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A field measurement method for large objects based on a multi-view stereo vision system

Zhenyuan Jia, Lingli Wang, Wei Liu*, Jinghao Yang, Yang Liu, Chaonan Fan, Kai Zhao

Key Laboratory for Precision and Non-Traditional Machining Technology of the Ministry of Education, Dalian University of Technology, Dalian 116024, China

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ABSTRACT

Field measurement of large objects is important in many fields of study. In this paper, an effective field measurement method for large objects based on a multi-view stereo vision system is proposed. First, to reconstruct the dimensional features of large objects, partially saturated laser stripes are projected onto the surfaces of large objects, and a light stripe model of saturated laser stripes is proposed to extract the feature points of the stripes. Then, a flexible laser-aided pattern is designed, and a high-precision feature extraction method based on a region-of-interest (ROI) is developed, by which the local dimensions of large objects acquired from different views can be transformed into the same coordinate system to complete the measurement of the object's overall dimensions. Experiments are performed both in a laboratory and a forging workshop; the laboratory experiments validate that measurements can be completed with only a small overlapping region (25%) in a field of 8.6 m × 5.0 m with a precision of up to 0.10% using the method proposed in this paper. The experiments in the forging workshop show that the method is effective at measuring the height of a large hot forging.

1. Introduction

It is a challenge to measure large objects accurately and quickly, particularly in industrial applications [1]. Currently, dimensional measurement methods for large objects include laser trackers, coordinate measuring machines (CMM), indoor GPS (iGPS) units, machine vision etc. Compared with other methods, machine vision has many advantages in improving production efficiency and automation that has been widely used in industrial manufacturing and quality control [2–5].

With the development of machine vision, monocular vision system and binocular stereo vision system have been commonly used. The three-dimensional laser scanning system equipped with a single grayscale camera and one standard line laser can obtain the geometrics of objects [6,7], which is simple and low-cost, However, it is not cost-effective for online measurement in terms of time and access to the global information of objects simultaneously, especially for measuring the dimensions of large objects with high accuracy. In our previous studies [8–11], a measurement system based on binocular vision was developed to measure the dimensions of forgings, and it was shown to be effective at measuring small- and medium-sized forgings with measurement errors of less than 0.2%. However, as for long-axle parts, such as a part used in marine with an 8.0-m length and half-a-meter diameter, it is difficult to measure the whole dimensions of these parts by monocular or binocular vision with high accuracy. El Hazzat et al. [12] used a binocular stereo vision system for multi-view 3D reconstruction, and the second camera was moved around to capture more images at different times; it could efficiently avoid the initialization errors, while the objects were required to be still when being measured, which made it difficult to applied in real time measurement. Those methods mentioned above using monocular or binocular stereo vision are unfit for real-time reconstruction of large objects. To acquire accurate and quick measurement of large objects in the industrial field, a multi-view stereo vision system should be adopted.

In the multi-view stereo vision system, large objects are generally divided into several small parts which are captured from different perspectives by vision sensors; then, the separated parts are integrated using registration technology, and a three-dimensional model is constructed. Lu et al. [13] developed a measurement system of the straightness of seamless steel, in which a semiconductor laser device and a camera were constituted a

* Corresponding author.
E-mail addresses: Jzyxy@dlut.edu.cn (Z. Jia), 21304079@mail.dlut.edu.cn (L. Wang), Lw2007@dlut.edu.cn (W. Liu), eeycn@mail.dlut.edu.cn (J. Yang), ly-sme@mail.dlut.edu.cn (Y. Liu), fanchaonan4226@mail.dlut.edu.cn (C. Fan), zkdlut@163.com (K. Zhao).

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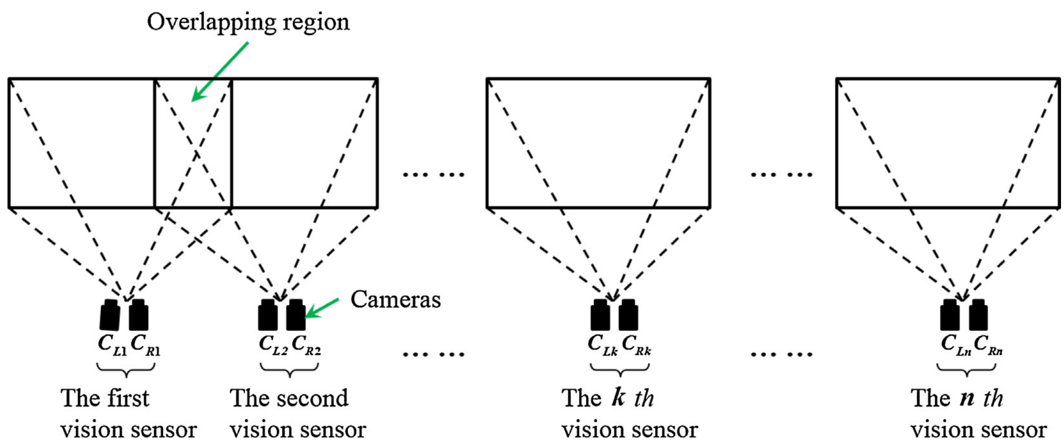

Fig. 1. Multi-view stereo vision system.

vision sensor. Sun et al. [14] presented a measurement method for large 3D free surfaces using two cameras and a Digital Light Processing (DLP) projector as a vision sensor.

