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The Influence of Subpixel Corner Detection to Determine the Camera Displacement

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Abstract

This paper deals with direct comparison of traditional pixel and chosen subpixel corner detection approaches. For this reason the Harris corner detector and two subpixel algorithms used to improve the detection accuracy were considered. First one is based on the orthogonal vectors theory and iteration process and the other one is refining the found pixel coordinates by fitting quadratic curve to the cornerness map in both x and y directions separately. As the procedure to verify the performance of these approaches the real displacement determination between two positions of the same camera using information coming from image stereo pair was chosen. To fulfill this task requires employing the several computer vision and image processing areas which are described in presented paper. The appropriate sets of image pairs were created and used for further testing and comparison. There were also the statistical analysis and evaluation performed and the obtained results were listed in corresponding tables.

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Keywords: pixel corner detection; subpixel detectors; image stereo pair; epipolar geometry; statistical analysis

1. 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

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high change of brightness intensity in all directions or point having the smallest radius of curvature for example. But there are situations when pixel resolution is not sufficient enough. For that reason the mathematical techniques such as approximations and interpolations can be used to find the chosen features in subpixel accuracy [1] [2].

One of the applications where localization of corresponding corner points is crucial is 3D scene investigation and distance measuring using image stereo pair [3]. But the problem of determining the displacement between two cameras is quite complex and consists from several particular tasks. The principles and theory behind camera calibration, feature detection and matching, image undistortion, epipolar geometry, essential matrix decomposition, image rectification and image disparity have to be employed to get the proper and valid results. All these procedure steps together with the corner detection algorithms are also briefly described in the following sections.

2. Corner detection

Many corner detectors were invented over the years and the Harris corner detector [4] is one of the most famous. The main idea is to find the minimum of brightness intensity difference between chosen parts of image (marked as *W*) and shifted parts of image in all directions. There is first-order Taylor series for that purpose used. The first step is the determination of matrix *A* according the following formula:

$$A = \sum_{W} \left(\begin{bmatrix} I_x \\ I_y \end{bmatrix} \begin{bmatrix} I_x & I_y \end{bmatrix} \right) \tag{1}$$

The elements inside represent the differences (as the approximations of derivations) in horizontal and vertical direction. Next step is the calculation of cornerness map using previously found matrices and it gives us the information how much the current point can be considered as the corner. After the global and local thresholding the final set of corner is found.

The first mentioned subpixel algorithm [5] is based on the orthogonal vector theory and iteration process. Due to the theory, a vector from the corner (marked q) to any part of its adjacent area (marked p) should be perpendicular to the gradient of the point p. If we use the points from the chosen adjacent area W and after applying some mathematical treatment the final formula looks like this:

$$\sum_{W} (I(p_i) \cdot I(p_i)^T) \cdot q = \sum_{W} (I(p_i) \cdot I(p_i)^T \cdot p_i) \tag{2}$$

The other elements inside stand for the gradients of particular points consist of x and y component. When this equation is solved and q point position is found, this point is taken as the new center of the searching window W and the whole process is solving through the iterations again. It should be noticed, that this algorithm was designed only for x-corner points detection (typically the corners appearing in the chessboard patterns). After the pixel detection to get the initial corner points, the algorithm is used to refine the corner position in subpixel precision.

The second method also uses the previously found pixel corner point as initial step. Once this point was detected, its positions according of this approach [6] is refined to subpixel accuracy by fitting the quadratic curve to the corner strength function (cornerness map) in x and y direction separately. The approximating function could be following:

$$h(x, y) = ax^2 + bx + c \tag{3}$$

When the coefficients are calculated, the assumption that the maximum of corner function corresponds to the first derivation of this function could lead us to the final subpixel coordinates very easily. In the contrary to previous algorithm, this one does not necessarily require the x-corner points and basically works with any kind of corners.

3. The displacement determination

The whole process of getting the distance between two cameras in SI units was also described in [7] and consists of several steps.

3.1. Camera calibration

Camera calibration [8] is primarily looking for quantities that affect the imaging process, such as focal length, principal point, skew factor and lens distortion. All these data are used later in distortion removal and epipolar geometry theory to provide us the better results.

3.2. Feature detection and matching

Feature detection and matching are one of the most crucial and important components of many computer vision algorithms. Basically the meaning of this step is the searching for interested parts of an image (features) which in case of two images contain the same scene can be correspondingly matched using so called feature descriptors. Amongst the common procedures can be counted SIFT [9] or SURF [10] algorithm for example.

3.3. Image undistortion

By the definition the term distortion [11] is in photography generally representing the deformation and bending physically straight lines what makes them appear curly in images. These effects are very often in form of radial and tangential distortion and are mostly caused by lens and manufacturing errors. Because the distortion can be described as mathematical function using the information coming from camera calibration, the reversed mathematical operation called image undistortion is usually applied. The found corresponding points (in our case the corners) are because of that reason undistorted and processed in this form for the rest of the procedure.

