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3D imager using dual color-balanced lights

Shoude Chang

Optics Group, Institute for Microstructural Sciences, National Research Council Canada, 1200 Montreal Road, M36, Ottawa, Ontario, Canada K1A 0R6

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Abstract

A novel method for grabbing 3D shape of an object is proposed. It uses a pair of color-coded light sources to create a 3D-coordinated illumination space. The intensities of two modulation colors are complementally balanced, which makes the sum of the intensities of the colors a constant. This method demonstrates the abilities of uniquely representing any point in the 3D-coordinated illumination space, reducing the measuring problems in blind area, and compensating the effect caused by changes of surface color and reflection. In addition, this method has the ability of acquiring the 3D shape information in parallel and the algorithm is fairly simple, so the 3D imaging speed is basically restricted by the frame rate of the color CCD camera.

Keywords: 3D sensor; 3D representation; Constructed light; Range imaging; Dual color-balanced lights

1. Introduction

3D information acquisition is of the most importance for many applications, including machine vision, biomedicine, and biometrics. The basic requirements for such an acquisition device are high accuracy, speed, and reliability. Various optical techniques have been developed, which can be classified into four groups:

1. Scanning based methods, including time/light flight and laser beam triangulation [1–8].
2. Structured-light based methods, in which lights project specific patterns such as fringes and moiré pattern on an object [9–13].
3. Stereo (binocular effect) based methods, for example, the photogrammetry [14–16].
4. Interferometry based method [17–20].

The shortcomings of scanning based techniques are low acquisition speed due to the scanning procedure. For the techniques using structured lights, as the accuracy is determined by the grids of the pattern projected on the object, there is a conflict between the high measuring accuracy and large measuring depth. The interferometry based methods also suffer from similar conflicts, and most of them have to use scanning mechanisms. The stereo-based technologies may require distinguishable markers such as retroreflective painted dots on the surface of a measured object to register two images.

In most of the commercial 3D-measurement systems, such as the triangulation method, Biris method, and synchronized-scanning method [5,6], the common bottlenecks are acquisition speed and blind area that inherently result from the laser beam scanning. The range or depth information of such sensors is obtained from the profile of the laser beam projected on the surface of the object, hence a 2D range image consisting of n-profiles will be calculated from n 2D beam-profiling images. In the current applications, to produce the 3D range image with on-line calibration takes considerable resources and computing time. Furthermore, as only one laser beam is used and the camera must have an angle with the laser beam, the blind area of the beam is unavoidable. Fig. 1 shows the principal of the laser beam based 3D sensor.

2. Principle of proposed 3D imager

2.1. Depth representation

The proposed 3D imager is based on the dual color-balanced illuminations. A 3D-illumination space can be

E-mail address: Shoude.chang@nrc.ca

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covered by a pair of 2D light sources, Light L and Light R, as shown in Fig. 2. For simplicity, the image in y direction is ignored. Two 2D transparency films, film L and film R that are linearly colored by green/blue and green/red, respectively, modulate these lights. On each film, at any position, the sum of the intensities of two colors remains constant. It is called color-balanced light. Fig. 2 shows that the sum of green and red and the sum of green and blue are always 10. The entire illumination system is called dual color-balanced lights.

For any point on the surface of a 3D object, its depth $z = f(x,y)$, can be represented by means of two color-balanced light sources. Fig. 3 illustrates the illumination space constituted by two light-source coordinates: b and r, in which a pair of values B and R on axes b and r can uniquely define the range z. Note that

$$(N - R)/B = R/(N - B), \tag{1}$$

and $\theta = 45^\circ$, so $N = R + B$. Because $Z/(M-N) = \sin\theta$, the range of the object is given by

$$Z = (M - R - B)\sin\ \theta, \tag{2}$$

where $\theta = 45^\circ$ and $\sin\ \theta = 1/\sqrt{2}$.

