Comparison of Subpixel Corner Detection Based on Reprojection Error Criterion

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Abstract. *This paper deals with conception of subpixel detection where the focus on accuracy of corner points detection is a goal. Specifically there is traditional Harris corner detector together with two subpixel approaches compared. The first approach is based on the orthogonal vector theory while the other one is refining coordinates by fitting quadratic curves over usual cornerness map. As the procedure for the results evaluation there was reprojection error criterion chosen. This task requires employing several problems from image processing and computer vision area which are also briefly mentioned in presented paper. Also the statistical analysis was performed and obtained results were shown in corresponding graphs and tables. This paper may contribute to the answer if subpixel detection paradigm could be useful in such applications as 3D reconstruction, robot navigation or many others.*

Keywords: Corner detection, Subpixel detectors, Reprojection error, Epipolar geometry

1. Introduction

The area and theory behind corner detection in usual is very well known and often used as one of the first steps in many practical tasks, e.g. object detection and recognition, motion tracking , robot navigation, 3D modelling, stereo matching and many others.
It is generally known that the smallest part of an image is a pixel. To access information between pixels there can be some mathematical techniques to interpolate or approximate the brightness intensity among pixels employed and used to find the chosen features in subpixel accuracy [1] [2].
One of the applications where the accuracy of corner points is crucial in 3D scene investigation using image stereo pair. The theory behind this is quite complex and consists of several particular tasks. All these procedure steps together with the discussed corner detection algorithms are briefly described in the following sections. This paper also slightly follows our previous paper dealing with camera displacement stating using image stereo pair and subpixel corner detection [3], where the more details about experiments is explained.

2. Subpixel Corner Detection

The corner point itself can be understood as a point around which is high change of brightness intensity in all directions, point where at least two edges are intersected or a point having the smallest radius of curvature for example.
One of the most famous corner detection algorithms is Harris detector [4]. The basic idea is to find the minimum of intensity difference between the chosen part of an image and shifted image part in all directions. Traditional corner detection in pixel accuracy is usually the first step to localize the corner position in subpixel accuracy. Next step is to apply the specific algorithm to the chosen area surrounding previously found corner point and specify the point coordinates in higher accuracy.
The first compared algorithm [5] was designed only for *x*-corner points detection, working directly with image brightness intensities and is based on the fact, that vector from the corner

(marked *q*) to its adjacent area (marked *p*) should be perpendicular to the gradient of point *p* as it is shown in the following formula:

$$I(p_i)^T \cdot (q - p_i) = 0 \tag{1}$$

The position of point *q* is then solved through the iterations.
The second method [6] primarily used for any kind of corners is refining the position of initially found corner point by fitting the quadratic curve to the corner strength function (cornerness map) in *x* and *y* direction separately. The approximation function is following:

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

Maximum of this function corresponds to subpixel corner coordinate in particular direction.

3. Image Stereo Pairs

As it was already mentioned, the investigation of the relation between images in stereo pair consists of several steps.
First of them is the use of camera calibration [7] process to get camera intrinsic matrix and camera distortion coefficients. Once the image pair containing the same scene is given, the corresponding points in both images have to be found. For that purpose is the SIFT [8] algorithm used for example. Then the set of found corresponding coordinates has to be undistorted [9] due to the lens manufacturing errors. The theory behind epipolar geometry [10] allows us to get essential matrix which can be decomposed into their mutual rotation matrix and relative translation vector [11]. When these parameters are known, using the linear triangulation algorithm [12] gives us coordinates of considered point in 3D camera space. As the evaluation criterion of 3D projection precision can be used the reprojection error [13]. It quantifies the position difference between projection of triangulated point and the original one in 2D image space. The formula to calculate reprojection error could be like this:

$$d(p,q) = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2} \tag{3}$$

where the p_i and q_i are representing corresponding coordinates of compared points.

4. Experimental Tests

For the purpose to demonstrate the advantage the subpixel detection unlike the usual pixel one, the practical test comparison consisting of steps describing in previous chapter were performed. There is an example of scene structure and matched points correspondences between two images shown in Fig. 1.

Fig. 1. Corresponding points between both images.

Specifically the Harris corner detector (marked as *P*) and both described subpixel detection approaches were compared (marked as *A* and *B* in order of referring in text). There were different image resolution chosen and to make the analysis more robust and accurate, multiple mutual camera distances were used, while each was containing multiple tested image pairs. For these configurations the reprojection errors were stated as the aim of comparison. The found results were statistically analyzed and are described in following section.

