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# An optimisation design of adaptive illumination for a multi-reflective 3D scene

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ABSTRACT

An illumination optimisation technique applied to multi-reflective 3-D machine vision based on a projector-camera system is introduced, in which the projector plays a key role to compensate for surface reflectance at each pixel to be inversely proportional to the brightness of the pixel under ambient light. The adaptive illumination technology was achieved by iterations emphasising different illumination intensities according to different surface orientations and requiring an accurate correspondence between the projector pixels and the camera pixels. In order to establish the most effective correspondence to prepare for subsequent adaptive illumination, 4 kinds of grating patterns, including sinusoidal, rectangular, triangular, and dual-frequency sinusoidal grating patterns, were projected and compared. The iterations were halted when an optimally lit scene was obtained; the further experiments under weak and strong light searched for the best method of illumination optimisation and confirmed the reliability of the adaptive illumination. The proposed optimisation design could run in real time and became a viable solution for industry.

## 1. Introduction

Machine vision analyses and makes decisions based on the quality of a captured image [1–3], which is determined to a large extent by the image capture devices and illumination devices. [4,5] In industrial applications, most frequently used digital cameras have a limited dynamic range, [6] so there will be a loss of pixel resolution in either high-reflective inspection areas or low-reflective inspection areas for a particular multi-reflective 3D scene.

In order to solve these problems, previous studies have investigated based on 2 methods: image-processing algorithms and adaptive illumination technology. In the first approach, image-processing algorithms are unfit for the real-time system, especially in the case of inspecting objects in the context of automation. Among them, High Dynamic Range (HDR) images can be obtained using multiple exposures and post processing algorithms. [7] An alternative approach to HDR is using multiple exposures to create a single image. But these seem inadequate for inspecting an object with different reflective materials, such as a metallic label on dull casing.

Compared to image-processing algorithms, adaptive illumination technology is more suitable for multi-reflective 3D scenes. [8] In recent research, adaptive illumination based on projector-camera systems [9–11] has been applied to balance dynamic range and processing speed, where the projector plays a key role in highlighting dark areas and avoiding saturate.

Sheng Zhou [12] proposed a complex optical system consisting of a light source and a Fresnel lens with an LCD panel, which projected onto a target surface as an initial illumination and adjusted the projected image to compensate for the negative influences. P. Castellini [13] introduced a projection system based on spatially modulated light intensity distribution. The projection was determined by an image inversion algorithm: the image acquired by the camera was inverted and used to modulate the light spatial distribution for projection. Siemens Corporate Research and Technologies [14] gave a semi-automated solution, describing an optimal lighting method based on establishing the correspondence by a depth map [15] of the scene. It was more suitable for real-time online inspection for industry than other previous methods. However, this article does not offer further research and exploration; some problems about the establishment of correspondence that are key to subsequent light compensation, have not been further studied.

In this paper, a camera-projector system was established with the aim to adapt local illumination to the characteristics of a target 3D surface. Mapping stages that establish the specific correspondence between the projector pixels and the camera pixels were compared by 4 kinds of grating patterns different from traditional Fourier transform profilometry. [16,17] We further discussed the correspondence accuracy to establish the most effective correspondence. After every pixel in

