A&QT-R 2002 (THETA 13)
2002 IEEE-TTTC International Conference on Automation, Quality and Testing, Robotics
May 23-25, 2002, Cluj-Napoca, Romania

Quality Control by using Surface Shape Analysis

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Abstract

The purpose of this work is to develop a method to detect possible errors in the production of industrial parts. *Photometric stereo* which provides the surface shape information by normal vectors, and also provides the reflectance map, is used to analyse the surface. This surface information gives us a powerful tool in order to detect surface irregularities, such as bumps, scratches, tooling marks and other blemishes. The mapping of surface normal data to the gradient space domain, offers a mechanism for the representation of global surface shape. An statistical method based on the analysis of gradient distributions is proposed to detect defects. This method can have particular application in many industrial inspection systems in which a single image with one specific illumination is not enough to realise the inspection.

Keywords: Industrial Inspection, Photometric Stereo, Surface Shape.

1 Introduction

Many systems devoted to quality control are using Image Processing and Computer Vision techniques to detect possible errors in the production process. In this sense, the physical configuration of a vision-based inspection system, particularly for the analysis of the surface, can present a challenging problem. The position and orientation of surface irregularities, such as scratches, tooling marks and other blemishes, are often random in nature. Optimal arrangement of lighting and camera position may therefore prove difficult or impractical.

It is often possible to associate specific products, materials and manufacturing processes, with particular kinds of observable surface defects. For example, injection moulded components may tend to exhibit undesired sink or tooling marks, and/or incomplete or additional topological features, whose form, position and orientation, directly relate to both component and tool design. Similarity, cutting, grinding and polishing operations may produce characteristic surface markings, including an altered texture and excessive burrs, as a result of tool wear or the inclusion of foreign abrasive materials.

The method called *photometric stereo* is able to develop a detailed surface description, or *bump map*, of a given component under investigation. The acquired surface description may then be subject to a synthetic or virtual lighting model, for subsequent detailed analysis. The local variation in the surface topography, caused by scratching or local indentations which are generally small in relation or the much larger spatial extent of the observed surface, is of particular significance in terms of industrial surface inspection.

In the last few years photometric stereo has been used to carry out surface texture analysis, determining surface shape and surface roughness [1, 2, 3, 4]. This method is based on the fact that image intensities depend on the surface orientation and its reflectance. Hence, if several images are taken from the same viewing position but with different lighting directions, variation of pixel intensities in these images will be due to changes in the relative positions of the illuminant and the surface. This constraint permits us to calculate the normal vectors, which represent the surface orientation of any point on the surface, and the reflectance factor or albedo, which describes the reflection properties of the surface.

The main objective of this paper, is to develop a method, which using photometric stereo, allows the identification of the defects in industrial parts. The proposed method is based on the analysis of the gradient distributions obtained by photometric stereo, enabling a good performance in the inspection, as is demonstrated in the experimental trials. The rest of this paper is organized as follows. In section 2, the photometric stereo method is briefly described. The method that allows us to detect the defects is explained in section 3. Some experimental results are presented in section 4 to illustrate the performance of this approach. Finally, the paper ends with conclusions.

2 Photometric stereo

Photometric stereo concerns the procedure for obtaining 3D shape from image intensity, and was first described by Woodham [5] for the reconstruction of object shapes from multiple images. In essence, three separate images are captured from a fixed location under a sequence of controlled illumination conditions. The local intensity data within each image is then used to derive a dense array of surface normal vectors across the observed surface.

In this work we use the 4-source colour PS described in [6, 7], which is a modification of the original PS method. This method allows us the best reconstruction of the local gradient and colour surface facet in the *Least Squares Error* (LSE) sense. Moreover, this method gives us the possibility to apply it for surfaces with unspecified reflectance funcion, as it tries to detect and appropriately deal with shadows and highlights in the input images. The idea proposed by their authors is to recover the local gradient ignoring the reflectance model. Since many non-Lambertian surfaces exhibit almost Lambertian behaviour outside their regions of specularity. Therefore, the method uses the linear

