Spot Position Extraction Based on High-resolution Parametric Subspace Method without Eigen decomposition

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1. Abstract:

This paper presents a subspace method of spot centroiding algorithm for locating the centers of laser spots. It focuses on how to find the position of the activated pixel which is the position of the imaged spot on the detector of the camera using Gaussian Approximation method (GAM), Center of Mass (COM) method and Blais and Rioux algorithm. The traditional subspace methods based on either singular value decomposition (SVD) or eigen decomposition (ED) to estimate the signal or noise subspace, these decomposition methods tend to be computationally intensive. In order to improve the algorithm of spot position determination, a proposed subspace analysis is used to determine spot position without eigen decomposition. Therefore, a method of fast subspace decomposition using Lanczos algorithm is presented and compared with other methods. A simulated example is provided to evaluate the proposed method and the simulation results shows that the proposed algorithm has the advantages of reduction the computational load and superior estimation performance.
Keyword: Lanczos, subspace, spot position

استخراج موقع البقعه بالاعتماد على طريقة الفضاء الجزئي الحدودي ذي الدقة العالية بدون تحليل ايغن

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الخلاصة :

يعرض هذا البحث أسلوب فضاء جزئي لخوارزمية النقاط الوسطى لتحديد مراكز البقع الليزرية. البحث يركز علىكيفية العثور على موقع النقطـة المنشطة والـذي هوموقـع البقعـة علـى كاشـف الكاميرا باستخدام طريقة تقريب كاوس، طريقة مركز الكتلة و خوارزمية Rioux&Blais. أن طرق الفضاء الجزئي التقليدية تستخدم اما من خلال تجزئة القيمة المفردة او من خلال طريقة ايغن لتخمين الفضاء الجزئي للاشارة او الضوضاء وهذه الأساليب للتحليل تميل الى ان تكون مطولة حسابيا. من أجل تحسين خوارزمية تحديد مركزالبقعة تم اقتراح استخدام تحليلال فضاء الجزئي لايجادالمركز بدون تحليل ايغن و لذلك تم تقديم طريقة مقترحة من تحليل الفضاء

الجزئي سريعة باستخدام خوارزمية Lanczos وتمت مقارنتها مع الطرق الاخرى . تم تقديم مثال محاكاة لتقييم الطريقة المقترحة واظهرت نتائج المحاكاة ان الخوارزمية الجديدة لها مزايا في تقليل كمية الحسابات وكذلك اداء افضل.

2. Introduction:

Many active scanners use one or more standard CCD or CMOS cameras, the term active means that some well-known light pattern (typically laser) in different geometry (points, planes, crosses, parallel bars, etc.) is projected onto the scene. An excellent survey on active range scanners was published by [1][2].

Various methods for acquiring range images were surveyed by Jarvis in 1983[3].More recently, Tiziani [4] and Chen, Brown, and Song [5] presented comprehensive surveys focusing on a few techniques used mostly for object modeling, and although 3-D object modeling applications are today quickly growing.

3. Spot Position Extraction:

This section examines in more detail who can extract the location of the laser spot in most short-range laser scanners. It is focused on how to find the position of the activated pixel *p* which is the position of the imaged spot on the detector (CMOS) camera.

At the sensor, since the energy pattern of laser stripe corresponds to a Gaussian profile, it makes sense to detect the point of maximum light intensity (or peak) by computing the zero-crossing point of the first derivative of such Gaussian profile.Josep F. [6] consider that stripe scanning is an inherently row-parallel process, every row of a given image must be processed independently in order to compute its corresponding peak position in the row, and this is very expensive process used in of digital filtering techniques in order to cope with the detection of a laser stripe. To determine the stripe to subpixel accuracy, the image of the stripe width must be observed over more than one pixel. Subpixel algorithms plus new proposed one are analyzed In the analysis, *p* is the pixel position of the observed peak sensor reading with *f(p).f(p-1) and f(p+1)* are the values of the adjacent pixels, the true peak is at $p+\delta$, and $\hat{\delta}$ is the estimated δ.

