A NEW DIGITAL INTEREST POINT OPERATOR FOR CLOSE-RANGE PHOTOGRAMMETRY

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ABSTRACT:

The process for automatic DTM, DSM generation in close-range photogrammetric applications is always a need but under investigation for many years so far. It is well known that close range conditions are wide big different from the aerial ones, basically due to the three reasons: (a) the perspective in images appears to be larger; (b) the existence of repeated patterns at every turn and (c) the occlusion problem eventuates prevailing. In all cases, the need for accurate and reliable automatic surface extraction still remains. In order, image matching applied and produced accurate results the detection of well-defined interest points is a requirement. Nowadays, a variety of key point detectors exist but each fits to specific needs. A survey of the existing interest point detectors is described in a short review. The correspondence problem, what we use to call image-matching process in digital Photogrammetry, remains of important interest in image analysis field. Matching feature points between images comprises a fundamental process in Digital Photogrammetry applications such as image orientation or DTM, DSM generation. In Computer Vision applications they use a different terminology for these processes and they target to the recovery of 3D scene structures, the detection of moving objects or the synthesis of new camera views. Even though solutions in automatic image matching are being examined yet, especially for difficult cases, such as close-range ones, significant progresses have been occurred in interest point detection. The most common advances in this field are the, Moravec, Plessey, Förstner and SUSAN interest point operator. It is well known that in digital Photogrammetry Förstner operator is the most usable operator for the detection of characteristics points. A strategy in matching process is considered useful if it is able to filter out many of the mismatches found in an input matching set of points, while keeping in most of the good matches present. This is the fundamental motive for detecting crucial interest points that will support in an optimum manner the matching strategy. The paper reports the problem of detection and representation of interest points in photogrammetric images as a part of a study for automatic image matching in close-range cases. We propose a new digital interest point detector, starting the approach from the existing key point detectors and extending the algorithm so as to fit in close-range photogrammetric conditions and requirements. The final result is the development of the interest point detector, what we call *Plessey-Grid operator*. The operator is tested in real photogrammetric conditions.

1. INTRODUCTION

The paper describes the problem of detection and representation of interest point in close-range photogrammetric images. The study is a part of a doctorate research in the thematic area of automatic image matching in close-range photogrammetric problems for calculating surface and terrain models.

The necessity for automatic DTM, DSM generation under close-range photogrammetric conditions is always of high need and under intense research for many years. Close range conditions are wide big different from the aerial ones, basically due to three reasons:

1. The perspective and image angles appear to be larger;
2. The occurrence of repeated patterns;
3. The often encounter of occlusion problem in close range scenes.

In all occasions, the demand for accurate and reliable automatic surface or terrain model extraction still remains. In order for the image matching to be applied and produce accurate results the detection of distinct interest points is a strict constrain. Currently, a variety of key point detectors exist, but each one fits to specific problems and definitions. A short survey of the existing interest point detectors is presented in the next paragraphs.

The correspondence problem still is a central aim in image analysis field. Matching feature points between images comprises a fundamental process in digital Photogrammetry applications such as image orientation or DTM, DSM generation. In Computer Vision applications a different terminology is used for these processes and the central aim is the recovery of 3D scene structures, the detection of moving objects or the synthesis of new camera views.

Although more robust solutions for automatic image matching are being still been sought, especially in difficult cases such as close-range ones, significant progress can be reported in interest point detection. The most common advances in this field are the Moravec, Plessey, Förstner and SUSAN interest point operator. In Digital Photogrammetry –aerial and close range- Förstner operator is the most widely used operator for the detection of interest points.

A strategy in matching process is considered useful if it is able to filter out many of the mismatches found in an input matching set of points, while keeping the majority of the good matches. This is the fundamental motive for detecting interest points that will support, in a maximum manner, the matching strategy. Besides, a good quality of matching assumes a good number and distribution of well-defined interest points.

The effort is not to develop a new digital interest operator from scratch but to advance the existing knowledge and build up a new concept that fits to specific needs; in particular to close range photogrammetric applications. This concept guides the attempt which this paper reports: for a quest for a new digital interest point operator, the *Plessey-Grid*.

