Single chord-based corner detectors on planar curves

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ABSTRACT

Detecting corner locations in the images plays a significant role in several computer vision applications such as motion detection, image registration, video tracking, image mosaicing, panorama stitching and object recognition. In this paper we have analyzed an existing state of art, Chord to Point Distance Accumulation (CPDA) corner detector and modified this detector in way that it uses a single chord instead of using three different chords. We named this detector as Single Chord CPDA (SCCPDA). We have also proposed a simple but effective new detector of detecting robust corner locations against different image transformations using cumulative distance calculation. The new detector has also used a single chord and we named it as Chord to Cumulative Sum Ratio (CCSR). A comprehensive performance evaluation has been performed by using Average Repeatability and Localization Error. We have found that the SCCPDA and CCSR detectors perform better than the original CPDA detector. Our experimental results show that the CCSR using simple cumulative calculation outperforms eight other existing contour based corner detectors in terms of repeatability and generates one of the lowest localization errors. In addition, the CCSR detector is also most efficient corner detector among other contour-based corner detectors.

Keywords
corners, contour-based corner detection, single chord, CPDA

1 INTRODUCTION

Feature detection is a major concern in the field of computer vision and image processing. Among different types of features, corner is one of the most stable features. There are a number of corner detectors have been proposed so far to detect repeatable corners. In this paper we concentrate on contour-based corner detectors, in particular, this paper analyses certain properties of the very popular chord-to-point distance accumulation (CPDA) detector, proposed by [Moh08]. Although CPDA has been reported to be one of the best corner detectors [Pen13, Moh10], we found that the CPDA detector uses multiple chord lengths and these chords do not give extra benefit rather it increases the overhead on the whole process. We demonstrate in the paper that, by using a single chord with accumulating distances, it is possible to get even better performance than CPDA achieving better efficiency. Finally, we propose another single chord detector of calculating the curvature values using cumulative distances among the points of a curve to detect corner locations. The detector achieves the best repeatability among existing detectors with highest efficiency.

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This paper is organised as follows. Section 2 reviews the contour based corner detectors while section 3 explains particularly about CPDA detector. Section 4 analyses the CPDA detector using a single chord and introduces a new corner detector using cumulative sum. The experimental results are presented in section 5. Finally, section 6 concludes the paper.

2 RELATED WORK

The typical representative among widely used contour based corner detectors is Curvature Scale Space (CSS) [Fmo01].The main idea of this approach is to extract edges using edge detectors, such as canny edge detector [Can86], then estimate the curvature of each point of the extracted edge and finally apply gaussian smoothing scale [Dav80] to smooth the planner-curves. Thus the absolute curvature maxima points obtained using specific thresholds by removing weak and false corners which are generally known as pseudo-corners. This detector has some major drawbacks. CSS detector uses a coarse smoothing scale to identify approximate locations of the corners and then uses a finer scale to track locations to improve the localization of these corners. A coarse scale is robust to noise but it may miss many potential corners. On the other hand, finer scale is good to detect spurious corners but it is sensitive to noise.

To overcome the weakness of CSS detectors, several detectors have been proposed which use multiple scales for curvature estimation. To detect corners, Awrangjeb et al. proposed a three scale-based detector (*ARCSS*) [Moh07] which uses affine-length parametrization. Although ARCSS detects more repeatable corners, it is computationally very expensive. Zhang *et al*. [Xia07] introduced another CSS based detector, Multi-scale Curvature Product(*MSCP*), which finds corners by multiplying curvature values using three scale to discard noise and false corners. A chord based detector, CTAR [RMN11a], measure curvature values based on a triangular theory.This detector is very efficient compared to CPDA detector. Another corner detector proposed by [RMN11b], is the combination of CPDA and efficient high curvature point detector IPAN [Dmi99]. Although this detector has better repeatability, the detector is computationally expensive. He and Yung [Xia04] modified original CSS detector in two steps. First, they use an adaptive local threshold to the curvature of its neighborhood region. Next, they find the angle of proper region of support to detect the corner. Eigenvalues of the covariance matrix [Dum99] and Gradient Correlation Matrix [Zha10] have also been used to derive contour orientation. Zhang et al. [Xia09] proposed another detector which applies multiple levels of Difference of Gaussian (DoG) on a curve to obtain corresponding planer curves that are later used to detect corners. This detector is also relatively expensive to compute.