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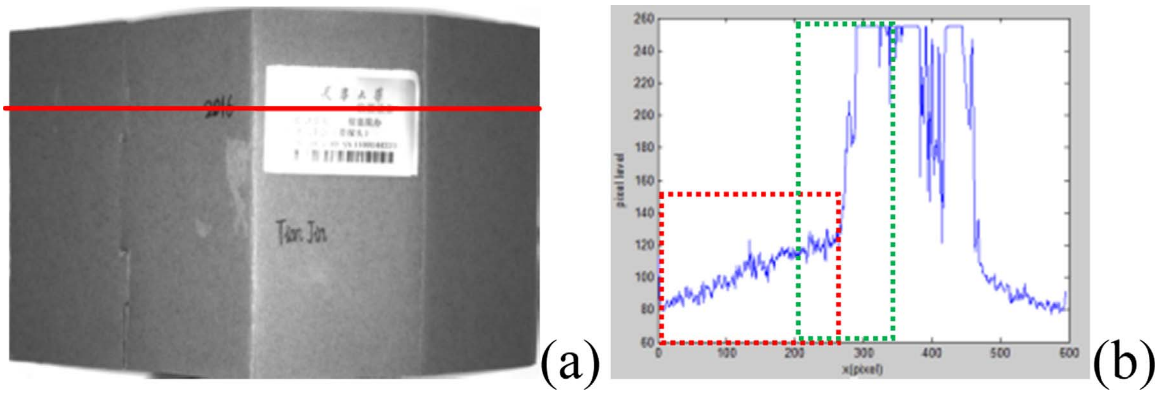


**Fig. 1.** (a) Curved paperboard. (b) Pixel intensity distribution.

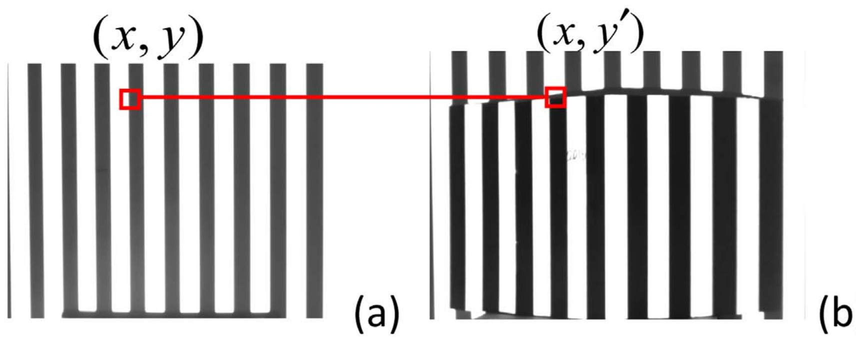


**Fig. 2.** (a)Reference grating pattern. (b) Distorted grating pattern.

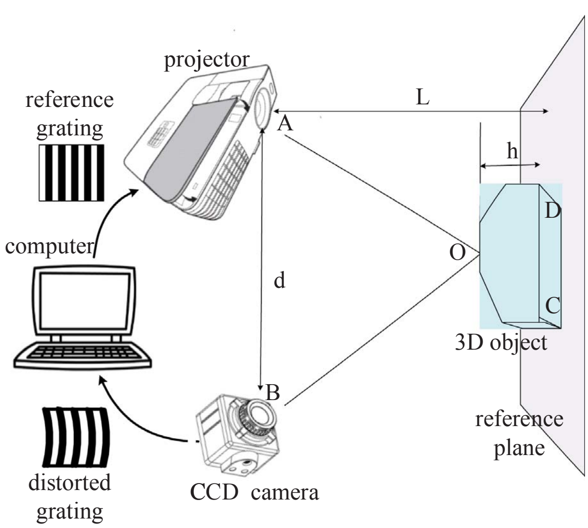


**Fig. 3.** Schematic diagram of Fourier transform.

the projector is optimally mapped onto the corresponding pixel captured by the camera, the adaptive illumination of the scene will be achieved by iteration, which emphasises different illumination intensities according to different surface orientations.

Besides the characteristic of real-time, reliability is used as another important design criterion to limit gross errors. In order to validate the adaptive illumination, we conceived 2 experimental conditions of weak light and strong light. The experiments have confirmed the reliability of the adaptive illumination design. These 4 illumination compensations are compared to analyse the optimisation of adaptive illumination.

## 2. Theoretical principle

### *2.1. The effects of surface orientation and surface reflectivity*

This paper uses a high-reflective label attached to a curved paperboard with low reflectivity as the target object, as shown in Fig. 1(a).

The curved paperboard is illuminated with a local light source. The pixel intensity distribution of the captured image along a red line is shown in Fig. 1(b). For the effect of surface reflectivity marked with a