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A New Approach to Obtain Subpixel Corner Point Coordinates Based on Position from Cornerness Map Refinement

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***Abstract*—This paper deals with a proposing a new approach to specify corner points coordinates in subpixel accuracy. The describing algorithm uses the regular cornerness map obtained from the usual corner detectors as initial step. The main idea is to consider the cornerness values from a neighboring area around found corner point as a 3D profile object and to find the coordinates of its centroid. The part of an article is dedicated to the comparisons of this method with the traditional pixel detector and two other subpixel detectors, which refine the coordinates using the overlaying of cornerness map with curve and 2D quadratic function. The all results were statistically analyzed and are listed in the tables and turned into corresponding findings and conclusions.**

Keywords— corner detection; subpixel detectors; Harris detector; homography

I. Introduction

The area of corner point detection is well known and very often used in many practical tasks, for illustration the motion tracking, object detection and recognition, robot navigation, stereo matching, 3D modeling and many others. It is possible to imagine the corner point as a point, where at least two edges are intersected, point around which is high change of brightness intensity in all directions or point having the smallest radius of curvature for example.

As it is known, the smallest part of an image is a pixel. We cannot access information “between” pixel in usual. But there is a possibility to use some mathematical techniques to interpolate or approximate the brightness intensity among pixels and increase the accuracy of detected corner points [1] [2]. The possibility of a more accurate location can decrease costs for cameras and other hardware equipment. Be able to find the chosen image features with a better accuracy could be very useful in many practical fields.

II. Pixel and Subpixel Corner Detection

Many corners detectors were invented over the years and the Harris corner detector [3] is one of the most famous. The basic idea is to find the minimum of intensity difference between the chosen part of an image (marker as *W*) and the shift part of image *W* in all directions. The first step is determination of matrix *A* as it is shown in following formula:

$$A(x,y) = \sum_W \begin{bmatrix} I_x \\ I_y \end{bmatrix} \begin{bmatrix} I_x & I_y \end{bmatrix} \qquad (1)$$

The variables I_x and I_y are approximations of derivations (also referred as differences) in horizontal and vertical directions. The next step is determination of the cornerness matrix *C*. There are various formulas for calculation of matrix *C* cornerness values published. The last step is looking for elements in matrix *C* having the highest values. These points are stated as corners.

As it is obvious, this algorithm can be used to find corner points in pixel accuracy. Here it will be shortly mentioned two ways how to obtain the subpixel coordinates of corner points. These two approaches were also implemented in our comparison. For some other algorithms of subpixel corner detection see [4].

Both methods using the previously found corner point in pixel accuracy as initial step. Once this point was detected, its position according of first approach [5] is refined to subpixel accuracy by fitting the 2D quadratic surface to the corner strength function in the local neighborhood and its maximum is found. The equation of surface is following:

$$h(x,y) = ax^2 + bxy + cy^2 + dx + ey + f \qquad (2)$$

When the coefficients are calculated, the assumption that the maximum of corner map corresponds to the first derivation of this function equals to zero could lead us to the final corner point subpixel coordinates very easily.

The second approach [6] is basically very similar to the previous one. The only difference is that the subpixel shifts are determined for *x* and *y* direction separately using quadratic curve equation:

$$h(x) = ax^2 + bx + c \qquad (3)$$

The final subpixel corner point position is combination of both shifts and is calculated by using the same assumptions as before.

III. Homography

A planar projective transformation [7], also known as homography, is a linear transformation on three homogenous vectors represented by a non-singular 3×3 matrix:

$$\begin{pmatrix} x_1' \\ x_2' \\ x_3' \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} \quad (4)$$

The variables x_i' and x_i represents the corresponding coordinates between two images and homography matrix H describes the relation between them. There is necessary find at least 4 pairs of corresponding points to solve this system of equations (the h_{33} element is usually chosen to be equal to 1). The example of projective mapping from one plane to another according homography is shown in *Fig. 1*.

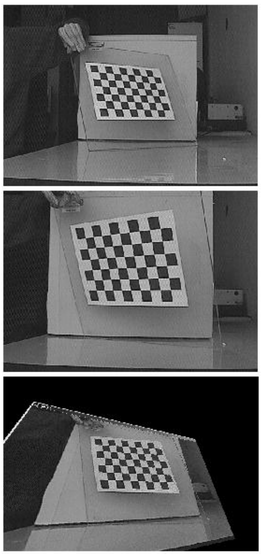

Fig. 1. *2D projective mapping using homography*

IV. A NEW PROPOSED SUBPIXEL DETECTOR

The subpixel detectors described before are based on the fact, that the cornerness map can be overlaid by geometric structures and the mathematical computation of their maximal points can give us subpixel coordinates.