2. SHORT REVIEW OF EXISTING OPERATORS

A set of interest point detectors has already been proposed in the international literature. The majority of the work concentrates in the two-dimensional feature points singly on “corners”. These features –corners- are mostly formed at the limits between image regions where boundary curvature is significantly high.

Moravec (Moravec, 1977 & 1979) was the first that developed the idea of using “points of interest”, which means points with special characteristics that can easily be recognized. These points are defined as points that appear when high intensity differences occur in every direction. Moravec in his approach computed an un-normalized local autocorrelation in four directions and then took the minimum result as the quantity of interest. This measure is thresholded and the local non-maxima are suppressed.

Harris and Stephens (Harris & Stephens, 1988) proposed what has become well known as the Plessey feature point detector. The approach was based to the Moravec interest operator, but the measurement of local correlation is valuated from first order image derivatives.

Förstner and Gülch (Förstner & Gülch, 1987) report a method, which seems to use exactly the same measure of “cornerness” like the Plessey operator. Due to their approach the detection and localization stages are separated into the selection of window in which features belong, and feature location inside the picked window. The algorithm runs in a slower mode than Plessey detector. In fact, the operator is useable in photogrammetric systems and applications.

Smith (Smith, 1995) proposed the SUSAN corner detector. Smith in his method proposed the use of small circular pixel mask of which a small area, called USAN, will present similar intensities. Noting how the position of the USAN center of gravity changes from the mask center, a concept is extracted to define corners.

Basically, the above mentioned operators are not the only ones in the international literature. However, the most well-known interest point operators in Digital Photogrammetry and Computer Vision are presented to introduce the reader in the relevant research field. Besides, the extent review of all the interest point operators does not constitute a high priority for the paper.

3. THE DIFFERENTIAL APPROACH

In this section we start by defining the basic differential approach theory for interest point operators and finally we proposed the appropriate extensions, which led to the development of what we call as interest point operator; the Plessey-Grid operator.

Starting from the very first corner detector, Moravec’s corner detector (Moravec, 1977) we compute in any pixel the average change of intensity $E_W(x,y)$ from a moving window W that shifts by a small distance in (x,y) directions. By this approach a global trend of local maxima in $min(E)$ above some threshold value over the directions is measured.

In the image areas where homogeneity exists, E_W is a small quantity in any direction. If the location is over an edge pixel, then the minimum value of E_W quantity is related to the edge direction and in the same way is a small quantity as well. In cases where corner points or junctions exist, any displacement reports a non-zero value for E_W.

The average change of intensity E_W is defined by the following formula (1), i.e.

$$E_W(x,y)=\sum_{i,j} w_{i,j}\left|I_{x+i,y+j}-I_{i,j}\right|^2 \qquad (1)$$

where I denotes the input image and w the local window that is moving around over the image.

Harris and Stephens in their approach (Harris & Stephens, 1988) proposed the extension of the average change of intensity in any direction calculating a Taylor series using small (x,y) shifts, i.e.

$$E_W(x,y)=\sum_{i,j} w_{i,j}\left|x\frac{\partial I}{\partial x}+y\frac{\partial I}{\partial y}+O(x^2,y^2)\right|^2 \qquad (2)$$

Expressing the above formula (2) in an equation mode we have the following

$$E_W(x,y)=Ax^2+2Cxy+By^2 \qquad (3)$$

where the parameters A,B,C are calculated by

$$A=\left(\frac{\partial I}{\partial x}\right)^2 \quad B=\left(\frac{\partial I}{\partial y}\right)^2 \quad C=\left(\frac{\partial I}{\partial x}\right)\left(\frac{\partial I}{\partial y}\right) \qquad (4)$$

The above equation 3 can be formed in a different mode like

$$E_W(x,y)=(x,y)M(x,y)^T \qquad (5)$$

However, the evaluation of gradients is sensitive in input image data. For this reason before computing the gradients we usually smooth the image using a low pass filter. A typical example is image convolution by a Gaussian

$$I_s = I \otimes G \tag{6}$$

where

$$G(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{\frac{x^2}{2\sigma_x^2}+\frac{y^2}{2\sigma_y^2}} \tag{7}$$

and $\otimes$ denoting the convolution product. This enhancement smoothes the image and reduces the level of noise since high frequencies are being removed.

