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On the detection of defects on specular car body surfaces

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ABSTRACT

The automatic detection of small defects (of up to 0.2 mm in diameter) on car body surfaces following the painting process is currently one of the greatest issues facing quality control in the automotive industry. Although several systems have been developed during the last decade to provide a solution to this problem, these, to the best of our knowledge, have been focused solely on flat surfaces and have been unable to inspect other parts of the surfaces, namely style lines, edges and corners as well as deep concavities. This paper introduces a novel approach using deflectometry- and vision-based technologies in order to overcome this problem and ensure that the whole area is inspected. Moreover, since our approach, together with the system used, computes defects in less than 15 s, it satisfies cycle time production requirements (usually of around 30 s per car). Hence, a two-step algorithm is presented here: in the first step, a new *pre-processing* step (image fusion algorithm) is introduced to enhance the contrast between pixels with a low level of intensity (indicating the presence of defects) and those with a high level of intensity (indicating the absence of defects); for the second step, we present a novel *post-processing* step with an image background extraction approach based on a local directional blurring method and a modified image contrast enhancement, which enables detection of defects in the entire illuminated area. In addition, the *post-processing* step is processed several times using a multi-level structure, with computed image backgrounds of different resolution. In doing so, it is possible to detect larger defects, given that each level identifies defects of different sizes. Experimental results presented in this paper are obtained from the industrial automatic quality control system *QEyeTunnel* employed in the production line at the Mercedes-Benz factory in Vitoria, Spain. A complete analysis of the algorithm performance will be shown here, together with several tests proving the robustness and reliability of our proposal.

1. Introduction

Product quality control is one of the most important processes in a production line, with final products put through several inspections in order to satisfy client expectations. This is especially critical in the automotive industry, where the finish of the car is of the utmost importance, which is why most manufacturers have a dedicated line of quality control in each of its assembly phases: raw plate, painting and final finishing.

Although the majority of production lines today are fully automated, the quality control process is still carried out using manual detection and subjective evaluation by experts, known as *check-men* (shown in Fig. 1). For instance, after a car body has been painted, these check-men inspect the car body based on how the light projected on the body is deflected when a defect is present. In addition, in order to detect defects of very small size, these experts pass their hands over the car body, using special gloves which help them in the detection process.

There are some issues regarding the current manual inspection process: first, the difference in evaluation criteria applied by *check-men* across the board, and second, the difference in the evaluation criteria applied on an individual basis by *check-men* on any one day. These issues make it impossible to guarantee the same minimum quality standard for all vehicles given that the process is affected by human errors. A third issue arising from this is the impossibility of performing a “big-data” analysis that would allow the detection of errors in these previous stages, since any reports compiled are affected by human errors and, moreover, only the most important of these are reported and saved to databases, resulting in the loss of valuable information.

As a consequence of limitations in human detection, product quality managers in the automotive industry are still looking for a systematic solution. Although the ideal scenario would be to detect defects as soon as possible and therefore save money and time and reduce the total cost of the final product, it is in the primary stages (raw plate) where small defects (around 6 μm of diameter) are more difficult to detect. Note

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Fig. 1. Check-men working on a production line, inspecting car body parts following the painting stage (image courtesy of FORD Dearborn, USA).

that when a defect of such small size has passed through the painting process, it can grow in size to the order of 0.2 *mm* in diameter or greater. As a consequence of painting, these defects become more visible if the surface is specular, currently the most common finish in vehicles today and therefore the focus of our research. This effect is not present in matt surfaces.

Let us turn our attention to existing research. Early work in the field of estimating surface deviations using lighting reflection techniques was carried out by [1] using the basic deflectometry principle on metal surfaces. The authors describe a system based on a stripe projection method using a high-resolution line scan camera for the recognition of dents and waviness of only 10 *pm* depth in less than 10 s/m^2. The detection is performed in the frequency domain by detecting the differences between an ideal surface and a surface with defects. This approach works on flat surfaces given that an ideal background can be computed a priori but not on surfaces with concavities or where there are positional variations, in which cases it is difficult to compute an ideal background.