3 OVERVIEW OF CPDA CORNER DETECTOR AND ITS WEAKNESSES

CPDA detector [Moh08] follows the basic idea of css detector described in Section 2. After extracting and smoothing out the curves, three chords of different length are moved along each curve to measure discrete curvature value for each location on the curves as L_i where i ε 10, 20, 30. Here the chord L_i indicates a straight line placed *i* pixels apart on the curve.

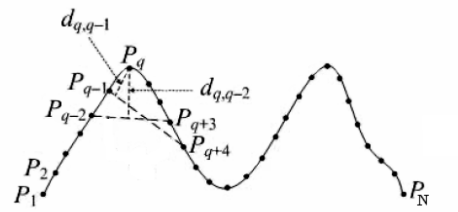

Figure 1: Curvature estimation using CPDA with chord

In Fig.1, let P_1, P_2, P_3,...., P_N be the N points on the curve. Now the value *i* of chord L_i defines the number of points of the curve segment between points P_j and P_{j+i}. To estimate the curvature value $h_{L_i(q)}$ at point P_q using a chord which is i pixels apart, the chord is moved on each side of P_q for at most i points keeping P_q as a central point and figure out the distances $d_{q,j}$ from P_q to the chord. In the end, CPDA assembles the curvature estimation using the Equation 1

$$h_{L_i}(q) = \sum_{j=q-i+1}^{q-1} d_{q,j} \quad (1)$$

Then the curvature values estimated using each chord, are normalized using Equation 2.

$$h'_{L_i}(q) = \frac{h_{L_i}(q)}{max(h_{L_i})}, \text{for } 1 \leq q \leq N,\ i \in \{10, 20, 30\} \quad (2)$$

The values calculated for three different chords from Equation 2 are then multiplied using Equation 3.

$$H(q) = h'_{L_{10}}(q) \times h'_{L_{20}}(q) \times h'_{L_{30}}(q), \text{for } 1 \leq q \leq N \quad (3)$$

Next, CPDA finds the candidate corners by rejecting weak corners using local maxima of absolute curvature and by comparing the curvature values with threshold T_h [0.2]. Then, CPDA calculates angle from a candidate corner to its two neighbouring candidate corners. The computed angle is then compared with the angle threshold ($\delta = 157°$) to remove false corners.

CPDA proposes to use big neighbourhood to estimate the curvature which tends to miss corner locations which are specially close to each other [RMN11a]. CPDA detector might potentially miss obvious corners if they were located closely. This is due to using multiple chords to measure curvature values. Besides this, CPDA detector fails to detect corners if there are two or more corners on the same curve and one of them is very sharp and another is less but should be considered as corner location. In this scenario CPDA misses the less sharp corner location. There are also some scenarios where the multiplication of three chords' estimated curvature values is responsible for losing the extrema on the corner location. In summary, all the limitations are being created due to using three different length of chords.

4 PROPOSED CORNER DETECTORS

In this section, we will first propose the single chord CPDA (SCCPDA) detector and next, we will propose another approach named Chord to Cumulative Sum Ratio(*CCSR*) to estimate the curvature value based on cumulative sum analysis. Both of the detectors start with the basic idea of CSS detector of extracting and smoothing the curves as described in Section 2.

Single Chord CPDA detector

The original CPDA paper [Moh08] mentions the use of multiple chords, but does not justify the reason for doing so with any experimental results. In particular CPDA uses three chords of length 10, 20 and 30. To understand whether using multiple chords is superior to using single chords, we modified the CPDA process to use a single chord L_i, i ε [5, 30], where i has been decided experimentally from the experimental results presented in Section 5. The modified CPDA detector does not need the step shown in Equation 3, as it is only meaningful when using multiple chords. However, as described in [Moh08], apart from combining the distances of multiple chords, Equation 3 also magnifies the difference between the chord-to-point distances of weak and strong corners. To achieve a similar goal we replace the step shown in Equation 1 with Equation 4, and follow it with the normalisation shown in Equation 2. Rest of the processes of using curvature threshold and angle threshold are kept same.

$$h_{L_i}(q) = \left(\sum_{j=q-i+1}^{q-1} d_{q,j} \right)^2 \quad (4)$$

CCSR Detector

Now, we will explain another approach which also use a single chord to detect corners. One of the basic ways of finding corner locations is to measure the flatness of a curve. In other ways, corner is a location where the slope of the curve changes the direction i.e. the curve is not flat. According to this hypothesis, if we put a straight line on the curve touching two ends of the curve or curve segment, the ratio of the length of the straight line to the curve length will give the essence of the flatness of the curve. As a result, this ratio value will also carry the information of the presence of corner location on the curve or curve segment if the curve length is small.