3.4. Essential matrix

In case of properly matched the corresponding points, the theory behind the epipolar geometry [12] in employed to extract the relative rotation and relative translation between both cameras (images) in stereo pair. As the first step the fundamental matrix has to be stated. This matrix describes the relation between the points in first image and so called epipolar lines in second image on which the set of corresponding points must lie. Using again the information from camera calibration and this matrix, the essential matrix can be computed.

3.5. Decomposition of essential matrix

There is possibility due its character to decompose the essential matrix into rotation matrix and translation vector what can fully describe the relative movement from one camera to another one in 3D Cartesian coordinate system. For that reason the SVD (singular value decomposition) technique [13] is usually used. But there is an issue. Due to fact that the objects having the different size and different scene distance can also look the same in image, the translation only relative up to scale can be obtained.

3.6. Image rectification

Image rectification [14] is basically a transformation process used to project two or more images onto a common image plane. The found translation vector as the information about mutual cameras position is used in rectifying process. It is not necessary to rectify the whole image due to fact that the rectifying transformation only for detected corners is for our purposes sufficient enough. Because of rectification both image planes are parallel and the depth triangulation is therefore much easier. Another parameter needed for 3D depth or camera displacement calculation is pixel distance between corresponding points.

3.7. Image disparity

If we assume calibrated and rectified stereo pair, disparity [15] by definition measures the displacement of a point between two images in pixels. It is obvious that in case of close points in scene there is large displacement and small displacement for far points respectively. The depth *Z* calculation using disparity *d* information is computed like this:

$$Z = \frac{f \cdot B}{d} \tag{4}$$

The sign *f* is stand for focal length in pixels we found during camera calibration process. The *B* as the baseline also represents the displacement between both stereo pair cameras in SI units.

Due to the mentioned fact that objects having different size and scene distance can look similarly or even the same in image, we need to know some intrinsic prior information like focal length *f* and depth *Z* (this information may easily be obtained using another sensors for example) in rectified 3D coordinate system to be able successfully determine real displacement *B* between cameras in SI units. In case this procedure is used for navigation purposes, the *Z* prior information is needed only in first step, for further steps (applying described procedure repeatedly) is possible to calculate another depth coordinates by using data (rotation, translation and so on) gathered during the process.

4. Experimental tests

For the purpose to demonstrate the advantage of subpixel detection unlike the usual pixel one, the image stereo pair configurations using calibrated camera were prepared. All particular presented steps together with pixel and subpixel algorithms were followed and the aim was to determine the distance (baseline) between the positions of the same camera. It is important to notice that these camera positions were mutually both translated and rotated. Except the camera intrinsic matrix also the real scene depth *Z* (in rectified coordinate system) in cm units was known for all chosen points. As the illustrative example you can see the scene structure and matched points correspondences between two images in Fig. 1.

Because of easy detected corners in case of both pixel and subpixel algorithms the chessboard patterns were used. Another advantage of these patterns is that corners having the same location even if scene view is shifted and rotated. This is not guaranteed in case of real scene because corners may change their position or even disappear from multiple views.

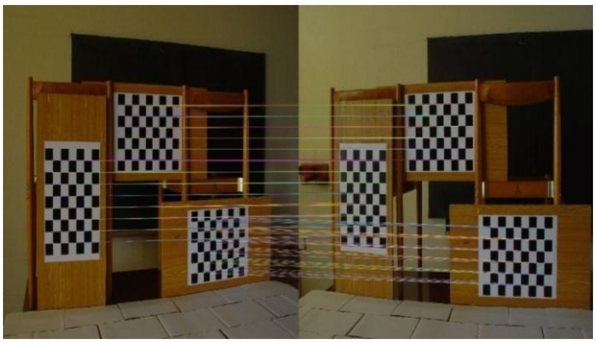

Fig. 1. Corresponding points between both images.

The detected chessboard corners (by methods we previously described) were used to obtain guess of essential matrix (translation vector and rotation matrix) and 9 point of them (3 in each chessboard) were further investigating to find displacement through disparity computation. Three image resolutions were processed: 2560x1920, 1280x960 and 640x480 pixel size. To make the analysis more robust and accurate, multiple mutual camera distances were tested. There were 7 image pairs for each 20, 30, 40 cm, 5 image pair for each 50, 60, 70 cm and 3 image pairs for each 80, 90, 100 cm shifts set. The found results were statistically analyzed and are described in following section.

5. Experimental results

Because the whole process is relatively complex, the robustness of procedure is based mostly on the right points correspondences position. In the other words, the better corner points localization, the better results and less change of algorithm failure.

Table 1. Stability results analysis.

