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Stereo matching method for non-coding circular reference points based on motion consistency

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ABSTRACT

Reference point-based fusion of multi-view measurement data is a popular method of object digitization that relies on the accurate matching of reference points in the images. However, due to the lack of coding information in the linear-structured light measurement, establishing a correspondence with the reference points becomes a challenging task. As the pose of a handheld linear-structured light measurement device undergoes very minor changes across neighboring views, this paper exploits this property and proposes a novel method of stereoscopic matching of non-coded reference circle points for a binocular linear-structured light measurement system. First, the polar line constraint is used to determine the initial set of matches, and these matches are used to compute the distance and direction of motion of the camera across neighboring views. The motion information is then used to eliminate the instances of mismatches from the initial results. Experiments on a self-locating linear-structured light measurement system show that the proposed algorithm can achieve an accurate and stable stereoscopic matching of binocular non-coded reference circle points.

1. Introduction

Object digitalization techniques can be used to obtain the discrete coordinates of the surface of an object surface using the principles of computer vision. The entire digitalization process has two broad steps: one-view reconstruction and data fusion. One-view reconstruction refers to the process of obtaining the local data by digitizing the measured object under a single view, and can be done via linear-structured or plane-structured lights. Due to the limited imaging range of the image acquisition device, only a part of the data related to the object contour can be obtained using the one-view reconstruction method. In order to gauge the object completely, the measurements collected under different views must be fused together by projecting all data into the same coordinate system to obtain the 3-D contour of the object surface. A popular method for fusing multi-view measuring data is to bind non-coded reference circle points onto the surface of the measured object to establish a correspondence. In this method, the 3-D spatial location of the reference points is first reconstructed using binocular vision. Based on the invariance of the reference-point topology, label-point correspondences are then computed across different views, thereby achieving a fusion of the multi-view data. This process relies on the accurate and stable 3-D matching among the reference points.

Stereoscopic matching, also known as correspondence point matching, is an important step towards binocular vision reconstruction. Currently, the stereoscopic matching algorithms can be classified into three categories: phase-based, region-based and feature-based [1]. The authors of [2] have reported a survey and comparison of the phase-based stereoscopic dense-matching methods. However, these methods require active projection of the structured grating onto the surface of the object. For one-view reconstruction using linear-structured light, only one data line can be obtained at a time (i.e., the data describing the intersection of the linear-structured light and the object). The limited amount of coding information renders the occurrence of a robust stereoscopic matching as almost impossible, and the phase-based method is therefore not feasible for linear-structured light measurement. The region-based matching algorithm is suitable for images with significant detail information, and requires a highly distinguishable gray scale distribution within the local window. The basic idea behind this method is to search in another image for the pixels lying near the polar line whose local gray scale distribution is most similar to the pixel being matched. As the non-coded reference circle points do not contain any features, this type of method is infeasible for reference point matching.

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In the feature-based stereoscopic matching algorithm, image features (point, line or edge) are first extracted and then matched. As the features are not sensitive to noise, we can obtain accurate and stable matching results. Further, the sparse distribution of the features being matched results in a high operation speed. The discrete feature point matching can be done using the global optimization method [3,4], the feature descriptor direct-matching method [[5],[6]], and the iterative relaxation method [7–10]. The global optimization method constructs a global energy function which is minimized to determine the optimal matching results. The strenuous search for global optimal solution results in a high time complexity and adds to the difficulty of real-time matching. The scope of its application is limited due to the requirements of a continuous second-order differential for the energy function. The idea behind matching using feature descriptors is to first extract the stable feature points from an image and then obtain a unique feature vector (feature descriptor) using the local grey level information of the feature points. Next, the feature points are matched based on the Hausdorff distance between the feature vectors of the two feature points in the pair of images. Typical examples are the scale-invariant feature transform (SIFT) [5] and its various variants [6]. The iterative relaxation method is a semi-optimal method that first constructs a set of initial matches that may also be mismatches. A cost function (i.e., a supporting degree function) is then constructed for the pair of matched points using the matching constraint, and the mismatches are eventually eliminated using a predefined updating strategy. The Pollard-Mayhew-Frisby (PMF) algorithm proposed by Pollard et al. uses shape continuity as the matching criterion. In this method, the shape continuity is described using a parallax gradient, and the mismatches are removed using a relaxation scheme. This method had a substantial influence on subsequent research into stereoscopic matching. Zhang et al. tried to address the matching problem by applying the relaxation scheme with unknown parameters of the pose of each camera [[7–10],9]. The improved updating strategy reported in [8] can achieve effective matching results. Following the cues from [8], the authors in [10] took into account the scale of the neighboring candidate, rotation, local region matching, and collaborative support from neighbors. In [11], the relaxation scheme was used for region-based matching.