The proposed approach here employs the cornerness map differently. The cornerness points in a chosen area surrounding the initially found corner point are considered as a 3D profile object. The key is to find the coordinates of its centroid point what can tell us the location of the expected corner point. The situation is illustrated in Fig. 2.

Also this subpixel corner point determination is not computationally expensive. It could be computed by stating the weighted average for the x and y coordinates (cornerness values represents the weights coefficients) while the z dimension is not taken into account.

V. EXPERIMENTAL TESTS

The proposed coordinates obtaining method was compared to the mentioned pixel and subpixel detectors to prove the advantage of its employing in real applications.

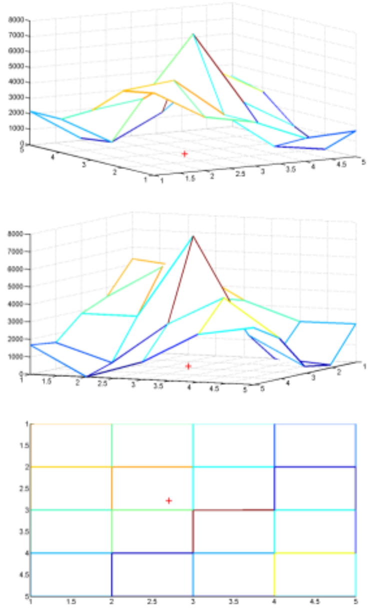

Fig. 2. *Centroid position in cornerness profile*

The first comparison is about result stability examination. Because the subpixel coordinates refinement is very often just theoretical mathematic procedure, the resulted coordinates could be found even out of inspected neighboring window area. For that reason, the ratio between coordinated found outside the considered window and all coordinates the window was calculated. The example of tested image is shown in Fig. 1.

The second comparison was based on homography matrix determination. From the stereo image pair there were the corresponding points matched and using them, the homography matrix was computed. The corner points from first image were transformed into image plane of second image and the average value of absolute Euclidean distances between particular corresponding points was stated. The example of this kind of transformation is shown in Fig. 1.

There were multiple testing images and multiple corner point sets taken into analysis.

VI. EXPERIMENTAL RESULTS

The compared detectors are referenced as *pixel* for Harris corner detector, *subpixel A* for the proposed approach, *subpixel B* for method using curve and *subpixel C* for method using quadratic function respectively. This naming convention will be used for rest of the paper. The used searching windows had size 3×3 and 5×5 pixels.

TABLE I. Success rate comparison

method	***subpixel A***	***subpixel B***	***subpixel C***
window	r_{oa}	r_{oa}	r_{oa}
3	0	0.0145	0.9825
5	0	0.0117	0.2120

TABLE II. Homography comparison

method	*subpixel A*	*subpixel B*	*subpixel C*
window	ad_{oht}	ad_{oht}	ad_{oht}
3	1.7523	1.5539	1.4822
5	1.7523	1.3274	1.1689

The symbol r_{oa} in Table 1 represents the ratio between coordinates found out of searching area to all found coordinates. The main advantage of proposed algorithm is that the found coordinates lay always inside the considered neighboring area. It is not the case of rest two subpixel detectors, where especially the *subpixel C* has in case of 3×3 window has this ratio more than 98%, what is caused mostly by the small size of window and the fact, that 2D quadratic function is less sensitive to reflect the cornerness profile than curve for example. There are ways how to improve this success rate but it is not the aim of our paper. The *subpixel B* proves much better results but still worse than *subpixel A* method.

In Table 2 there are results from comparison between pixel detector and two subpixel detectors listed. The symbol ad_{oht} stands for averaged distance between original and homography points. As you can see, the *subpixel A* proves better results than pixel detector but only slightly worse than another subpixel detector for both sized of window.

VII. CONCLUSION

This paper has dealt with proposal of a new approach to specify the coordinates of corner point in subpixel accuracy using cornerness map. The main idea was to consider the cornerness values around initially found corner point as 3D profile function, where the position of its centroid was used as final subpixel coordinates.

The first parts contain the description of Harris corner detector and another two often used subpixel approaches. Also the theory behind homography matrix was briefly explained.

For the reason to properly compare the performance of proposed method the set of initial experiments were done and the results were statistically analyzed.

The first comparison deals with stability of detected subpixel coordinates position and the proposed algorithm has got the best results against to the rest tested algorithms.

The second experiment demonstrated the suitability of tested algorithm in practical application from computer vision area. The proposed detector has got the results better than pixel one and comparable to another subpixel detector.

The results so far indicate the possible convenience of usage the proposed subpixel method in are of corner detection, but the deeper analysis has to be performed to get the final answer.

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