Deflectometry setup definition for automatic chrome surface inspection

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Abstract— **A recurrent problem in the industrial sector is the quality control and surface inspection of reflecting pieces with non-planar surfaces. This is an extended and non-solved problem because it is related not only to the material itself but also to the coating. This problem appears in a wide spectrum of industrial sectors such as automation, aeronautics or orthopaedics. In recent years, a new imaging technology called deflectometry has been introduced in the field of surface inspection for industrial applications. This technology features a high resolution camera and a dedicated illumination system –based on displaying fringe patterns in a monitor- allowing the detection of irregularities in surfaces. However, the introduction of this technology into automated quality control systems remains a challenging task, due to the wide range of defects and shapes that can appear. It becomes thus necessary to characterize different types of errors and their associated detection setups. In this paper we propose a novel methodology to define and analyse the best setup for each pattern. We also explore an efficient technique to maximize the number of different pieces inspected without modifying the setup of the acquisition system. Experimental results show that the presented methodology defines an inspection method that can be installed in an automatic quality control device for non-planar surfaces analysis of manufactured products.**

Keywords—computer vision; deflectometry; quality control; surface inspection;

I. INTRODUCTION

A recurrent problem in the industrial sector is the quality control and surface inspection of reflecting pieces. This represents a challenging task, since it is related not only with the material but also with the coating it may have. This problem is present in a wide spectrum of industrial sectors such as automation, aeronautics, or orthopaedics, remains unsolved, and it is at the moment an active area of research [1][2][3][4].

Computer vision-based systems can offer novel solutions for surface quality control. A set of cameras with the appropriate illumination can detect a wide number of categorized defects, classify them and notify to the operator or to the production control the status of each piece online. However, in the case of specular surfaces, vision-based techniques have severe difficulties, due to the reflectance behaviour of such pieces. The illumination required to “see” the pieces generates a semi-noisy image affected from the numerous shines and reflections generated on the surface. This semi-noise can even overexpose the image, producing only a large white spot instead of the piece under inspection.

During last years a great effort has been devoted to solve the problems presented in specular surface inspection [4][5][6]. A very promising technology in this area is deflectometry. This technology makes use of a high resolution camera and a dedicated illumination system –based on display fringe patterns in a monitor. This technique allows detecting irregularities in the surfaces.

Even though the physical effect that forms the basis of deflectometry has been known for several years, the application of this technique is relatively new due to its complexity [7][8][9]. Deflectometry has been mainly applied in two fields: quality control systems [6][10] and 3D modelling [11] [12]. However, these works are focused mainly in painted pieces with smooth geometries and large sizes. Unfortunately, the requirements of chromed pieces are more demanding due to the presence of highly changing surfaces, small pieces and highly shining coatings.

In this paper, we present a detailed study of the behaviour of deflectometry when applied to complex shapes and surface defects detection. This work represents a first step towards the development of a fully-functional quality control system for in-line inspection of chromed pieces.

The rest of this paper is structured as follows: we first introduce the physical fundamentals of deflectometry. Next, we develop a new methodology to compute and analyse the best setup. Finally, we present experimental results regarding the configurations that maximize the number of detected objects over the widest variety of pieces. We end up with some concluding remarks and possible directions of future work.

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II. BACKGROUND

One of the most important unsolved problems by computer vision algorithms is the surface inspection on specular surfaces. The class of defects present in mirror reflective surfaces can be seen by a human operator by forcing shines on the surface in the area affected by the defect. However, for conventional illuminations, this is not possible. The reason is that the acquisition process is unable to obtain the surface information. The camera acquires either an image of the reflection of the camera itself or a set of noisy images with white spots and shines from light sources reflected in the material. When diffuse illumination is employed [13], the obtained image may not capture small surface changes. For comparison, we show in Fig. 1 several pictures acquired from the same test piece with different types of conventional lightings, as well as with deflectometry.

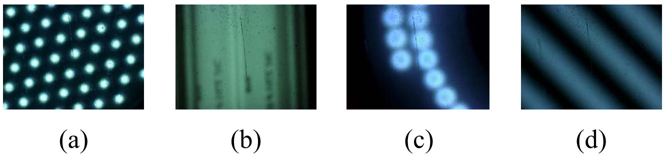

(a) (b) (c) (d)

Fig. 1. Illumination: a) LEDs; b) Fluorescent; c) LED ring; d) Deflectometry

Fortunately, it is possible to face these obstacles with deflectometry. The term deflectometry refers to the procedures used to acquire topographical information on specular surfaces by the automatic analysis of reflections of known scenes [14]. A common scheme is shown in Fig. 2, where a set of algorithms running in a computer make comparisons between a displayed fringe patterns and what the camera acquires on the surface illuminated by these patterns.

