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Utilizing polygon segmentation technique to extract and optimize light stripe centerline in line-structured laser 3D scanner

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ABSTRACT

Light stripe centerline extraction is the basic and key procedure in line-structured laser three-dimensional (3D) scanner. Based on the fact that light stripe's contour is approximately parallel to its centerline, a novel contour polygon segmentation method is proposed for extracting and optimizing centerline. Different light stripe segments are identified in images by contour tracking, and then each of them is segmented into several parts using contour polygonization. Interior angle is defined to trim open light stripe polygon and contour to make sure that centerlines extracted from open light stripes do not include superfluous points. Taking advantage of polygon segmentation, piecewise polynomial fitting method and self-adaptive interpolating strategy are adopted to acquire smoother and evenly spaced centerline points. Simulated experiments show that the proposed method can calculate centerlines from images robustly with a 0.309 pixel average accuracy. Point clouds and surface models of different objects acquired by a line-structured laser scanner demonstrate that the proposed method can produce more complete and smoother 3D models compared to other classical methods. Processing time for the proposed method is approximately positive proportional to the number of pixels in image. Quantitative analysis of time used for each sub-procedure puts forward an improvement direction for the proposed method.

1. Introduction

Due to its advantages, such as non-contacting, fast measuring speed, high precision and automatic processing, optical three dimensional (3D) measurement is one of the most important 3D measuring technique. Compared to passive optical techniques, such as stereo vision [1] without the help of any specific light source, active techniques which use an external light source to help acquire the shape of object can provide more accurate 3D profile information. Based on the light source shape, active techniques can be categorized into: point-structured light, line-structured light and code-structured light [2]. Now active 3D measuring techniques have a wide range of applications such as range finding, industrial inspection of manufactured parts, reverse engineering, object recognition, 3D map building, biometrics, clothing design [3–5].

Fig. 1 shows the schematic overview of standard setup of line-structured light 3D scanner. Laser is often used as the light source due to its well-known advantages. The incident light plane is modulated by the object's surface, and a matrix CCD camera captures the scattering distorted light stripe to acquire the light stripe image. The shape of the laser stripe in the acquired image makes it possible to calculate 3D information about the profile of the object. Whole 3D measurement of object surface can be realized while the object and scanning sensor consisting of laser source and matrix camera can move relatively.

The light plane is usually generated by oblique incidence of laser light on cylindrical reflector, and it has a certain varying thickness along the direction of propagation which makes the thickness of scattering light stripe varied as well. Due to the fact that its shape information is totally determined by its centerline, light stripe centerline extraction is the key and basic problem in line-structured light scanning 3D measurement system. Approaches for extracting light stripe centerline in such system should meet some general requirements [6].

(1) Accuracy: It is an indispensable requirement for such system. In general, the accuracy of centerline should reach sub-pixel level.
(2) Robustness: The proposed approach should be able to deal with various kinds of light stripe with invariable accuracy.

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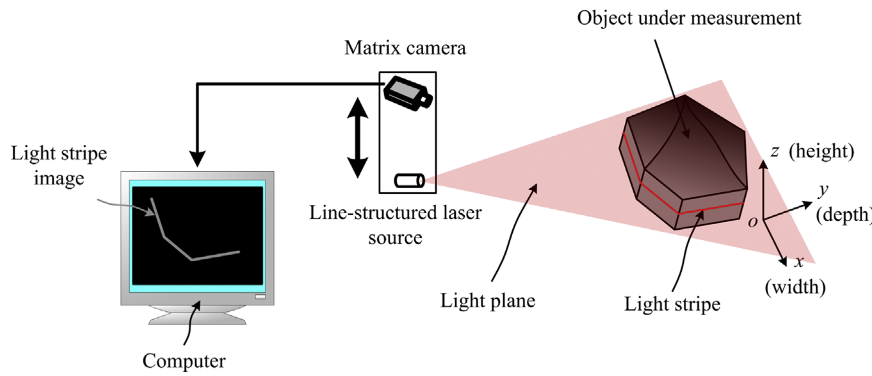

Fig. 1. The schematic overview of line-structured laser 3D scanner.