Matrix M is a 2×2 symmetric matrix and it is defined as follows

$$M = \begin{pmatrix} A & C \\ C & B \end{pmatrix} \text{ or} \tag{8}$$

$$M = \begin{bmatrix} \left(\frac{\partial I}{\partial x}\right)^2 & \left(\frac{\partial I}{\partial x}\right)\left(\frac{\partial I}{\partial y}\right) \\ \left(\frac{\partial I}{\partial x}\right)\left(\frac{\partial I}{\partial y}\right) & \left(\frac{\partial I}{\partial y}\right)^2 \end{bmatrix} \tag{9}$$

Diagonalizing matrix M we receive the two principal gradient components, which are given by the eigenvectors and their length, which is given by the eigenvalues. Therefore, a corner can be defined as the point where the magnitude of both directional gradients is high.

Moreover, according to Förstner approach (Förstner, 1994); matrix M is defined as the average squared gradient matrix, which depends on two scales:

1. The natural scale used to describe the blurring process and related to the differential operator;
2. The artificial scale used to integrate the local differential values and related to the size of window w.

From the above analysis it is derived that we are seeking for regions in the image where matrix M is a full rank matrix. Thus, what is needed is a function which effectively measures the rank deficiency of matrix M. This function is used to call as a response function.

Harris and Stephens (Harris & Stephens, 1988) in their approach develop the idea of high gradient magnitude using the determinant and the trace of matrix M. As a consequence they proposed formula 10 -response function- for the extraction of corner point from images. This is what comprises the approach that became commonly known as the Plessey feature point detector.

$$R = det(M) - k\,(trace(M))^2 \tag{10}$$

Since

$$det(M) = \lambda_1\lambda_2 = M(1,1)M(2,2) - M(1,2)^2 \tag{11}$$

and

$$trace(M) = \lambda_1 + \lambda_2 = A(1,1) + A(2,2) \tag{12}$$

value R can be computed directly from matrix A without requiring evaluating eigenvalues λ_1, λ_2.

The parameter k in formula 10 has not been examined yet. Harris and Stephens (Harris & Stephens, 1988) do not give any

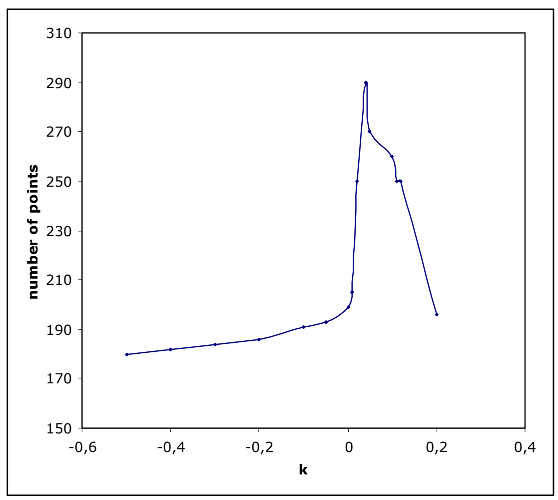

Figure 1. Number of key points in image of for various values of the parameter *k*

additional information of k parameter. Nevertheless, several experiments occurred for the behavior of this parameter. Bres and Jolion (Bres & Jolion, 1988) prove that the number of detected corners is highly depended on this parameter value. Using the Derich operator (Deriche, 1987) for calculating the local gradient, they proved that k parameter does not effect as a threshold, i.e. there is no linear behaviour between k parameter and detected corner points. Through their experiments they found a maximum k value at 0.05. This value approached the values proposed by Derich (Deriche, 1987) $k = 0.04$ and by Schmid (Schmid, 1996) $k = 0.05$. Figure 1 (Bres & Jolion, 1998) shows the results for k parameter related to the number of the extracted key points in a generic image presenting a human face.