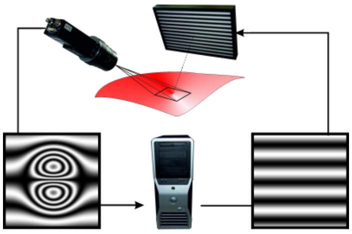


Fig. 2. Deflectometry inspection schemeextracted from [14]

Like other technologies based on light projection, deflectometry also uses displayed patterns [6]. When a light projection system is used (e.g. laser triangulation or structured light) the camera is focused on the surface to be inspected. However, in deflectometry, the camera is focused on the pattern displayed system –that is frequently a computer monitor or a similar device– by means of the reflection effect on the surface. For this reason, the material (or coating) to be analyzed is required to be reflective.

The idea behind deflectometry can be better understood by comparison with what happens when we see ourselves in a mirror. In this case, we can focus on the mirror plane itself –what is happening with structured light- or we can also focus in ourselves –as we usually do- through the mirror which apparently is far away from the mirror plane. In the same way, in deflectometry the camera is pointing at the same region, but depending on where the focus is, what the camera registers can be different amounts of light.

The main problem that traditional computer vision systems find when dealing with chromed pieces is their mirror reflective surface. Fortunately, this reflectivity is precisely what makes these chromed pieces open to a solution based on deflectometry techniques.

III. METHODOLOGICAL APPROACH

We propose an experimental methodology with two main goals. The first one is to identify the layouts of camera, monitor, and piece that allow the detection of each defect.

Being the eventual objective of this work to produce an industrial solution, it is not possible to manage a wide number of setup possibilities, and look for each of the defect types. It is necessary to deliver an inspection system with processing times close to the ones of current manual inspection processes. Therefore, the second goal of our experimental design is to reach a set of N setups that allow detecting M types of defects, being N significantly smaller than M.

Following the deflectometry requirements, it is necessary to acquire a set of images where fringe patterns are displayed on the area to be inspected. This means that both the way in which the camera and monitor are to be deployed in the system, and the way different pieces will be positioned, need to be defined. The layout elements to be controlled are the distance between camera and observed piece, the distance between monitor and observed piece, the monitor angle and the camera optic. These elements are shown in Fig. 3.

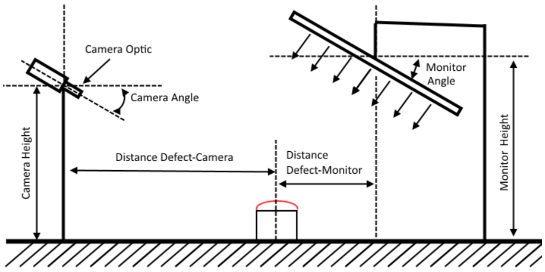


Fig. 3. Proposed layout and setup variables

However, we not only have to specify the geometrical values, but also which kind of patterns has to be displayed from the screen. In our case, we must determine the kind of fringe pattern, its frequency and angle. The proposed pattern scheme is shown in Fig. 4.

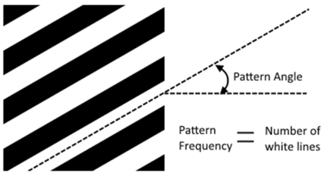


Fig. 4. Proposed pattern scheme and variables associated

Finally as deflectometry techniques rely on the curvature variation measurement, it is mandatory to acquire the images with the deflectometry system keeping its angular relationship to surface's normal controlled for every measure. This means that, to guarantee correct values, it is necessary to calibrate the inspection surface in order to establish a common axis for the components. To demonstrate the described experimental approach, we have prepared a controlled laboratory testbed, with the appropriate degrees of freedom shown in Fig. 5.

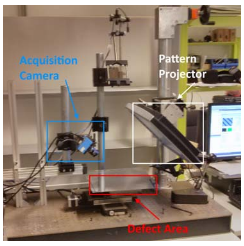


Fig. 5. TECNALIA's Laboratry testbed

Due to the high number of elements to be positioned in the testbed, a set of manual preliminary tests to define their ranges has been performed. The result is summarized in Table I.