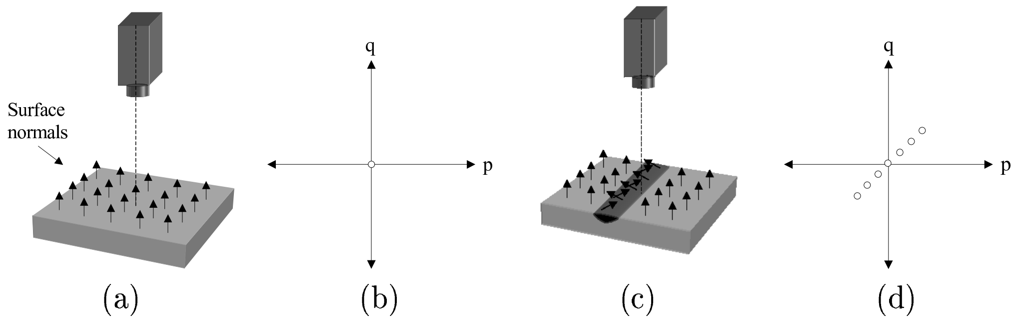


Figure 1: Examples of surface gradient distributions.

algorithm, developed for Lambertian surfaces, to surfaces with arbitrary reflectance, and treat highlights as deviations from the Lambertian law. That was also done, for example, by Coleman and Jain [8], who proposed the 4-source PS technique.

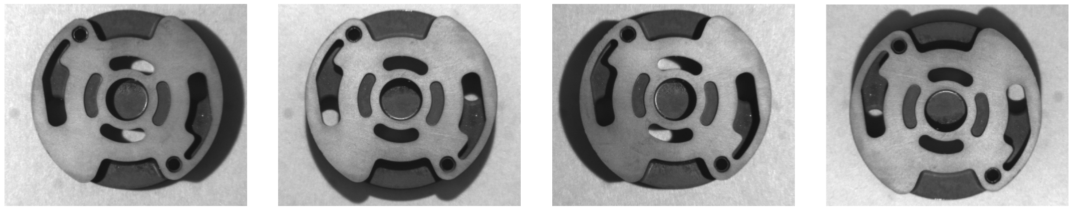
Note that it can be useful to map an array of surface normals onto gradient space in order to obtain an indication of the global surface distribution. If the topography of the surface can be estimated, it may be possible to improve on the performance of the intensity classifier by instead classifying on the surface derivatives.

3 Gradient distribution

In essence, the concept of gradient space facilitates the mapping of an array of surface normals to a series of coordinate points (p,q) within the two-dimensional (2D) gradient domain, where p and q describe the local surface slope or gradient in two orthogonal degrees of freedom, at a given location. By mapping such an array of surface normals into gradient space, an indication of the global surface normal distribution, and hence, global surface shape, can readily be obtained.

By way of a simple example, consider a planar surface arranged to the viewing direction, as shown figure 1.(a). In the case of an idealized flat all surface normals will be observed to be parallel to the viewing direction. Hence, when plotted in 2D gradient space, and assuming orthogonal projection, all mapped normals will appear as a cluster of points located precisely at the origin. Using this representation we may consider such a grouping as an impulsive distribution, as illustrates figure 1.(b). If we now consider the presence of a local discontinuity, as depicted by the depression of figure 1.(c), then the corresponding gradient space image will be altered accordingly, and appears as shown figure 1.(d). It is the character of this distribution which provides an indication of the nature of the observed defects, and we may usefully consider particular defects to have a particular character or signature when plotted in gradient space.

The utilization of gradient space mapping offers an additional advantage in terms of object pose independence. A position change within the plane of the idealized flat surface will not alter the gradient distribution, similarly, as a consequence of rotational



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

Figure 2: Set of photometric stereo images.

symmetry of the featureless surface, surface rotation about the surface normal will also cause no change.

The inspection strategy used in this work is based on the analysis of the gradient distribution. In general terms, a local defect, such as a single scratch, may be considered as a relatively small isolated surface region which tends to deviate from the surface shape *model* obtained a priori. This surface model is the result of average different surfaces of correct parts. The recognition process starts obtaining the surface shape of an input part, described as an array of gradient vectors. Afterthat, the input gradient distribution is compared with the gradient distribution of the surface model. A simple statistical process, the analysis of anomalous data, is used to detect presence of defects, considering this deviation as bumps, scratches and other blemishes.