A few years later, [2] differentiates between structured and smooth surfaces. In this work, an image fusion technique based on data fusion techniques [3] is presented, expressing the image fusion as an energy term $E_k(\mathcal{D}, \mathcal{N}, \mathcal{F})$, which involves raw data $\mathcal{D}$, the nuisance parameter $\mathcal{N}$ [4] and the fusion result $\mathcal{F}$. The energy terms are then combined to an energy function E by means of weighting summation $E = \sum_k \lambda_k E_k(\mathcal{D}, \mathcal{N}, \mathcal{F})$, with $\lambda_k > 0$. The authors claimed that the advantages of this approach are its generality such as the possibility to add additional information and constraints by simply adding further energy terms. The approach is then tested on several surfaces, one of them the door of a painted car body, where the image fusion is performed by the minimization of the energy function E. Again, E can not deal with sudden surface slope changes, such as style lines, corners or edges, so the detection was performed on flat surfaces or those with smooth slope changes.

Despite different laboratory setups, a commercial and very successful system based on the ideas in [2] was developed and installed in Ford factories all around the world. This system, described in [5,6], uses a moving structure made up of several light bars (fluorescent tubes at high-frequency) and a set of cameras in fixed positions around the stationary car body, and is able to detect defects of up to 0.2 *mm* in diameter, speeding up and improving the quality of the manual inspection carried out until that point. Unfortunately, as with previous research, only flat surfaces and those with smooth slope changes are inspected, meaning again that all style lines, edges and corners are excluded.

In [7], a very similar system installed in the Opel factory in Spain is presented, the main difference of which is that the inspection is carried out whilst the car body is moving. Again, information about the algorithm detection developed, as well as its performance, is limited.

Other commercial systems dealing with defect detection on painted car bodies use robots to cover the entire area, such as in [8]. This approach tries to cover as much area as possible by bringing the vision and illumination systems close to the body surface, but the details of the detection algorithm are not clear or well explained. In this approach, the area that is not expected can be reduced and the system could cover a much larger area compared with [5,6]. The main problem of this approach is with regard to cycle time production requirements, since it takes a long time to cover the entire surface of the car body and, as far as we are aware, it is still currently an industrial prototype.

In addition, some patents such as [9–13] can be found, proposing systems for the inspection and detection of defects on specular surfaces, none of which clarify or indicate how to overcome the problems of detecting defects in concavities, style lines, edges and corners, etc.

Therefore, this paper outlines a novel automated vision inspection approach based on deflectometry and image fusion techniques which is able to detect defects not only in flat areas and those with smooth slope changes, but in car body style lines (sudden surface slope changes), concavities, edges and corners, etc. This means that the approach is able to detect defects in areas that are very difficult to inspect, such as handles for example, assuming of course that the area is well illuminated. Thus, the paper describes a two-step algorithm: a new *pre-processing* step (image fusion algorithm), which is more robust when faced with environmental illumination pollution (or diffuse light) than, for example, and as is proved in this paper, the one used in [5,6]; and subsequently, we present a new *post-processing* step to extract the image background using a local directional blurring in order to make it possible to detect defects on style lines, edges and corners.

In addition, a multi-level detection approach is presented enabling the detection of larger defects. The input at each additional level is the re-sized image background computed at a higher level. Since one defect can be detected at more than one level, a well-known clustering approach based on distance is used.

Experimental results are obtained from the *QEyeTunnel* industrial automatic control quality system employed in the production line at the Mercedes-Benz factory in Vitoria, Spain. The paper describes briefly both the hardware and software architectures of this system, focusing on the industrial vision system in which the algorithm has been implemented. We provide the computational cost of our algorithm when it is implemented in a dedicated vision system in both *CPU* and *GPU* platforms. We also provide examples of the detection performance and analyze its robustness and reliability by carrying out several tests. In addition, a comparison of the detection using our approach and the manual inspection carried out by check-men is reported and commented upon.

The paper is organized as follows: in Section 2, the preliminaries and objectives of the paper are outlined. Then, in Section 3 the proposed approach is explained in detail. Afterwards, in Section 4, the experimental industrial setup is explained, together with all tests and results, complete with comments. Section 5 discusses some details of our proposal where improvement is possible. Finally, conclusions are provided in Section 6.

2. Preliminaries and objectives

a) *Deflectometry-based detection on specular surfaces:* this technique has proven to be a reliable and accurate approach to accomplishing the task of detecting defects on car body surfaces [14]. In fact, this is what check-men do nowadays in manual inspections using their own eyes, analyzing the reflections on the car body reflected in the car body and looking for deformations. In the same way, as in the case with projection techniques, deflectometry is based on the projection of structured light patterns over a surface. When a triangulation method like fringe projection is used, the camera is focused on the surface onto which a light pattern is projected, as shown in Fig. 2. Thus, when a deformation (i.e. ding or dent) appears, the light rays are deviated, producing a sudden change in