A.Gaussian approximation(GA):

This algorithm uses the three highest, intensity values around the observed peak of the stripe and assumes that the observed peak shape fits a Gaussian profile. The subpixel offset ($\hat{\delta}$) of the peak is give by [7]:

$$\hat{\delta} = \frac{1}{2}\frac{\ln(f(p-1) - \ln(f(p+1))}{\ln(f(p-1)) - 2\ln(f(p)) + \ln(f(p+1))} \quad (1)$$

B. Center of Mass:

The center of mass algorithm also assumes that the spread of intensity values across the stripe conforms to Gaussian distribution. Thus, the location of the peak can be computed by simple weighted average method. These can be applied using only three points, five points or seven points denoted (COM3, COM5 and COM7). The subpixel location of the peak for COM3 is given by:

$$\hat{\delta} = \frac{f(p+1) - f(p-1)}{f(p-1) + f(p) + f(p+1)} \quad \ldots\ldots(2)$$

For COM5:

$$\begin{aligned}\hat{\delta} = &\{\ 2f(p+2) + f(p+1) \\ &- f(p-1) - 2f(p-2)\ \} \\ &\div \{\ f(p-2) + f(p-1) + f(p) \\ &+ f(p+1) + f(p+1) + f(p+2)\ \}\end{aligned} \quad \ldots.(3)$$

For COM7:

$$\begin{aligned}\hat{\delta} = &\{\ 3f(p+3) + 2f(p+2) \\ &+ f(p+1) - f(p-1) \\ &- 2f(p-2) - 3f(p-3)\ \} \\ &\div \{\ f(p-3) + f(p-2) + \\ &f(p-1) + f(p) + f(p+1) \\ &+ f(p+1) + f(p+2) + f(p+3)\ \}\end{aligned} \quad \ldots.(4)$$

C. Blais and Rioux Detectors:

Blais and Rioux [8] introduced second and fourth order linear filters:

$$g_2(p) = f(p-1) - f(p+1) \quad \ldots\ldots(5)$$

$$\begin{aligned}g_4(p) = &f(p-2) + f(p-1) \\ &- f(p+1) - f(p+2)\end{aligned} \quad \ldots\ldots(6)$$

These operators act like a form of numerical derivative operator. The peak position is estimated as above by:

$$\hat{\delta} = \frac{g(p)}{g(p) - g(p+1)} \quad \ldots\ldots(7)$$

The above equation applied in the given form for *f(x+1)>f(x-1)*. If *f(x+1)<f(x-1)* then:

$$\delta = \frac{g(p-1)}{g(p-1) - g(p)} - 1 \quad \ldots\ldots.(8)$$

4. The Proposed Spot Position Algorithm :

After studying of the previously mentioned algorithm for

peak detection, a new spot position algorithm for peak detection, is introduced.

First a laser beam image is captured by a camera. The pixel with higher intensity from the image must be extracted, but since the laser spot cover more than one pixel , the traditional methods use this pixel with higher intensity and next select a square window around it of (2n+1) by (2n+1) around the center pixel. Then according to the intensity information of these selected pixels, the centroid could be obtained.

To improve the algorithm of spot position determination, the proposed algorithm uses subspace analysis to determine spot position. After the laser image is acquired, a setting to threshold level is used to filter out the background noise, then the pixel exceed the threshold are selected and an evaluation of spot position based on subspace without eigen decomposition is used. The intensity distribution of laser beam is supposed to be elliptical Gaussian function. The center of ellipse is found by mean of the proposed method. Most of the traditional subspace methods have used either singular value decomposition (SVD) [9] or eigen decomposition (ED) to estimate the signal or noise subspace. These decomposition methods tend to be computationally intensive. Therefore, a proposed method of fast subspace decomposition using Lanczos algorithm is introduced. The Lanczos algorithm is presented in [10][11].