Figure 2: Three different curves with three different flatness

Figure 2 (a)-(c) show three different curves of having different flatness. Now if we measure the ratio of the straight line to the curve length, we get 0.9232, 0.8039, 0.6706 respectively. The ratio values clearly indicates that lower value carries more bend characteristics of the curve. Therefore, if we calculate the ratio on a small part of the curve this might tell the presence of a corner in that segment of the curve. Next, the distances from all the interior locations of the curve segment to the respective straight line are calculated. The location of the highest distance to the straight line from the curve segment is then considered as a corner location. This also helps to localize the corner locations.

Similar to CPDA detector, the new detector also starts with extracting and smoothing curves from the image. Since the length of the curve segment needs to be measured, we have used cumulative sum for distance calculation to calculate the curve length of two given location on the curve. The cumulative sum of the distances between each point of the curve gives a sequence of a partial sum of the distances. For example, the cumulative sums of the distances between each location of the curve from the start $d_1, d_2, d_3, ...$ are $d_1, d_1 + d_2, d_1 + d_2 + d_3, ...$ Therefore, the cumulative distance (CD)can be expressed as follows,

$$CD(i) = \sum^{i} d_i \quad (5)$$

Let $P_1, P_2, ..., P_N$ be the N points of a curve and a fixed length chord will be moved along with the curve. Please note that, the length of the chord in chord based corner detection means the number of points apart to place the chord on the curve. For example, if the chord length is $L = 5$, the chord is placed from location P_1 to P_6, next the chord is placed from P_2 to P_7 and so on. Each ratio is assigned to the middle location of the curve segment as expressed in Equation 6.

$$R(i + ceil(L)) = \frac{\sqrt{(x_{p_i} - x_{p_{i+L}})^2 + (y_{p_i} - y_{p_{i+L}})^2}}{CD(i+L) - CD(i)} \quad (6)$$

Now, we filter out the curve segments based on a threshold against the ratio, which are minima on a curve. Now the perpendicular distances from each interior points from the curve segment to the straight line is measured and the location having the longest distance is considered as a corner. We named this detector as Chord to Cumulative Sum Ratio (*CCSR*).

5 EXPERIMENT

This section presents the experimental setup and the results to evaluate the performance of the proposed detectors. First, the experimental setup and evaluation process have been described. Second, the characteristics of the SCCPDA detector and CCSR detector have been shown in term of different parameters.Third, the overall performance of these detectors have been compared with other existing corner detectors from literature. Finally, the efficiency of the detectors has been presented based on the time taken to detect corners by the detectors.

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Experimental Setup

To measure the performance of the corner detectors, the corner locations from the original images detected by the detectors are considered as the reference corners and then a known geometric transformation is applied on the original images to detect the corners again [Moh08, Moh07, RMN11a]. Now a corner of reference image is considered as repeated if the corresponding location of that corner is at a 3-pixels distance from a detected corner location in transformed image.

Two types of evaluation metrics are used to measure the robustness of the proposed detectors 1) Average Repeatability [Fmo01, Moh08] and 2) Average Localisation Error [Moh08]. These evaluation metrics have been used by [Moh08, Moh12] in order to compare the performances. The average repeatability R_{avg} measures the average number of repeated corners between original and transformed images. It is defined as,

$$AverageRepeatability = 100\% \times \frac{\frac{N_m}{N_o} + \frac{N_m}{N_t}}{2} \quad (7)$$

Where N_o and N_t are number of corners detected in the original and transformed images respectively and N_r is the number of repeated corners. The localization error L_e is defined as the amount of pixel deviation of a repeated corner. It is measured from the repeated corner locations between the original and transformed images,

$$L_e = \sqrt{\frac{1}{N_m}\sum_{i=1}^{N_m}(x_{oi} - x_{ti})^2 + (y_{oi} - y_{ti})^2} \quad (8)$$

Where (x_{oi},y_{oi}) and (x_{ti}, y_{ti}) are the positions of i-th repeated corner in original and transformed images respectively. Experiments were conducted on a 64 bit MATLAB R2009 (7.14.0.739) installation, running on Windows 7. The computer had an Intel Core i3 (2.3 GHz) processor with 4GB ram.