(3) Speed: Time complexity is a very important technical index for algorithm design. The proposed approach should have fast processing speed.

Unfortunately, it is not a simple matter for the existing approaches to satisfy the above three requirements at the same time due to the following reasons. Firstly, though ideal light intensity distribution in any light stripe cross-section satisfies Gaussian distribution, actual captured images are likely to be deteriorated by noises, such as speckle noise of object surface, random noise from image grabber, CCD camera electronic noise and thermal noise. Secondly, referring to Fig. 5, light stripe image captured from real measured objects may have significant changes: (1) light stripes can be categorized into open and closed light stripes as shown in Fig. 5(a) and (c); (2) the number of light stripe segments in one image can vary; (3) the curvature of light stripe changes greatly; (4) the width of light stripe cross-section changes greatly.

Based on the observation that light stripe's contour is approximately parallel to the centerline except in the vicinity of two endpoints, this paper proposes to take advantage of light stripe segmentation technique to fulfill light stripe centerline extraction and optimization. The rest of this paper is organized as follows: Section 2 describes related works about centerline extraction and curve optimization which have been proposed in the literature. Section 3 presents methodology used for light stripe segmentation and a trimming algorithm for open light stripe contour. The initial experimental results using the proposed method are illustrated and the advantages and disadvantages are pointed out in Section 4; Section 5 introduces centerline optimizing method including centerline points fitting and self-adaptive interpolating algorithm. In Section 6, extensive experiments using data generated by both computer and a line-structured laser 3D scanner are performed. The performance of the proposed method are discussed quantitatively and qualitatively compared with two other methods. Section 7 draws some useful conclusions.

2. Previous related work

Light stripe centerline extraction can be divided into two steps: calculating center point coordinates lying on cross-section and calculating the direction of light stripe cross-section. Due to independence of each cross-section and influence of other factors, the extracted centerline should be optimized before applied for 3D point's calculation. This section introduces related literature.

2.1. Center detection on cross-section

Many methods have been proposed for calculating center point coordinates lying on light stripe cross-section, such as maximum intensity method, intensity threshold method, derivative method, traditional center of mass method and fitting-based methods [7–9]. Maximum intensity method uses the point with maximum gray value as center point, whereas the intensity threshold method calculates the two intersecting points of light stripe cross-section with a gray threshold and the average of two intersecting points is treated as center point. Derivative method defines a numerical peak detector that computes the zero-crossing of the first derivative of light stripe based on its Gaussian profile. These three methods are likely to be affected by various noises, and if the gray value of light stripe reaches saturation, the width of centerline extracted by maximum intensity method is not a single pixel. In order to reduce the influence of noise on centerline extraction accuracy, center of mass method means the sum of weighed coordinates of pixels by gray value; Fitting-based methods [34] usually fit the light stripe cross-section to parabolic or Gaussian curve to calculate center point coordinates. Fisher [10] compared the accuracy, robustness and computational speed of five light stripe peak position detection algorithms, center of mass, linear approximation, parabolic estimator, Gaussian approximation, and Blais and Rioux detector [11], and concluded that all of them display performance within the same sub-pixel range. Haug [12] indicated that the center of mass is the only method that not only has sub-pixel accuracy, but can be processed in real-time and strong robustness.

2.2. Cross-section direction calculation

Direction of cross-section should be carefully handled because it severely influences the accuracy of the extracted centerline. Many methods simply treat the direction of cross-section as the direction of the column/row [6,7,13], which assumes that light stripe roughly runs along row/column direction and its curvature does not change greatly. If these hypotheses cannot be satisfied, this method may produce errors or inaccurate points as seen in Fig. 10(e)–(h). The second category of method for calculating direction of cross-section is first extracting the pixel-level skeleton of a light stripe [14–16] and then uses the normal of local skeleton segment as direction of cross-section. WU [17] adopts direction template to calculate cross-section direction from skeleton. The initial skeleton extracted from light stripe may include some small and superfluous branches that severely influence the accuracy of the calculated normal, and skeleton extraction is usually time-consuming. The third category of method for calculating direction of cross-section is based on the characteristic matrix. Steger [18,34] indicates that light stripe cross-section direction can be