An Approach to Automatic Reconstruction of Apictorial Hand Torn Paper Document

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Abstract: *Digital automation in reconstruction of apictorial hand torn paper document increases efficacy and reduces human effort. Reconstruction of torn document has importance in various fields like archaeology, art conservation and forensic sciences. The devised novel technique for hand torn paper document, consists of pre-processing, feature extraction and reconstruction phase. Torn fragment's boundaries are simplified as polygons using douglas peucker polyline simplification algorithm. Features such as Euclidean distance and number of sudden changes in contour orientation are extracted. Our matching criteria identify the matching counterparts. Proposed features curtail ambiguity and enriches efficacy in reconstruction. Reconstructed results of hand torn paper document favour the proposed methodology.*

Keywords: *Reconstruction, apictorial, torn documents.*

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1. Introduction

Deterioration of document is unavoidable. Document includes historical art work, pots, wall paintings, sculptures, inscriptions and manuscripts. Document gets deteriorated intentionally, naturally and accidently. Reconstruction of deteriorated document is essential in fields like archaeology [8, 9, 11], art conservation [12, 13] and in law enforcement [7, 17]. Due to advancement in technology printed paper replaces hand written manuscripts. Paper document can be torn accidently or incidentally. Incidentally tearing of paper document can be of in two ways, mechanically or manually. Reconstruction is a tedious and time consuming job, needs lot of experienced personals. The human visual system in combination with our relatively small amount of short term memory, limits reconstruction capabilities [15]. Human inabilities in reconstruction of hand torn document, leads digital automation. Automation of reconstruction through image processing algorithms yields effective solution [1]. According to literature, reconstruction of torn documents have got root from jigsaw puzzle solving technique. Ever since assembling of jigsaw puzzles, reconstruction is considered as a single handed pattern recognition game [5]. Reconstruction is arrangement of torn fragments in a single form which replicates original document both in shape and content. Freeman and Garder [5] looked jigsaw puzzle solving through computer vision. Right from their visualization, 2D puzzles are classified as pictorial and apictorial. In apictorial puzzles, only the shapes of fragment pieces are considered to reconstruct the original document. Pictorial puzzles account shapes as well as the texture of the pieces to find the correct solution [9] and 3D reconstruction also, has enormous application [3]. Wolfson [16] puzzle solving method has two curve matching algorithm in which simplified boundaries are represented by shape feature strings. Kong and Kimia [10] used polygonal approximation for complexity reduction and dynamic programming to align fragments. Chain code of contours and Minkowski sum are employed in Biswas *et al.* [1] method. Justino *et al.* [7] proposed methodology reconstructs hand torn paper document using extracted features from simplified polygon. Pimeta *et al*. [14] method calculates LCS score using extracted features and uses modified Prim's algorithm to determine the matching fragments. Cao *et al*. [2] method employs minimum spanning tree method in reconstruction of shredded photo. We proposed a novel algorithm for reconstruction of Apictorial hand torn paper document. This automated reconstruction methodology accounts changes in contour orientation and Euclidean distance for effective reconstruction.

This paper is organised into four sections. Section 2 narrates the design aspects of proposed algorithm. Discussions over experimental results are provided in section 3. Section 4 concludes the paper.

2. Proposed Work

Hand-torn paper fragments are digitized. The digitized images I_f, f= 1, 2, ..., sz are stored in an array arr. n is the size of arr.

- *Step* 1. Pre-Processing: The scanned images' I_f contours C_f are extracted [6]. Contours C_f will have irregularity in its boundaries. Douglas and Peucker [4] polyline simplification algorithm is implemented on contours C_f to get well defined, simplified polygon P_f with reduced irregularities in boundaries. The simplified polygon P_f approximates original contour shape.

- *Step* 2. Frame Part Identification: The simplified polygon P_f sides P_l (l= 1, 2, 3 ..., m, m=No. of sides of simpleified polygon) are categorised as frame part and inner part.

