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A novel three-dimensional imaging method by means of coded cameras array recording and computational reconstruction

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Abstract

In this paper, we propose a novel three-dimensional imaging method by which the object is captured by a coded cameras array (CCA) and computationally reconstructed as a series of longitudinal layered surface images of the object. The distribution of cameras in array, named code pattern, is crucial for reconstructed images fidelity when the correlation decoding is used. We use DIRECT global optimization algorithm to design the code patterns that possess proper imaging property. We have conducted primary experiments to verify and test the performance of the proposed method with a simple discontinuous object and a small-scale CCA including nine cameras. After certain procedures such as capturing, photograph integrating, computational reconstructing and filtering, etc., we obtain reconstructed longitudinal layered surface images of the object with higher signal-to-noise ratio. The results of experiments show that the proposed method is feasible. It is a promising method to be used in fields such as remote sensing, machine vision, etc.

Keywords: Three-dimensional imaging; Coded camera array; Computational reconstruction; Correlation decoding; Global optimization

1. Introduction

Three-dimensional imaging is widely used in such fields as medical diagnoses, machine vision, remote sensing, visual art, etc. It has been subject of research due to their diverse applications and benefits. Holography is a typical coherent three-dimensional imaging method invented by Gabor [1] in 1948. This sort of coherent method has great limitations in practical applications because it requires coherent light source and rigorous conditions to guarantee the interference not be destroyed in recording procedure. Computed tomography (CT) [2] is a specialized X-ray technique that is successfully used in medical diagnoses. CT creates the image by using an array of individual small X-ray sensors and a computer. By spinning the X-ray source and the sensors around the patient, data are collected from multiple angles. A computer then processes these data to create reconstructed images. These images are called "sections" because they appear to resemble cross-sections of the body. As mentioned above, CT is a specialized technique used in invisible light realm. To visible realm, it is not available. In recent years, integral imaging (II) has been studied for three-dimensional

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imaging, television and visualization [3–5]. II uses a microlens array to capture light rays emanating from an object from different directions on an image sensor. Captured information through each microlens forms a demagnified two-dimensional image with its own perspective. These captured two-dimensional images are referred to as elemental images. To reconstruct the three-dimensional image from elemental images, one needs to propagate the rays coming from the images through a similar microlens array used for the recording. This process generates reverse propagation to form a three-dimensional image where the object is originally located. Commonly, II is suitable for the imaging applications of small, close object.

In this paper, we propose a three-dimensional imaging method by which the object is captured by a coded cameras array (CCA) and reconstructed computationally as a series of longitudinal layered surface images. The idea of the proposed method was inspired by coded aperture imaging (CAI) [6–8] and II. It is a combination and development of those. Compared with coded aperture and microlens array, CCA is more flexible. The number and distribution of cameras in array are adjustable according to the practical requirements. Moreover, it has the ability of imaging for arbitrary scale, arbitrary distant object within the view angle of cameras.

In Section 2, we introduce the key processes and basic principle of the method. Theoretical analysis shows the distribution of the cameras in the array, named code pattern, is crucial for reconstructed images fidelity. We use DIRECT global optimization algorithm to design the code pattern that meets our imaging requirements. These works are described in Section 3. Section 4 introduces the primary experimental results we obtained with a simple discontinuous object and some discussions about the method. Finally, we conclude our works in Section 5.

2. Coded cameras array recording and computational reconstruction

Our method contains three key processes as shown in Fig. 1. In the first step, CCA is used to capture the photographs of the object. CCA is an array that is composed of several cameras. The distribution of cameras in array is not arbitrary. Each camera is located at an appointed position, i.e. distribution of cameras is coded. Each camera in array captures a photograph of the object. These photographs are referred as elemental images. In the following step, elemental images are integrated into an image according to the scaling and positions where they are captured, respectively. This integrated image is referred to coded image. In the final step, coded image is decoded to obtain a series of reconstructed images of the different object layers.

To explain basic principle of capturing, integrating and reconstructing in detail, we simplify the practical experimental setup of Fig. 1(a) to geometric optics illustrated in Fig. 2. By simplifying, CCA is simplified to a points array. We name it encoding array. Coded image plane is a virtual plane assumed to connect all the CCD detectors of the cameras. Firstly, we consider a simple case that the object is a planar. So we only reserve layer 1 of the object in this simplification. For three-dimensional object case, we discuss it at the end of this section. z_1 is the distance from object layer to CCA,

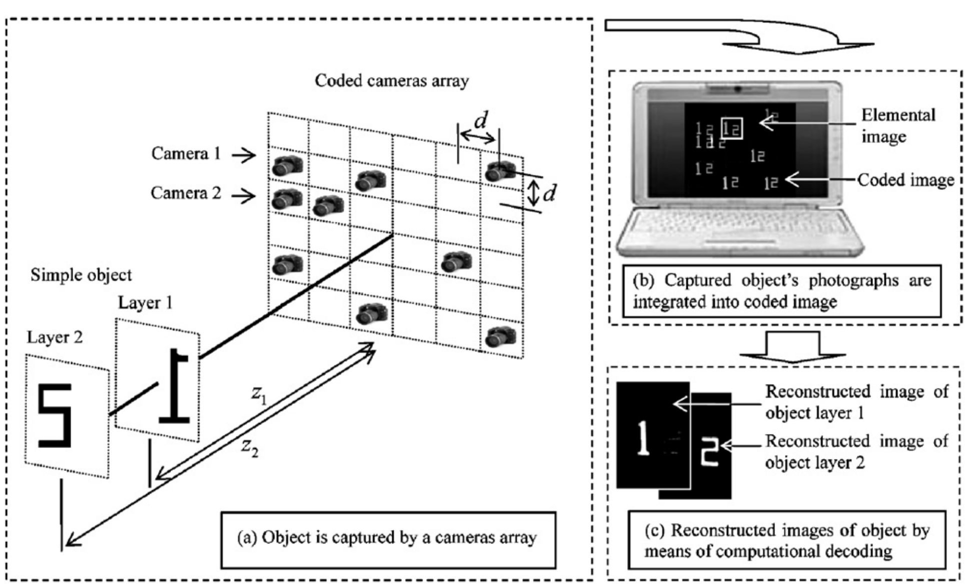

Fig. 1. Three key processes of the proposed three-dimensional imaging method.