We have used an image dataset of 23 grey scale images to evaluate the performance of the corner detectors. The same dataset is also used by [Moh08, Moh12]. Seven Different transformations have been applied to these 23 images-Scaling, Shearing, Rotation, Rotation-Scale, Non-uniform Scale, JPEG Compression, Gaussian Noise.

Parameter Optimization

In this section, we have produced average repeatability of single CPDA detector against a series of chords from 5 to 30 and threshold from 0.15 to 0.25 with 0.01 apart. Although we have evaluated the performance of 26 chords of different lengths, we would like to show the results only for the chords from 11 to 20, because the performance of higher and smaller chords are relatively worse than the selected chords.

Figure 3 (a) - (g) show the average repeatability of SC-CPDA detector for different chord lengths and different curvature thresholds against seven different transformations respectively mentioned in the previous section. Figure 3 (h) shows the average of average repeatability of all the transformations. We have not added the axis title to any of the graphs as the titles take much space and make the actual graph smaller. The vertical axis of the graphs shows the average repeatability and the horizontal axis shows the threshold values. Each curve shows the repeatability of a chord for different thresholds. From the average of the average repeatability of all transformations, we can see that chord 15 has the best average repeatability for threshold 0.22.

Similar to SCCPDA detector, the performance of CCSR detector has also been evaluated for different chord lengths and different thresholds against seven different transformations. The average repeatability of each chord is shown in Figure 4 (a)-(g). Figure 4 (h) shows the average of average repeatability of the seven transformations. The evaluation process has been conducted for the chords from 5 to 21 with 2 apart and from 0.979 to 0.990 with 0.001 apart. From the average of average repeatability in Figure 4 (h), we can see that the chord length 9 has the highest average repeatability for threshold 0.981.

Performance Evaluation

This section compares the average repeatability and localization error of proposed detectors with eight contour based detectors - DoGDetector [Xia09], CTAR [RMN11a], CPDA [Moh08], He_Yung [Xia04], MSCP [Xia07], ARCSS [Moh07], Eigenvalues [Dum99], GCM [Zha10]. Figures 5 and 6 show the average repatability and localization error respectively. Both of the figures are showing the result for seven different transformations along with the average values of the seven transformations.

In terms of average repeatability, except scale transformation, CCSR and SCCPDA have consistent better performance against different transformations. However, CPDA and MSCP have superior results in scale and shear transformations respectively. Considering all the transformations, CCSR has the best average of average repeatability followed by CTAR and SCCPDA.

In terms of Localization Errors, presented in Figure 6, the CCSR is not the best corner detector. Please note that, the lower localization error, the better the detector is. Except the shear transformation and gaussian noise, the original CPDA detector has the lowest localization error. However, similar to average repeatability, CCSR and SCCPDA detectors are always in the first four detectors in all the transformations. In summary, CPDA has the lowest average localization error against all the transformation followed by SCCPDA and CCSR detectors.