4. THE PLESSEY-GRID APPROACH

The proposed approach as it can be extracted from the definition is closely relevant to the original Plessey interest point operator. A few arrangements, mainly requirements and restrictions of the algorithm were set up to fit close range photogrammetric needs.

In close range photogrammetric issues where conditions are more complicated than the aerial ones, dense cloud of interest points is not necessarily the appropriate solution for surface generation through image matching techniques. Contrarily, in most of the cases is an unpleasant situation. This argument was a fundamental precondition while modifying the operator. It was a high notice requirement to prevent the operator detecting interest points very close to each other. This condition forces image matching to have a more clear view of points which are under correspondence inspection.

Initially, the proposed technique assumes a fictitious grid (Fig. 2) which is predefined in specific dimensions. In the area of grid nodes the algorithm is applied to detect the points of interest. (e.g. 15 pixels). In addition, an area of 15×15 pixels

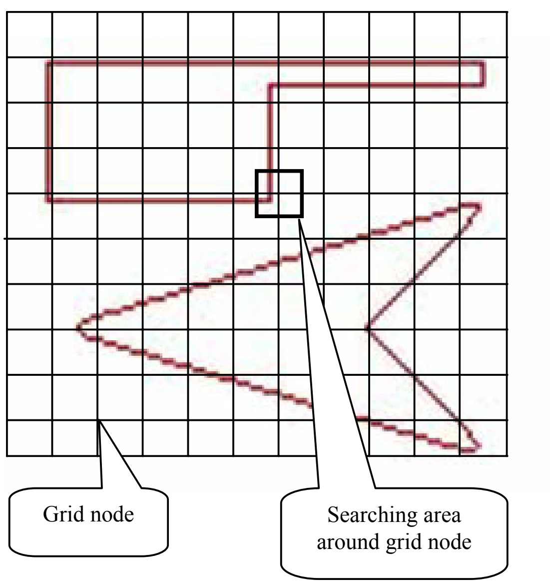

Figure 2. Fictitious grid over the digital image

is arranged around every grid node (see fig.2 detail). This area is used as a search area for the quest of the potential interest point.

In the following, the image is smoothed by convolving the original image with a Gaussian (Equation 7) so as to reduce the level of noise. It is well known that the assessment of gradients is sensitive in input image data and that is why a low pass filter is applied.

For each pixel in the searching area image gradient is computed in order to calculate matrix M and its components (Equation 9). Thus, by diagonalizing matrix M we receive the two primary gradient components, which are given by the eigenvectors and their length, which is given by the eigenvalues.

Sequentially, using formula 10 we compute the response function R. In our approach the value 0.04 was used for k parameter. It was proved that using the specific value good enough results were extracted from the images.

The next step refers to the evaluation of the above computations in order that interest points to be detected. The minimum point in matrix R for each searching window around grid nodes may detect an interest point. The crucial threshold value for the evaluation of the minimum value in the response function R is defined by the user. An easy and effective way to overcome the definition of threshold value is to acquire automatically a value above the mean, for example 75%, from all R values all over the image. The users that are familiar with the algorithm's efficiency may define threshold value themselves.

Moreover, an additional restriction, which is anticipated a critical difference between the classical approach and the current one, can be applied. The evaluation of intensity values across horizontal and/or vertical pixel direction so as a big difference between adjacent pixels exist in both directions (Fig.

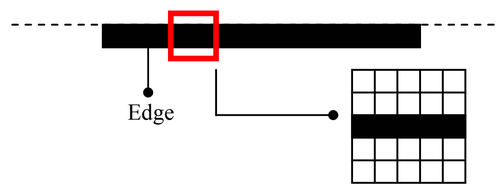

Figure 3. Seeking for interest point across an edge

3). The definition is very useful is cases where geometric shapes exist (like the ones in Fig. 2) where horizontal and/or vertical lines appear. This way image matching is prevented; while adjacent "similar" points are not so easy to be detected across the epipolar line.