It may be noted that these iterative relaxation algorithms do not check correctness of the matching results after relaxation. Hence, achieving correct matching among the non-coded reference circle points for linear-structured light measurement is an issue that warrants further studies. As only one data line can be derived after carrying out a linear-structured light measurement, the measuring device needs to sweep past the surface of the measured object in a slow and stable fashion for the purpose of digitization. Meanwhile, the interval between capturing image shots is so small that the motion of the measuring device across neighboring views may be approximated as a translational motion. Hence, by jointly exploiting the polar line constraint and the consistency of the motion information in neighboring frames, this paper proposes a novel method for stereoscopic matching of non-coded reference points achieved from linear-structured light measurement. In the proposed algorithm, the polar line constraint is first used to determine the initial matches. Next, the mismatches are eliminated using the information regarding motion of the measuring device in the shot interval, thus yielding a stable and accurate stereoscopic matching.

The rest of the paper is organized as follows. The theoretical description of the steps of the proposed matching algorithm is presented in details in Sections II and III. The experimental setup and the results of the proposed algorithm are elaborately discussed in Section IV. Important findings and conclusions from the study are summarized in Section V.

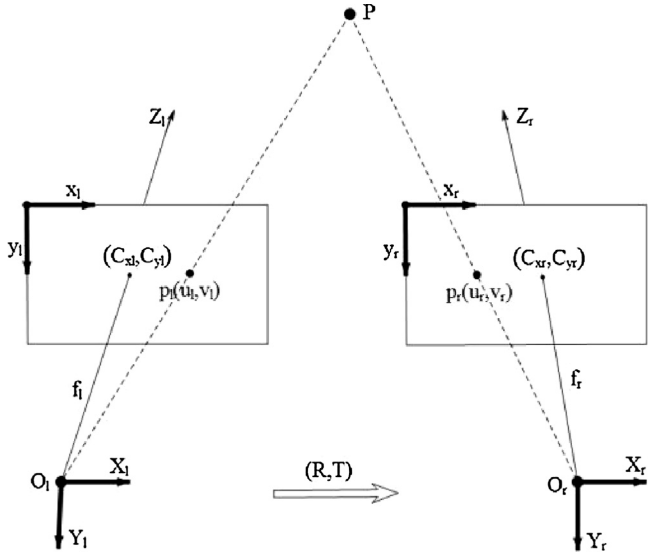

Fig. 1. Binocular vision model.

2. Proposed algorithm – step1: search for initial matching points

This section presents the details of the selection of initial selection and matching of reference points and the binocular vision model.

2.1. Reference point extraction

Several algorithms have been reported for the extraction of the center of round reference points. However, most of existing algorithms rely on simple criteria of image processing and shape determination. For example, the algorithm reported in [12] directly extracts the Canny edges from the initial images and performs filtering. In [13], the images are first preprocessed and binarized; elliptic fitting is then performed on the pixel-level edges of the binarized images. In [14], sub-pixel locations of the edges are determined through cubic polynomial fitting prior to elliptic fitting in order to determine the center of the reference points. Due to the use of local fitting, the algorithm is very sensitive to noise and is unable to obtain global optimal edges. The authors in [15] locate sub-pixel edges using the gradient method. However, the differential-based gradient method is sensitive to noise, thus resulting in a poor positioning accuracy of the ellipse center. Therefore, the center of the ellipse cannot be extracted robustly simply by using image processing and elliptic fitting methods.

An improved method for locating the center of the round reference points is used in this paper. First, the brightness of the image is augmented to the range [0,255]. Next, the Canny edges of the image are extended, and a global optimal search is performed on the edges using the Snake method [16]. Finally, the Zernike operator is used to determine the sub-pixel locations of the image edges, and the RANSAC-based elliptic fitting algorithm is used to locate the center of the ellipse in an iterative fashion [18]. Due to the integral properties of the Zernike operator and the robustness of the adopted fitting method [20–22], the center of the ellipse is located with an accuracy of less than 0.04 pixels, and is further verified with the simulation results.

2.2. Binocular vision model

As shown in Fig. 1, the imaging location of the point P in the space is $pl(ul, vl)$ and $pl(ur, vr)$ in the left and right cameras, respectively.

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