TABLE I. EXPERIMENT'S PARAMETER RANGES

Parameter	**Value Ranges**		
	Initial value	***Intermediate value***	***Final Value***
Distance Defect – Monitor (mm)	150	225	330
Distance Defect – Camera	150	225	330
Camera Optics (Focal mm)	25	35	50
Monitor Angle variation	-5º	0	+5º
Pattern Angle	-60º	Step: 3º	+60º
Pattern Frequency	5	Step 5	+60

Apart from the different tests regarding to geometry setup, it is also necessary to determine which range of angles is the most appropriate and which pattern frequencies maximizes the defects characterization. The resulting procedure to run a test follows the steps below:

- Set the distance between the centre of the pattern monitor and the defect to be observed.
- Adjust the monitor height and angle to illuminate the defect area with the central area of the monitor.
- Adjust the camera distance to the defect according to the distance between defect and monitor
- Adjust camera angle according to the monitor angle.
- Adjust camera height and optics to see the defect with the assigned angle in the inspection area.
- Start the fringe pattern display test.

This methodology has been followed to characterise the most frequent defects present in chromed pieces: globules, no fill areas, pits, porosities, rack burns, scratches and burrs.

The defects and their locations can present a huge amount of possibilities. The goal is to have a setup independent of the piece and type of defect as much as possible. First of all, the set of samples are randomly divided into two groups: one to define the optimal settings of the system (characterization set) and a second one for checking the selected optimal settings (evaluation set).

Following this procedure the characterization set is analysed with the complete previously proposed scanning methodology. For each experiment, the evaluated values are the initial pattern angle (**α_{min}**) and frequency (**f_{min}**) where the defects start to be visible and the final angle (**α_{max}**) and frequency (**f_{max}**) where the defects stop being visible.

The calculation of these evaluation variables has been done by two different observers that have visually analysed every acquired image. Each HW setup has 533 images, each one with different pattern angle and frequency. The visual analysis of all these images by the two independent observers has defined the minimum and maximum values for each evaluated variable.

The criteria have been the following: a) determine the angle when the defect starts to be visible by the observers; b) for this angle, determine the pattern frequency when the defect is visible; c) with the new frequency, refine initial angle value; d) follow the same steps for final angle and frequency values.

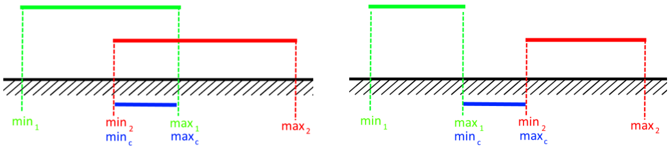
Finally the identified common setups have been assessed over the evaluation set to examine if the defects are visually detected in this second set of defects.

IV. RESULTS

Two types of experiments have been carried out: one to characterise the optimal settings of the system and another one to validate the selected settings. Each experiment has been validated using different pieces with similar defects in order to obtain a generalized result. The values under evaluation are:

- **α_{min}** and **α_{max}:** make reference to the minimum and maximum angle of the pattern in which the defect is visible for any of the frequencies available.
- **f_{min}** and **f_{max}**: make reference to the minimum and maximum frequency of the pattern in which the defect is visible for any of the angles available.
- **Dist.:** distance between the surface and the monitor.
- **Optics:** focal length used by the acquisition camera

To merge these values we have to keep the minimum values of the upper border ($max_c = max_1$, $max_1 < max_2$) and the maximum values of the lower border ($min_c = min_2$, $min_2 > min_1$) as it is shown in Fig. 6b:



(a) (b)

Fig. 6. Range fusion scheme. a) Possible. a) Impossible

However, it is possible that some acquisition setups are impossible to combine. They can be detected looking at the minimum and maximum value of a range. When a configuration is impossible the minimum value is higher than the maximum one as it is shown in Fig. 6b.

Table II collects these ranges, being α_{min} and f_{min} the maximum value and α_{max} and f_{max} the minimum value that allows correct defect visualization even though slight monitor angle deviations are applied:

TABLE II. COMMON PARAMETERS RANGE VALUES (IN GREY UNFEASIBLE CONFIGURATIONS)

	Optics	α_{min}	α_{max}	f_{min}	f_{max}
Dist.:150 mm	50 mm	-6	12	30	25
	35 mm	-6	6	25	30
	25 mm	-6	12	45	40
Dist.:225 mm	50 mm	-9	15	30	25
	35 mm	-6	15	40	25
	25 mm	0	9	45	35
Dist.:330 mm	50 mm	-6	9	20	25
	35 mm	-6	9	25	20
	25 mm	-9	6	25	20

According to Table II there are just two possible hardware setups: a) Distance defect-monitor 150mm and camera optics 35mm; b) Distance defect-monitor 330mm and camera optic 50mm. The criteria used to choose the setup for the validation process has been size to minimize the volume of the final device (distance defect-monitor 150mm and camera optics 35mm).