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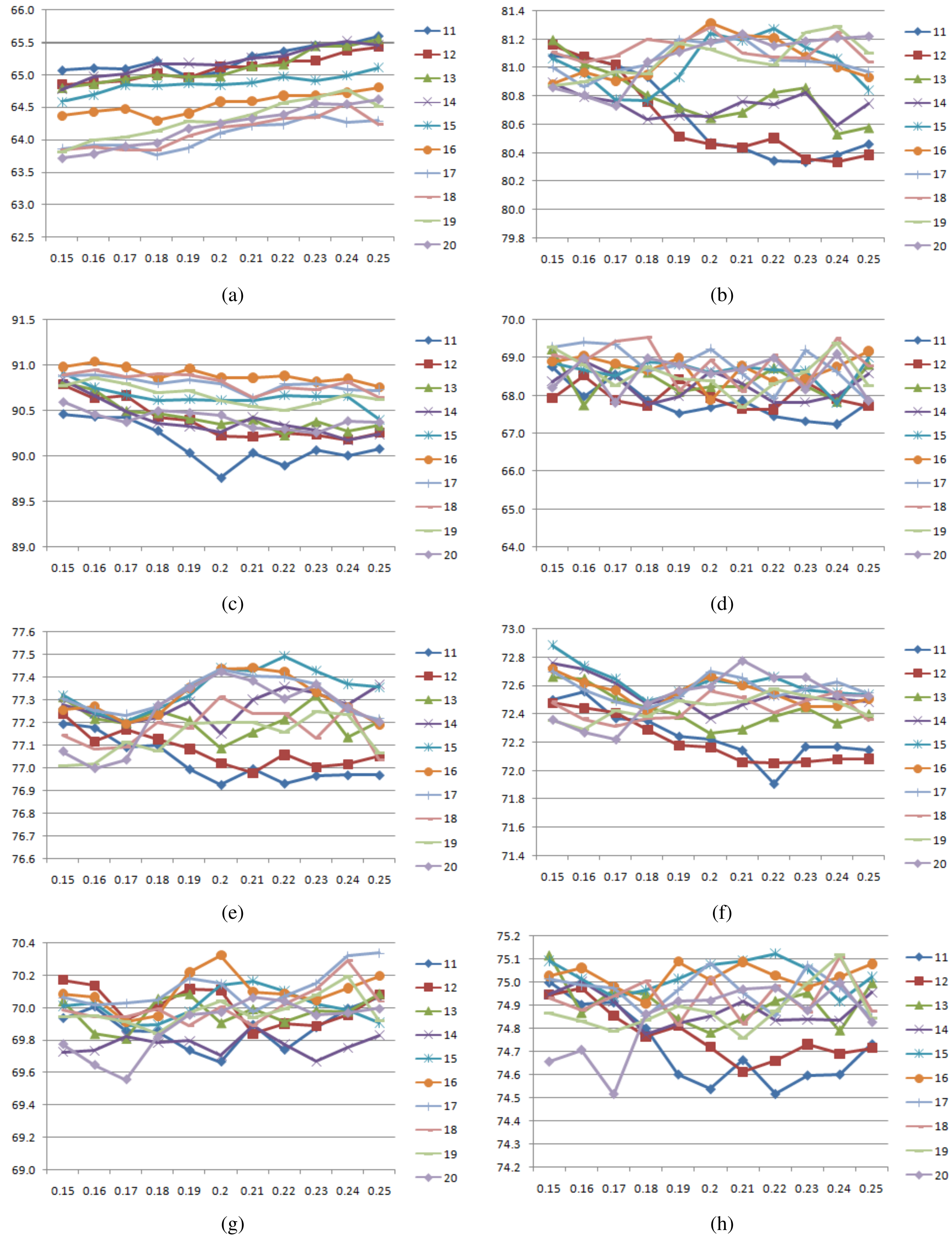

Figure 3: Average repeatability of SCCPDA detector for different chord lengths and different threshold against (a) scale transformation (b) rotation transformation (c) JPEG compression (d) Gaussian Noise (e) rotation+scale transformation (f) nonuniform transformation (g) shear transformation (h) average of all transformations