Each side of polygon's corresponding contour c_s segments is checked for its probability to be a frame part or inner part. Angle values of pixels that lie in c_s are calculated and stored in an array a_1. Each angle value stored in a_1 is compared with its successor. If comparing two subsequent angle values of array a_1 are different, then successor of current value is stored in b_1. Similar comparison is done in b_1 and number of successor which varies from its previous value is counted as di_θ. The ratio fP_r between number of pixels c_{pix} in contour segment c_s and di_θ decides whether that particular polygon side is frame part or inner part.

$$fp_r = \frac{c_{pix}}{di_\theta} \tag{1}$$

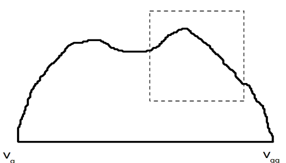
Line segment P_l of P_f is considered as frame part ES if fP_r is greater than a predefined threshold.

$$p_1 = \begin{Bmatrix} p_{ES} & if \ \ fp_r > threshold \\ p_{SS} & else \ \ fp_r < threshold \end{Bmatrix} \quad \begin{matrix} P_{ES} = frame\ part\ side \\ P_{SS} = inner\ part\ side \end{matrix} \tag{2}$$

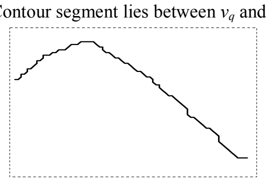
Where P_{ES}=Frame part side, P_{SS}=Inner part side.

Each paper has four machined cut edges. These edges form outer frame and do not contribute to inner part of paper document. The frame part polygon sides P_{ES} are left aside since they do not become adjacent sides of matching inner parts. Inner parts P_{SS} of polygon enter into step 3. Exclusion of frame part P_{ES} of polygon reduces comparison iterations in reconstruction phase.

- *Step* 3. Feature Extraction: The vertices v_k of P_{SS} of the pre-processed and simplified polygon P_f, where k= 1, 2, 3 ..., t, (t= total no. of inner surface vertices of polygon) is subjected to feature extraction process. Feature extraction process is of two stages.
  - *Step* 3.*a*: Number of sudden changes Ω as shown in Figure 1 in contour orientation, which falls between v_q and v_{qq} with respect to the polygon line segment $\overline{v_q v_{qq}}$ is counted.



a) Contour segment lies between v_q and v_{qq}.



b) Enlarged portion shows sudden changes in contour orientation.

Figure 1. Changes in contour orientation.

  - *Step* 3.*b*: The distance between the inner side P_{SS} vertices is calculated. Euclidean distance, dE_{v_q} of the vertex v_q with the next vertex v_{qq} (qq= (q *mod* t)+1) such that:

$$dE_{vq} = \sqrt{((x_q - x_{qq})^2 + (y_q - y_{qq})^2)} \tag{3}$$

Where (x_q, y_q) are the coordinates of the current vertex (v_q), (x_{qq}, y_{qq}) are the coordinates of the current vertex (v_{qq}).

- *Step* 4. Decision Matrix: A decision matrix FM as shown in Table 1 is set of size $n \times n$ FM values are created using Equation 4. The FM values identify which fragment pair (i, j), has to be compared and also, avoid duplication (j, i) in comparison. The fragments pair's (i, j) features are compared whose FM values are 1. FM's zero value indicates the comparison of fragment with itself. The null value of FM indicates duplication of existing pair. Comparing the features of fragments pair is trivial whose FM value is zero and null.

$$M(i,j) = \begin{Bmatrix} 0 & if & i=j \\ 1 & if & ((i \neq j)\ and (j > i)) \\ null & if & ((i \neq j)\ and (j < i)) \end{Bmatrix} \quad i = 1, 2, ..., n,\ j = 1, 2, ..., n \tag{4}$$

Table 1. Decision matrix.