	Number of valid result stereo pairs									
Resolution		*2560 x 1920*			*1280 x 960*			*640 x 480*		
Algorithm		*P*	*A*	*B*	*P*	*A*	*B*	*P*	*A*	*B*
Shift between cameras [cm]	*20*	0	3	3	1	3	1	1	5	2
	30	1	5	3	1	1	5	1	4	5
	40	1	4	5	3	5	3	2	4	2
	50	0	2	1	1	3	2	1	4	4
	60	2	4	3	1	2	2	1	3	1
	70	2	2	1	1	1	3	0	2	3
	80	1	2	1	0	3	1	1	1	1
	90	0	2	1	0	0	1	1	1	1
	100	2	2	3	0	0	3	0	0	1
Total		9	26	21	8	18	21	8	24	20

The first comparison was dealing with stability results analysis. The ground truth (real displacement) information was known and therefore the simple filter was applied to confirm or neglect the results as satisfactory or not. Just for illustration the ratio between found and real camera shift for every considered point correspondences and correct translation and rotation decomposition were taken into account. The obtained results are listed in Table 1.

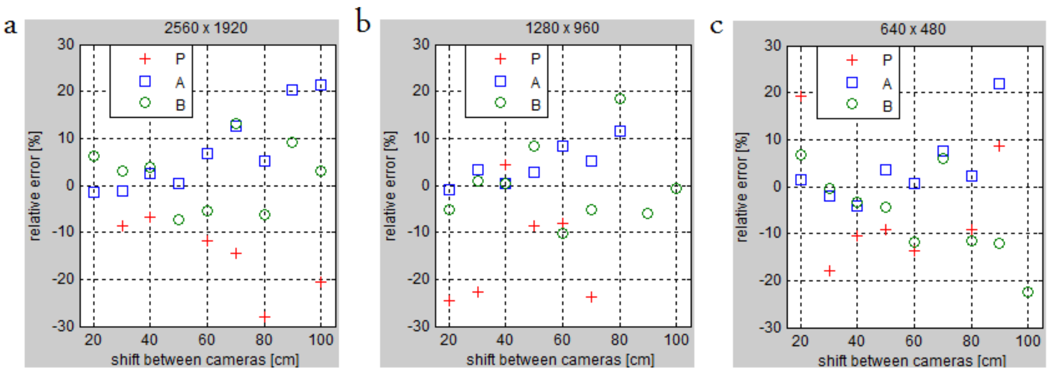

Fig. 2. Averaged relative error of found displacements.

The pixel approach is in table marked as *P* and subpixel algorithms in same order as they were described are represented by sign *A* and *B* respectively. As it is possible to see in table last row, probability of not failed stereo pair is between 2 and 3 times higher for subpixel detection than in case of traditional pixel one. The number of all tested image pairs for every resolution was 45 (as was explained in previous section) and it gives us roughly 50% of success rate for subpixel algorithm. These results prove the fact that employing the subpixel detection is advantageous and significantly increases the algorithm robustness and the chance of valid results.

The second comparison is about relative errors of found displacements. These errors were computed using following formula:

$$\delta_B = \frac{B^* - B}{B} \cdot 100 \qquad (5)$$

The variable B represents real shift and B^* stands for found shift. These values belonging to particular shift and resolution were averaged and are shown in Fig. 2. The same image pairs as it was in first comparison were investigated and according to data in Table 1, there are also the shifts where no results were obtained (missing legend signs). As it is obvious, the subpixel algorithms produce again better results for most of cases in every resolution. Moreover, the accuracy of subpixel results tends to decrease in case of longer camera shifts. One of the explanations could be that image rectification (part of presented procedure) is working mostly for quite similar images with small mutual rotation and translation. For large rotations and translation these algorithms are losing precision as well.

Conclusion

This paper has dealt with comparison of tradition pixel and two algorithms of subpixel corner detection. As the subject of this comparison the determination of displacement between two positions of the same camera using image stereo pair was chosen.

In first section the considered corner detectors were explained. Specifically the well known Harris corner detector, the detector based on orthogonal vector theory and the one using quadratic curve over cornerness map.

Second section is explaining the theory behind displacement determination from single image pair and the whole process. The image processing and computer vision areas like camera calibration, feature detection and matching, image undistortion, epipolar geometry, image rectification and image disparity were briefly mentioned.

The experimental test which was performed according the described procedure is presented in next section. All particular procedure steps together with pixel and subpixel detections were followed to determine the shift between two cameras. Also the intrinsic information such as scene depth coordinates for investigated points were known. The example of used scene containing the chessboard patterns was shown in Fig. 1. The multiple mutually shifted (and rotated) image were tested and statistically analyzed.

The first test was about comparing the results stability. Because of knowing the real displacements (ground truth), only certain results were considered as satisfactory enough. In Table 1 the numbers of these successful configurations were listed. As it is obvious, the probability of not failed stereo pair was between 2 and 3 times higher in case of subpixel detection in the contrary of pixel one and the success rate was roughly 50% from all tested pairs. It proves the advantage of subpixel detection paradigm and significant increasing of procedure robustness.

Second analysis was comparing the relative errors computed from found and real displacements and the results were displaced in Fig. 2. As it was possible to see, the subpixel approaches produce again better results for most of cases in every resolution. Moreover, in case of relatively longer mutual camera shifts the accuracy is decreasing, what can be caused by larger mutual translation and rotation.

There are many ways how to continue to this research. It would be interesting to examine how to subpixel detection affects the accuracy of position determination in case of navigation purposes if this procedure is applied repeatedly.

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