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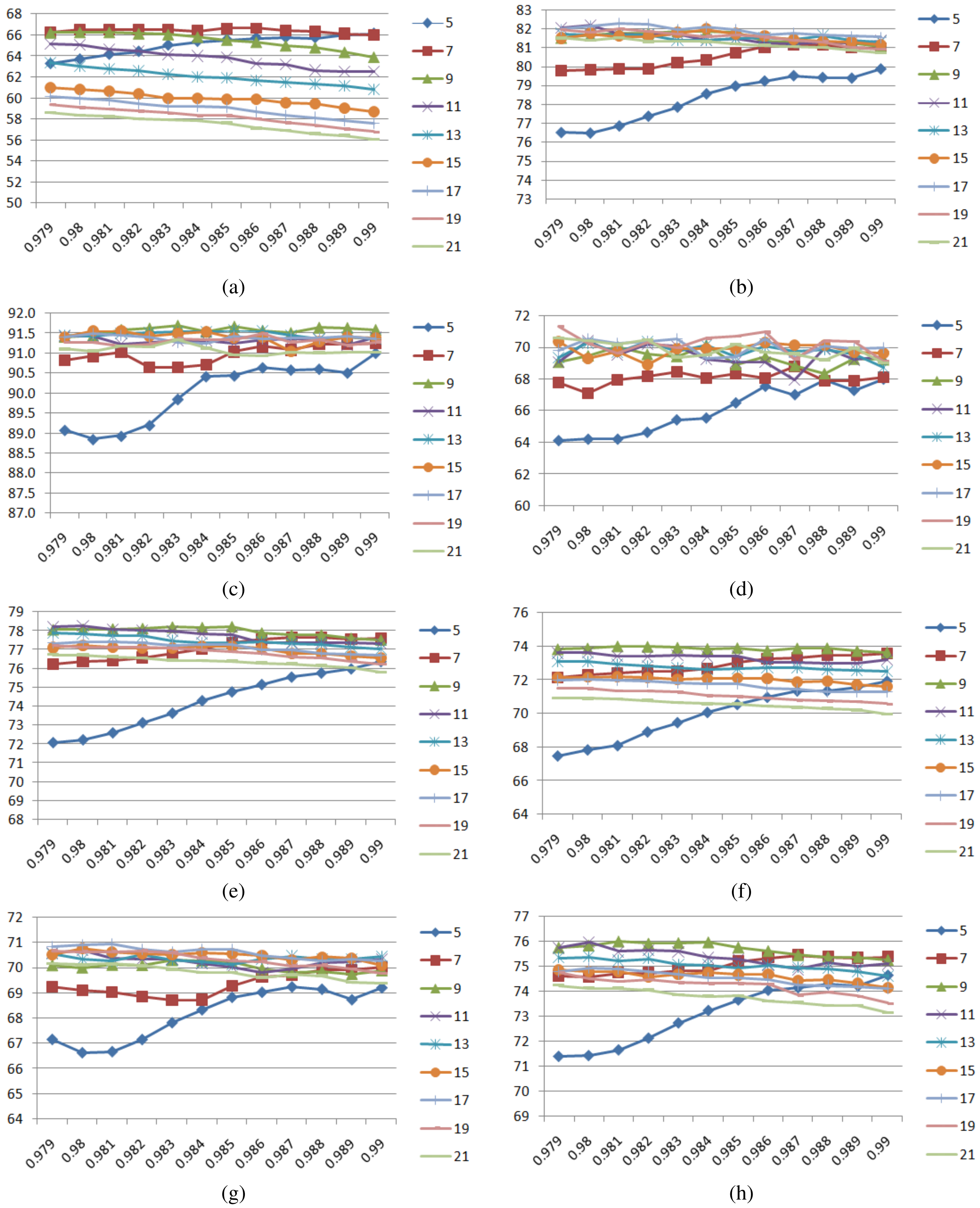

Figure 4: Average repeatability of CCSR detector for different chord lengths and different threshold against (a) scale transformation (b) rotation transformation (c) JPEG compression (d) Gaussian Noise (e) rotation+scale transformation (f) nonuniform transformation (g) shear transformation (h) average of all transformations

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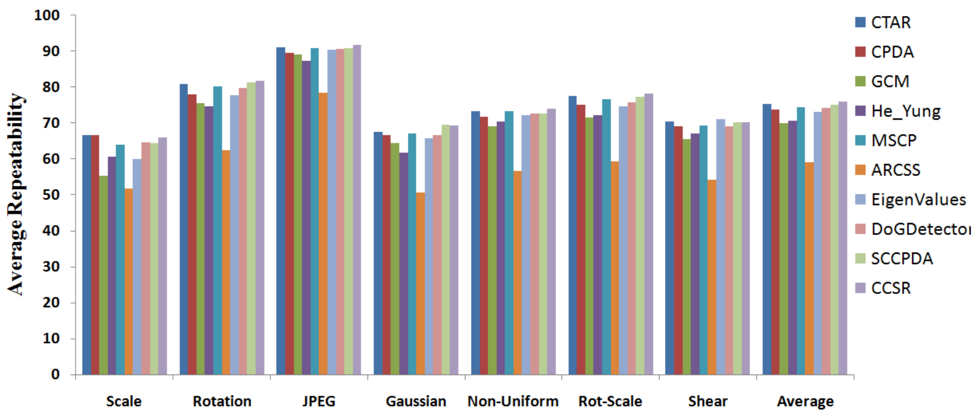