4 Experimental results

A system consisting on specialised imaging hardware and a series of computer programs were developed to verify the proposed approach. In these experimental results we have analyzed one type of industrial part, which presents scratches and tooling marks as a defects.

The images were acquired in a darkbox so the influence of unwanted extra light was prevented in the scenes. Halogen lamps were used as the point light sources, making stable and well-controlled illumination conditions. Sixty photometric sets of images were taken for the same kind of industrial part. Figure 2 shows a photometric stereo set of the analyzed part. We have constructed two groups of photometric sets: one is the training group used to generate the surface shape model, and the other is the testing group, used as inputs in the recognition system.

One important constraint of our experimental system is that we know exactly the position and orientation of the analyzed part. A mechanical system is used to do that. Therefore, is it possible to know a priori which is the surface region of the part, and analyze only this information.

Some experimental results are shown in figure 3. Note that images only show a small region of the whole surface. The three images shown in figure 3.(a), 3.(b) and 3.(c) are the surface shape information obtained by photometric stereo. The first two are samples

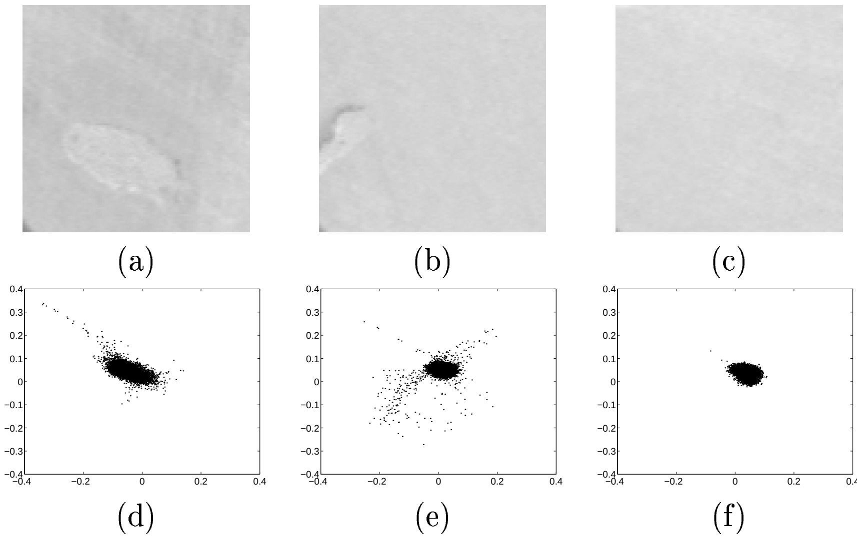


Figure 3: Surface shape and surface gradient distributions. (a)-(b) Surface shape with defect. (c) Surface shape of a correct part.(d)-(e) Gradient distributions of (a) and (b). (f) Gradient distribution of (c).

of defect parts, while the last is one of the surfaces used as a model of correct part. Figure 3.(d), 3.(e) and 3.(f) show the gradient distribution corresponding to figure 3.(a), 3.(b) and 3.(c). It is possible to see how the gradient distribution of a correct part forms a compact cluster. However, data which differ from the correct model, *anomalous data*, appear when the surface contains defects. Hence, calculating the amount of anomalous data which appears in the input distribution the inspection is performed. We choose empirically the threshold which indicates the minimum amount of anomalous data in order to consider the presence of defects in the analysed part.

5 Conclusions

A simple and efficient method to detect defects in industrial parts has been proposed. Photometric stereo has been used in order to obtain the surface shape information. The atraction of using photometric stereo is the possibility to work with 3D information, which enables a better inspection of surface irregularities, such as bumps, scratches or tooling marks, than the systems based on the use of images taken with an specific illumination.

The mapping of surface normal data to the gradient space domain is used in our approach in order to obtain a representation of global surface shape. Assuming the surface model is known a priori, the deviation between the observed gradient distribution (input part) and the gradient distribution of the model, allows us the defect detection. Promising results have been obtained using real sets of images. The work has potential application to inspection problems in industrial environments.

Acknowledgments

This work was supported by an UdG grant BR00/03 and the project CeRTAP-CIF.

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