The Lanczos algorithm is well known asthe fastest method solving eigenvectors for large sparse matrices [12]. Itconstructs simultaneously a

symmetric tridiagonal matrix T and orthonormal matrix V such that:

$$T = V^T A V \quad \text{......(9)}$$

The algorithm can be deduced as follows:

Let

$$T = \begin{bmatrix} \alpha_1 & \beta_1 & \dots & 0 \\ \beta_1 & \alpha_2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \beta_{n-1} \\ 0 & \dots & \beta_{n-1} & \alpha_n \end{bmatrix} \text{......(10)}$$

And $V = (v_1, v_2, \dots, v_n)$. then the equation

$$V^T A V = T$$

or

$$AV = VT$$

or

$$A(v_1, v_2, \dots, v_n) = (v_1, v_2, \dots, v_n) \times \begin{bmatrix} \alpha_1 & \beta_1 & \dots & 0 \\ \beta_1 & \alpha_2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \beta_{n-1} \\ 0 & \dots & \beta_{n-1} & \alpha_n \end{bmatrix} \text{......(11)}$$

Gives

$$A v_j = \alpha_j v_j + \beta_{j-1} v_{j-1} + \beta_j v_{j+1} \quad \text{where } j = 1, 2, \dots, n-1$$

Multiplying both sides of this equation by v_j^T.

$$v_j^T v_j = 1$$

$$v_j^T v_k = 0 \qquad j \neq k$$

After all the spot position can be gotten by searching the peak of the following spatial spectrum:

$$P = \frac{1}{a^H V V^H a} \quad \text{........(12)}$$

some computationally subspace-based algorism shown in [13][14].

5. Results:

In order to evaluate the effect of peak position estimation, experiments have been arranged. The former consists on evaluating the behaviorof the proposedmethod comparing with six other peak estimators. These peak estimators are known as GA, COM3, COM5, COM7, and BR.

The laser source employed for an illumination source is He-Ne of wavelength 632.8nm and power of 1mW. The detector used is a CMOS sensor camera of 1/3 inch sensor.

Because the laser projection beam does not run parallel to the optical axis of the camera, the shape of the laser spot projected on the target surface could be circular or elliptical. When the shape of the spot is elliptical its orientation could be varied either vertical or horizontal or in between. In this paper, the peak detection algorithms are investigated by considering these different shapes of laser spot which are either circular or oblique ellipse as shown in figure (1).

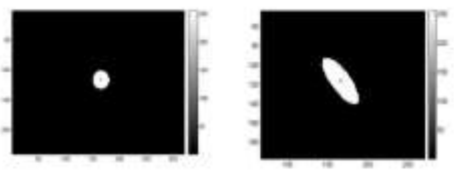


Figure (1): Intensity image generated with single pixel for laser spot of shapes circular and oblique ellipse.

Figure (2) shows some of the captured images with laser spot at different positions and the cross label in the center of the laser spot represent the position of the centroid that was calculated using the new proposed method.