Figure 5: Average repeatability of corner detectors against different transformations

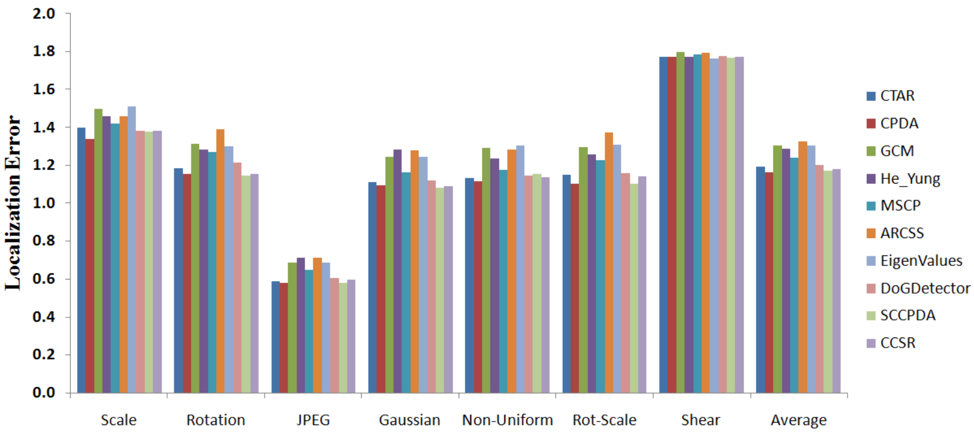

Figure 6: Localization Error of corner detectors against different transformations

Corner Detector	# of detected corners	% of CPDA corners
CPDA	922	100
SCCPDA	1000	91.398
CCSR	1264	92.437
DoGDetector	1342	88.152
CTAR	1364	94.557
ARCSS	1402	76.431
He_Yung	1617	88.167
EigenValues	1710	94.757
MSCP	1747	92.646
GCM	2714	94.878

Table 1: Number of corners detected by the detectors

Table 1 shows the number of corners in the base 23 images detected by the corner detectors. We see that CPDA detects the least number of corners followed by SCCPDA and CCSR detectors. However, both SC-CPDA and CCSR detectors have better repeatability than CPDA detector (Figure 5). Higher repeatability means more corners from original image been detected in transformed image irrespective to the number of corners matched between original and transformed image. Therefore, a higher number of repeated corners with same repeatability has more advantages than less corners. Although other detectors detect more corners than CCSR, their repeatability is less than CCSR. We have also shown the percentage of CPDA corners of 23 base images detected by other corner detectors. Both SC-CPDA and CCSR detectors are detecting more than 90% of the corners which are detected by CPDA detectors. Therefore, we can claim that the corners detected by these single chord detectors are qualitative and quantitative.

Complexity Comparison

Table 2 tabulates the total time taken to detect all the corners for the 23 base images by all the corner detectors. We see that CCSR is the most efficient corner detector followed by CTAR. Although SCCPDA detector is not one of the fastest corner detectors, it performs faster than the original CPDA detector. Note that, the process of extracting edges from the images has been discarded from the total time as this process is same for all the detectors. The time shown in the Table 2 is taken only to detect the corners from the extracted curves.

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Corner Detector	Time(Sec)
CCSR	0.056090
CTAR	0.057176
Zhang	0.083072
MSCP	0.167033
He & Yung	0.310473
SCCPDA	0.310724
CPDA	0.384464
ARCSS	0.384809
DoGDetector	0.405147
EigenValues	1.078661

Table 2: Total time to detect corners from 23 images

6 CONCLUSION

In this paper, we have analyzed a state of art corner detector named CPDA and modified this detector in a way that the modified version not only has better average repeatability but also better efficiency. We have also proposed another contour-based corner detector, named CCSR, that outperforms CPDA and seven other existing corner detectors in term of average repeatability. CCSR also has very comparative average localization error. In addition, CCSR also detects more stable corners than CPDA detector. Another achievement of CCSR detector is that, CCSR is the fastest detector to detect corners among all the detectors compared in the experiments. In summary, discarding the use of multiple chords in CPDA detector increases not only the efficiency but also the average repeatability and CCSR, a single chord detector, is the most efficient corner detector having the best average repeatability.

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