The algorithm is very fast and can be executed under standard PC specifications. The denser the fictitious grid size the more delay in algorithm execution. It is obvious that grid size is defined by the user and varies according to the specifications of the application.

The algorithm can be applied either on the whole image space or in a selected part of the image that is given by the user. In addition, the algorithm can be used both in grey scale and colour images. In Table 1, results checking the speed of the algorithm are given and the relevant graph is presented in Figure 4. The dimensions of the test image were 1024 x 768.

Grid size (pixels)	Time (sec)
15	17
20	10
25	7
30	5
50	2

Table 1. Time tests for different values of grid size

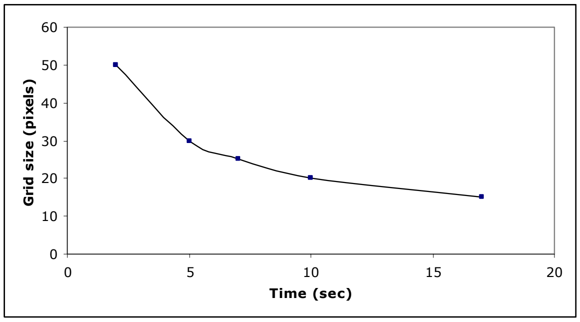

Figure 4. Testing algorithm's speed for various grid sizes

To give an illustration of how algorithm works in close range images, a set of examples is given in Figure 5.

4.1 Algorithm overview

In line to the above analysis an overview of the proposed algorithm is presented below to summarize the most important steps in key point detection process.

1. Smooth the image by convolving the original image with a Gaussian.
2. For each pixel compute image gradient $\nabla I(x, y)$.
3. For each pixel compute matrix M.
4. For each pixel evaluate the response function R.
5. Choose the interest point as local maximums of function R.
6. Check adjacent (vertical and/or horizontal) pixels around the candidate interest point.
7. Select the appropriate interest point according to the above specifications, if it exists.

5. DISCUSSION - CONCLUSIONS

The paper reports the development of the *Plessey-Grid* interest point operator. Advancing the knowledge from the existing operators we propose effective extensions so as to develop a new digital interest operator for close range photogrammetric applications.

The algorithm, which has been developed to run under standard PC's specifications, has been tested under real close range conditions and satisfactory results have been concluded.

In the near future we intend to extent the application of the algorithm in aerial photogrammetric cases.

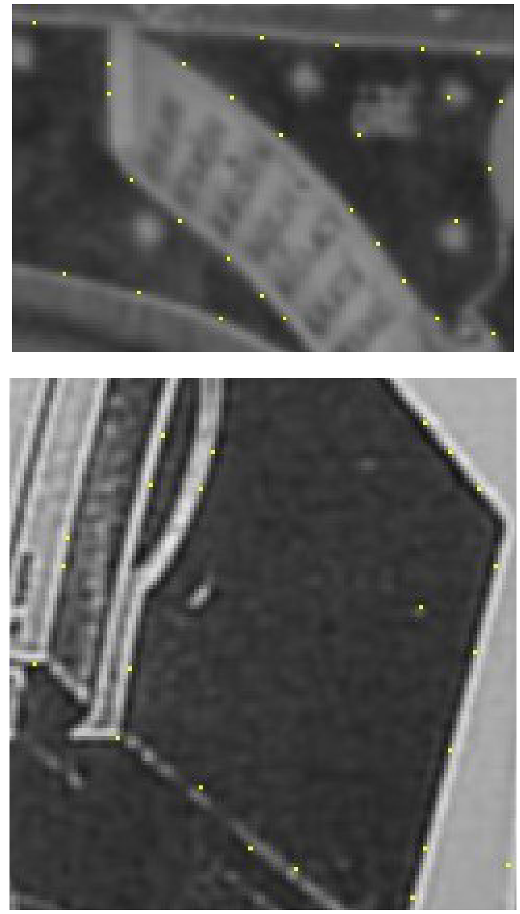

Figure 5. Test images examples with detected interest points superimposed

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