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Computers in Industry 56 (2005) 918–934

COMPUTERS IN INDUSTRY

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Dynamic photometric stereo for on line quality control of ceramic tiles

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Received 1 December 2004; received in revised form 31 March 2005; accepted 31 May 2005
Available online 10 October 2005

Abstract

The rapid and automated detection of manufacturing flaws is becoming increasingly important in order to maintain competitive advantage in many production environments. In the case of natural and ornamental materials, the presence of both surface colouration and surface topography is often such that manual inspection, along with many conventional imaging techniques, fails to isolate physical or structural defects in the presence of complex and random patterns. In this paper the concepts of photometric stereo are adapted and extended for application in manufacturing environments. A case study on the high speed inspection of ceramic tiles is presented for the analysis of surfaces at production line rates of up to 30 m/min. This new technique, for the first time, demonstrates a genuine and commercially attractive potential for the practical automated quality control of complex surfaces. A commercial system, based on this research, is currently being developed.

Keywords: Dynamic photometric stereo; Bump maps; Surface inspection; Quality control; Machine vision

1. Introduction

Machine vision often involves the acquisition, digitisation and analysis of images for the purpose of data capture and process control. When data resulting from these processes is translated into information equivalent to that derived from human visual perception, it can often provide a versatile means for improving efficiency, product quality and consistency in manufacturing industries. Testimonials in published literature are numerous [1,25].

Practical machine vision inspection systems consist of a combination of computer software, hardware, cameras and lighting, working together to capture and analyse image data. Machine vision is a broad discipline which encompasses aspects of image acquisition, computer vision, image processing and pattern recognition as well as aspects of data extraction and or environment interaction. Often the overall process involves a conversion of physical quantities into digital data and subsequently into

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0166-3615/$ – see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.compind.2005.05.017

meaningful information. Needless to say, the term meaningful information is representative of a specific requirement and therefore is nearly always subjective and application dependant. The output of these systems is increasingly being used to automate manufacturing inspection, feature detection and control. For example, inspecting date codes on pharmaceuticals delivers meaningful information in the form of a production or expiry date for batch classification. Awcock and Thomas [2] describe machine vision in terms of seven stages, these are shown in Fig. 1. The process is considered to be logical, practical and serves well as a template for the design of machine vision systems.

1.1. Surface inspection

In surface inspection applications, surfaces can be analysed using a range of techniques including vision based methods. Surface analysis is sometimes referred to as the study of surface metrology or surface texture. Swonger [3] identifies vision based 3D metrology as a ‘‘niche’’ market area. His paper highlights the advantages of an automated approach over human inspection where hazardous environments, subjectivity, inconsistency, limited attention span, speed of operation and accuracy all affect and limit human operation.

Photometric stereo (PS) emerged in 1978 [4] and has developed into a robust technique for object shape recovery using a simple methodology. However, it has largely remained dormant in its range of application. The classical application of photometric stereo (CPS) has been based on the interaction of collimated, uniform lighting with stationary continuous Lambertian surfaces. Although the technique is widespread, in the main it has remained essentially a laboratory tool, which is capable of recovering discrete surface orientation information for the regeneration of surface form. Within this domain of reverse engineering the emphasis has often been in obtaining surface height information or surface profiling. This type of output requirement, e.g. a CAD model, is sometimes regarded as a complication to the technique as the recovered gradient data must be integrated and therefore is prone to the effects of noise. Weiner filters have been successfully used to suppress spurious noise providing a mechanism for smoothing of the information for reliable profiling. Applying these types of noise reduction transforms is time and processor consuming and seem only beneficial to applications where regions of interest are relatively small. In an industrial application of static PS, Hansson and Johansson [5] have used this approach to analyse surface profiles for ink coverage analysis.

Smith et al. [6] innovated the application range by employing PS for surface inspection purposes without generating height information. This new realm exploited the properties of ‘bump maps’ [7] whereby gradient information was used directly to analyse topography. Here, the surface data is held as an array of surface gradient values. Furthermore, along with the recovery of 3D topography, the isolated reflectance (surface colouring) or 2D information could be analysed simultaneously yet independently. Thus emphasising the appropriateness of applying PS to examine complex surfaces. That is, those surfaces that contain superimposed variable surface colouring on variable surface geometry. It was further shown how existing image processing algorithms could now be

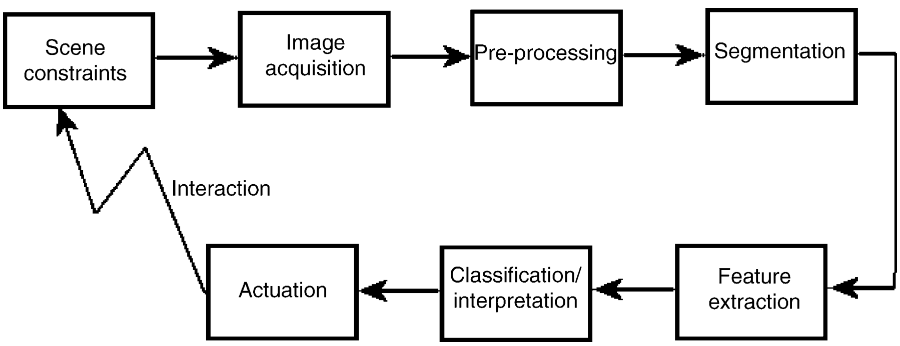

Fig. 1. The seven stages of machine vision [2].