inspection algorithm.

The table 1 that represents the inspection results of 50 parts shows the good robustness of our system.

Good detection	41
False detection	6
No detection	3

Table 1. Inspection results of 50 parts.

4. STUDY OF THE FRINGES DESIGN

To reduce the number of necessary images to perform the scanning of large industrial parts, the lighting system is composed of juxtaposed luminous and dark strips. It enables a large number of light transitions to scan the surface and defects are always revealed in dark areas surrounded by luminous ones: it enables to reveal the entire defect surface. Nevertheless, size of the fringes are both linked to the number of images to take and the size of defect to detect. Figure 9shows that the system does not reveal a bigger bump defect.

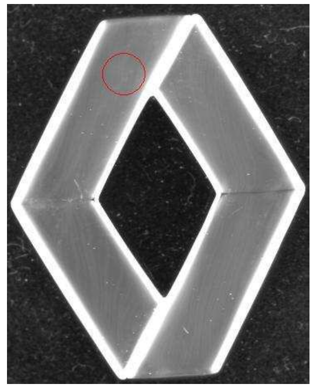


Figure 9. Bump defect detection failed.

4.1. Theoretical overview

The contrast between the defects zones and the rest of the surface is dependent from the thrown strips width. Let consider a one-dimensional representation of the structured lighting system as shown in Figure 10. We define:

T_W	the width of the luminous strip,
T_B	the width of the dark strip,
Δ	the translation step of the lighting between two images,
N	the number of captured images $N = (T_W + T_B)/\Delta$.

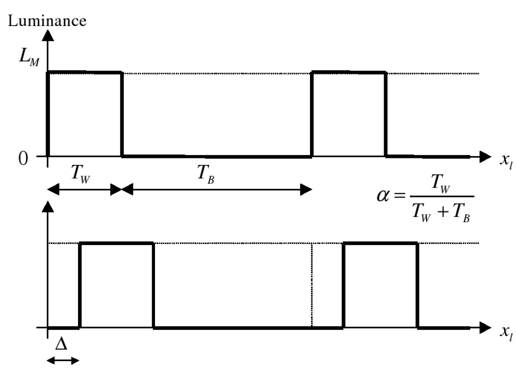


Figure 10. Lighting translation.

To obtain a well contrasted "aspect" image two conditions must be respected. The translation step has to be inferior to the half luminous strip width: $\Delta \leq T_W/2$ and the lighting system position has to vary from $x_i = 0$ to $x_i = (N-1)\Delta$. These two conditions enable an homogeneous gray level in flawless areas. By respecting the two previous conditions, maximum contrast is ensured. The ideal lighting configuration would give an infinite contrast. It corresponds to $\alpha = 0$ meaning $T_W \ll T_B$. So, with an infinitevely small luminous strip traveling through the surface, we obtain an infinite contrast between defects and flawless areas. It implies that the number of necessary images is infinite.

The number of necessary images has to be minimized in our industrial application.[6] The absolute minimum number of images is obtained with $\Delta = T_W/2$ because of camera saturation. After all those considerations, a compromise must be chosen between the desired contrast for the resulting images and the number of necessary images. The industrial parts production rate conditions the allowed imaging time. This constraint imposes the necessary images number. Thus, to obtain a maximum contrast, the translation step Δ and the duty cycle α are chosen.

4.2. Experiments

To study the influence of the fringes design, we create a system made of a TFT monitor and a CCD camera. The monitor enables to generate fringes of various sizes and duty cycles. The system automatically computes the different parameters of the fringes in order to get an "aspect" image with a uniform gray level in the region of the surface without any defect. As one can see on Figure 11, in this experiment, just one screen is used to study the fringes parameters.

(a) (b) (c)

Figure 11. "Aspect images" with different configurations (a) $N = 30 - \alpha = 1/6$, (b) $N = 20 - \alpha = 1/4$ and (c) $N = 28 - \alpha = 1/4$.

In the previous configuration (Figure 9), 25 images were used with a duty cycle of 1/6, and the defect was not detected. On Figure 11(a), the number of images is slightly increased and the defect appear. Nevertheless, the contrast between the flawless region and the defect decrease. By choosing a duty cycle of 1/4, the average gray level decrease and the contrast is better but it leads to increase the number of images. Indeed, the first satisfactory configuration is $N = 28$ (Figure 11(c)): $N = 20$ is not enough (Figure 11(b)).

5. CONCLUSION

A particular lighting system has been presented. It is the critical point of a machine vision system designed for the automatic inspection of highly reflective surfaces industrial parts made by plastic plating. The basic principle and the application have been exposed. The revealing of aspect defects is effective and the system provides very contrasted images where defect segmentation is elementary. Therefore, real time inspection is possible. Moreover, defects that present a lower curvature can also be detected by just changing the parameters of the fringes. We have experimentally shown that the size and the duty cycle of the fringes can be adjusted in order to improve the inspection of various kind of defect. Future work will consist in implementing a tunnel of two or more TFT screens into the system to ensure the detection of the different aspect defects.

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