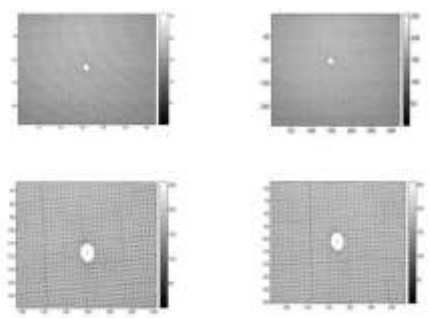
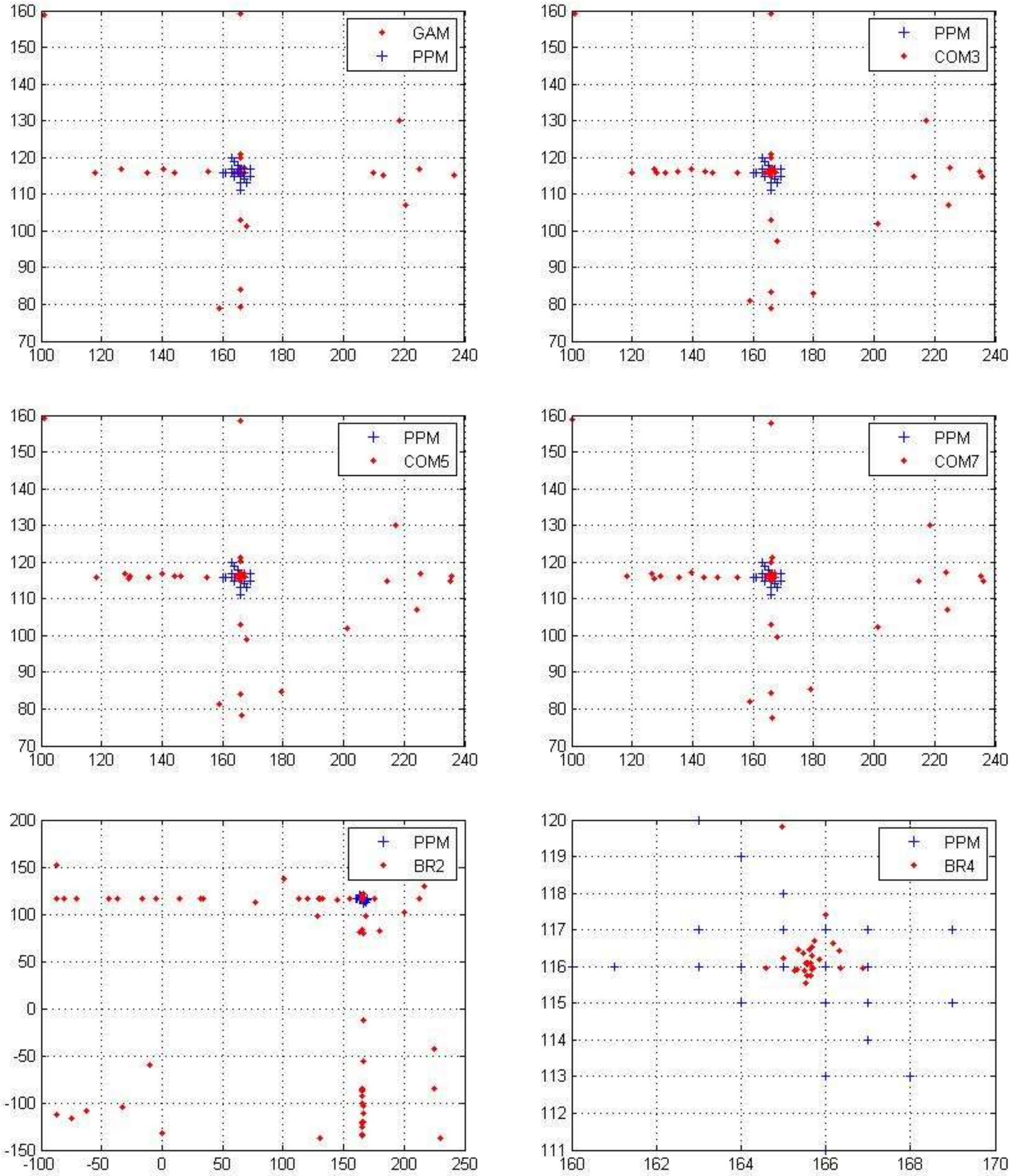


Figure (2): Some of the captured images with their resulted pixel position calculated using centroid of the laser spot after determining the area of the spot using the new proposed method.

The scatter plotof the proposed position method (PPM) with other six methods to estimate the position of spot at location (166, 116) is shown in figure(3), where fifteen different independent trails are used to estimate the spot position at location (166, 116) for the purpose of the comparison between the performance of the proposed method and the other six methods.

6. Conclusions:

The spot position extraction based on high-resolution parametric subspace method without eigendecompositionis compared with other six method. The proposed method has the advantages of reduced computational load and superior estimation performance with high probability of success.



Figure(3): Scatter plot of the proposed position method (PPM) with other six methods to estimate the position of spot at location (166, 116)

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