In each field of vision sensor, it is common to use targets or auxiliary lighting to emphasize certain features of large objects to achieve high-precision measurements. Large numbers of retro-targets were used to measure the wing root of an Airbus aircraft using a monocular vision system [15]; however, retro-targets may obscure the surfaces of the tested objects. The methods based on retro-targets used at normal temperatures do not work in extreme conditions, such as forgings, which can reach high temperatures of up to 1200 °C. Therefore, the non-contact features produced by auxiliary lighting will likely be more effective when measuring large objects [14,16,17]. Lasers have been widely used as auxiliary lighting, due to good physical characteristics. Steger [18,19] presented an algorithm to calculate the centre points of laser stripes; however, because of the associated computation expense, it was unable to produce rapid extraction accurately and reliably.

Images registration is critical in multi-view stereo vision systems, which transforms dimensional data taken from different perspectives to a reference coordinate system with the relation between vision sensors [20], and the relation is acquired mainly by two methods: the direct method using mechanical structures and the indirect methods using patterns placed in overlapping region. The mechanical structures, such as turntables, frames, and guide rails, are used to obtain the relation directly based on the relative movements of mechanical structures [21,22]. However, the measurement range of these methods is limited by the mechanical structure and their bearing capacity. The patterns, such as planar patterns and pattern balls, have also been used to establish feature information in overlapping regions [16,23]. Yu et al. [24] used pattern balls as feature points whose centres were extracted using a Faro laser scanner. However, planar patterns and pattern balls are difficult to arrange in the complex industrial field. More flexible patterns should be designed to calculate the relation between vision sensors. In addition, the registration algorithm plays an important role in images registration. Besl et al. [25] proposed the iterative closest point (ICP) method, a classic high-precision point-based algorithm used for registration; however, the speed of optimal convergence significantly depended on the estimate of the initial transform. To solve this problem, many modifications have been proposed [26,27]. Moreover, Tsin et al. [28] proposed a optimization based registration method which was accomplished by searching for the maximum kernel correlation configuration of two point sets. Jian et al. [29,30] presented a robust registration using Gaussian mixture models to express point sets, and a statistical discrepancy measure between the two corresponding mixtures was minimized. However, these algorithms are complex and thus have computational costs, which are not suitable for some field conditions.

In this paper, a multi-view stereo vision system is proposed for the measurement of large objects in the industrial field. Laser stripes are projected onto the surfaces of objects to determine indirectly the dimensions of large objects, and these features are captured simultaneously by multi vision sensors to accomplish the real time measurement. This paper is organized as follows: measurement principles are introduced in Section 2, and the extraction of feature information from the laser stripes is described in Section 3; Section 4 details a laser-aided pattern as well as an extraction method proposed for registration, which is divided into coarse and fine registration; and in Section 5, the proposed method is verified by experiments in a laboratory and a forge workshop.

2. Measurement principles

2.1. Measurement method

To determine the dimensions of large objects, a multi-view stereo vision system based on binocular vision is applied, as shown in Fig. 1. There are n groups of binocular Charge Coupled Device (CCD) cameras, and each group constitutes a single vision sensor. The cameras are named $C_{L1}, C_{R1}, C_{L2}, C_{R2}\cdots C_{Lk}, C_{Rk}\cdots C_{Ln}, C_{Rn}$, where the left and right cameras of each vision sensor are distinguished by L and R subscripts, and the relation between left and right cameras is obtained by calibration. The area shared by two adjacent vision sensors is called an overlapping region, where the relation between the two vision sensors is determined with a pattern by technology of images registration. The processes of cameras calibration and images registration are completed before the measurement. Each vision sensor captures simultaneously part of the feature information of a large object of interest, which will later be reconstructed using the calibration results. Then, the feature information of the large object of interest is transformed into the same coordinate system (i.e., the reference coordinate system (RCS)).

In each vision sensor, the three-dimensional coordinates of point $P(X_c, Y_c, Z_c, 1)^T$ in the camera coordinate system (CCS) can be obtained by transforming the corresponding points $p(u, v, 1)^T$ and $p'(u', v', 1)^T$ in the images of right and left cameras, which is described by [31]:

$$\begin{bmatrix} m^{2T} - vm^{3T} \\ m^{1T} - um^{3T} \\ m'^{2T} - v'm'^{3T} \\ m'^{1T} - u'm'^{3T} \end{bmatrix} P = 0 \tag{1}$$