Eq. (2) gives the range of a 3D object expressed by the values on coordinators b and r. The value B or R represents the intensity, or the value of saturation, of blue or red color, which is linearly changed along the b- or r-axis:

$$B(b) = kb + M, \tag{3}$$

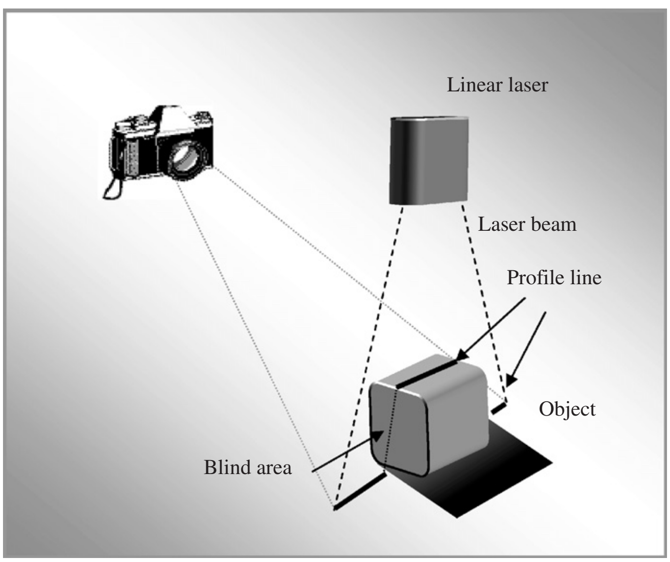

Fig. 1. Laser beam based 3D sensor.

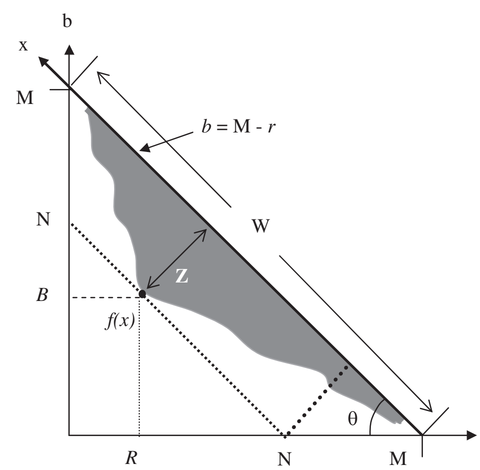

Fig. 3. Depth space spanned by two coordinates.

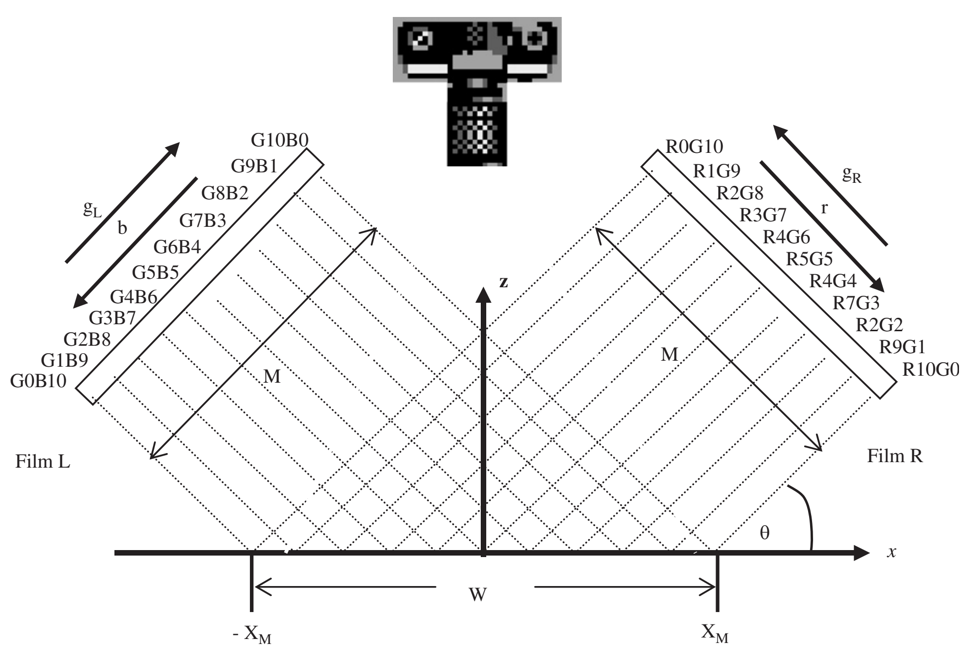

Fig. 2. Plan illustration of 3D imager using dual color-balanced lights.