Once optimal settings are selected, the next step is to check this configuration with the evaluation set of pieces and defects, different from the ones used in characterization. The aim is to generalize it with pieces and defects not tested before that should be visible with the chosen configuration.

The results of the validation with the chosen configuration are that all the defects on the evaluation set can be visually detected and the configuration is also robust to disturbances, as this has been proven in carried out experiments that variations in the angular relationship camera-monitor and defects were still perfectly visible.

V. CONCLUSIONS AND FUTHER WORK

This paper presents a new methodology to obtain an optimal set of configuration parameters that allows visual detection of defects in chrome pieces, for an acquisition system based on deflectometry. An analysis of the different elements to take into account when a deflectometry system is deployed is also provided. A set of characterization tests have been carried out to identify the best parameter ranges for the different types of errors. The best configuration has been selected applying a set of context constraints such as mobility, weight and available space. In order to validate these setups, a new set of experiments has been carried out with different pieces and errors for checking the configuration selected. Experimental results showed the suitability of the proposed method to analyse chrome pieces (e.g. chromium coating or reflecting material).

For a fully automatized quality control prototype it is also necessary to design a robust error detector and classifier set of algorithms as well as to design a deflectometry end-effector for mounting it on a robot. In this way it will be possible to carry out a full surface inspection. The last step will be to test the full system to check the viability of these solutions for an industrial production line.

In this work different relevant obstacles and potential error sources were detected and discussed. These should be kept in mind while developing an automatic process to achieve an efficient industrial solution design.

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References

[1] M. Zierbarth, "Empirical Comparision of Defect Classifiers on Specular Surfaces," in *Proceedings of the 2013 Joint Workshop of Fraunhofer IOSB and Institute for Anthropomatics, Vision and Fusion Laboratory*, 2014, vol. 17, p. 155.

[2] T.-T. Le, "Wavelet Filter Bank Optimization for Classification of Deflectometry Measuring Data," in *Proceedings of the 2013 Joint Workshop of Fraunhofer IOSB and Institute for Anthropomatics, Vision and Fusion Laboratory*, 2014, vol. 17, p. 41.

[3] P. M. F. Forte *et al.*, "Exploring combined dark and bright field illumination to improve the detection of defects on specular surfaces," *Opt. Lasers Eng.*, vol. 88, pp. 120–128, Jan. 2017.

[4] J. Tornero, L. Armesto, M. C. Mora, N. Monteś, Á. Herráez, and J. Asensio, "Detección de Defectos en Carrocerías de Vehículos Basado en Visión Artificial: Diseño e Implantación," *Rev. Iberoam. Automática E Informática Ind. RIAI*, vol. 9, no. 1, pp. 93–104, Jan. 2012.

[5] S. Kammel and F. P. Leon, "Deflectometric Measurement of Specular Surfaces," *IEEE Trans. Instrum. Meas.*, vol. 57, no. 4, pp. 763–769, Apr. 2008.

[6] S. Kammel and F. Puente Leon, "Head-mounted display for interactive inspection of painted free-form surfaces," 2003, vol. 5079, pp. 254–264.

[7] O. Kafri and I. Glatt, "Moire Deflectometry: A Ray Deflection Approach To Optical Testing," *Opt. Eng.*, vol. 24, no. 6, pp. 246944–246944–, 1985.

[8] E. Keren, K. Kreske, and A. Livnat, "Measurement of surface quality using a moire deflectometer," 1990, vol. 1266, pp. 207–214.

[9] J. Beyerer and D. Perard, "Automated inspection of specular surfaces by means of pattern reflections," *Tech. Mess.*, vol. 64, no. 10, pp. 394–400, 1997.

[10] R. Hsakou, "Curvature : the relevant criterion for Class-A surface quality," *JEC Compos.*, no. 23, pp. 105–108, 2006.

[11] T. Bothe, W. Li, C. von Kopylow, and W. P. O. Juptner, "High-resolution 3D shape measurement on specular surfaces by fringe reflection," 2004, vol. 5457, pp. 411–422.

[12] Y. Tang, X. SU, Y. Liu, and H. Jing, "3D shape measurement of the aspheric mirror by advanced phase measuring deflectometry," *Opt. Express*, vol. 16, no. 19, pp. 15090–15096, Sep. 2008.

[13] "Dispositivo de iluminación sin brillos para la inspección de objetos mediante visión artificial."

[14] S. Werling, "Inspection of specular surfaces - Deflectometry for the inspection of specular surfaces," *Fraunhofer IOSB*, 2011. .