5. Experimental Results

Because the whole process is relatively complex, the results are based mostly on the precision of corner point localization. There are the averaged values of reprojection errors for specific detection algorithm displayed in Fig. 2. The exact values are also stated in Table 1.

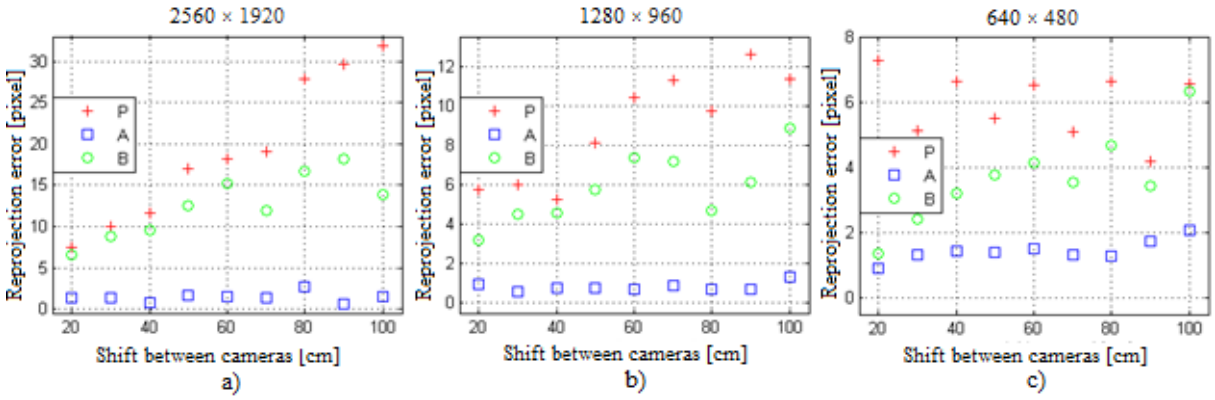

Fig. 2. The results of compared algorithms reprojection errors

As it is possible to see, the reprojection error for every parameters configuration in the case of subpixel approaches gives us better results than traditional pixel method. Moreover, the algorithm *A* produces significantly better results unlike the other two detectors.

Table 1. The reprojection error of compared algorithm based on tested configuration parameters

Reprojection error [pixel]										
Resolution		*2560 × 1920*			*1280 × 960*			*640 × 480*		
Algorithm		*P*	*A*	*B*	*P*	*A*	*B*	*P*	*A*	*B*
Shift between cameras [cm]	*20*	7.54	1.43	6.62	5.75	0.98	3.18	7.29	0.92	1.37
	30	9.95	1.42	8.79	6.02	0.59	4.52	5.16	1.32	2.43
	40	11.65	0.80	9.49	5.28	0.80	4.60	6.66	1.44	3.22
	50	16.95	1.66	12.59	8.13	0.79	5.76	5.51	1.42	3.80
	60	18.23	1.47	15.25	10.39	0.71	7.39	6.56	1.54	4.15
	70	19.11	1.30	11.97	11.27	0.89	7.21	5.12	1.33	3.58
	80	27.90	2.77	16.71	9.72	0.69	4.67	6.66	1.29	4.68
	90	29.59	0.61	18.16	12.61	0.73	6.10	4.19	1.76	3.44
	100	31.83	1.45	13.80	11.37	1.32	8.88	6.58	2.10	6.34
$\bar{x}$		**19.19**	**1.43**	**12.60**	**8.95**	**0.83**	**5.81**	**5.97**	**1.46**	**3.67**

The explanation could be the fact, that this algorithm is suitable only for *x*-corners detection. The direct comparison between algorithm *B* and Harris detector looks also interesting, the reason being both of them are working with the same cornerness map. Follow the expectations, the reprojection errors are decreasing with the image resolution.

6. Conclusions

This paper has dealt with comparison of usual pixel and two subpixel corner detection algorithms. As the subject of this study the reprojection errors computed using chosen experiment related to image stereo pair area were compared.
In the first two sections the theory behind considered corner detectors and relation between two cameras investigating using image stereo pairs were introduced.
The experiment and the results were presented in next sections. It was shown, that subpixel detection can significantly decrease the reprojection error of triangulated points using image stereo pairs, what makes it suitable and convenient in many practical applications from computer vision area.

Acknowledgements

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0469-12.

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