0	1	2	3	4	5	6
1	0	1	1	1	1	1
2	null	0	1	1	1	1
3	null	null	0	1	1	1
4	null	null	null	0	1	1
5	null	null	null	null	0	1
6	null	null	null	null	null	0

- *Step* 5. Matching Phase: The criteria to find the matching pair is:

$$\xi = max \begin{Bmatrix} 5 & if \ \left(dE_{v_{P_i}} = dE_{v_{P_j}}\right) and \left(\Omega_{v_i} = \Omega_{v_j}\right) \\ 3 & if \ \left(\left|\left(dE_{v_{P_i}} - dE_{v_{P_j}}\right)\right| \leq u_d\right) and \left(\Omega_{v_i} \approx \Omega_{v_j}\right) \end{Bmatrix} \tag{5}$$

The inner sides p_{ss_i} of polygon P_i is compared with all other p_{ss_i} of polygons P_j whose FM value is 1. The matching pair strength value is assigned as 5, if Euclidean distance and number of sudden changes in contour orientation of p_{ss_i} and p_{ss_j} of two fragments P_i and P_j (FM_{ij}=1) are equal. The matching pair strength value is assigned as 3 if the difference in Euclidean distance of inner side line segments p_{ss_i} and p_{ss_j} of two fragments P_i and P_j (FM_{ij}=1) is less than or equal to u_d and number of sudden changes in contour orientation of p_{ss_i} and p_{ss_j} is approximately equal. Maximum matching pair strength is matching score ξ value. ξ value decides the matching pair. The maximum scored pair P_i and P_j is fused together with respect to the matching polygon's sides p_{ss_i} and p_{ss_j}.

The corresponding *FM* rows and *FM* columns values of (i, j) are turned zero so as to avoid trivial matching iteration.

$$\begin{aligned} FM\left(i\,,\,z\right) &= FM\left(z\,,\,i\right) = 0,\left(1\le z\le n\right) \\ FM\left(j\,,\,z\right) &= FM\left(z\,,\,j\right) = 0,\left(1\le z\le n\right) \end{aligned} \tag{6}$$

Comparison continues with another set of pair. Fused pair forms a new fragment and stored in R and the fragments who do not find any match with the images of *arr* stored in R. Once the first iteration is over:

$$arr = R, \quad n = size(R) \tag{7}$$

Then, procedure continues from step 1, till the array *arr* size becomes one.

3. Results and Discussion

The experiments on reconstruction of apictorial hand torn documents were implemented in Matlab on an INTEL core (TM), 2.53GHz machine. Our method concentrates only on single page reconstruction. Manually torn test fragments used for proposed algorithm are shown in Figure 2.

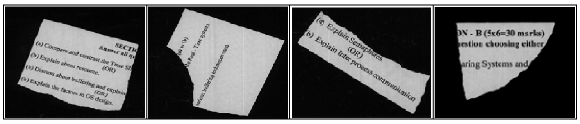


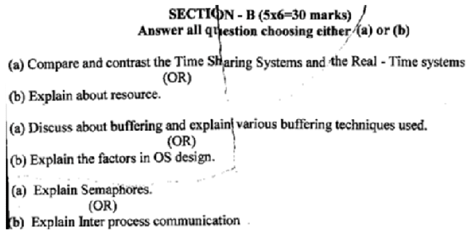
Figure 2. Test image torn fragments of a paper document.

The threshold value is set as 4. Frame parts of fragments are clearly identified and excluded from reconstruction. In our experiment u_d value is 10. Relaxation given in Euclidean distance dE and number of changes in contour direction Ω in matching criteria rectify, if scanning and simplification errors exist. When more number of hand torn fragments is to be reconstructed, there may be duplication of same Euclidean distance between more than two fragments. Comprising Ω in matching criteria avoids ambiguity in fusion, when more than two fragments have same Euclidean distance. Since, the fragments have interlocking boundaries, Ω of matching counter parts, will be approximately equal. Table 2 depicts proposed algorithm's feature list and frame part identification of test image fragments. In Table 2, fP_r values 9.750, 8.969, 8.724, 18.50, 6.611, 23.20 and 20.57 are greater than 4 and find the sides as frame part. This frame part sides features are not computed so as to exclude them from reconstruction phase. The proposed methodology's features, precisely find matching counterparts. The reconstructed result of test image is shown in Figure 3.

To measure the efficacy of reconstructed paper document, same sentence of similar size is cropped from original image I and reconstructed image R. Cropped images of I and R are converted into black and white images $cropI_{bw}$ and $cropR_{bw}$. Efficacy factors (Ef) are number of words WC in chosen sentence and each words last segment's information pixels (black) count I_p. A window $w_{m\times k}$, m= No. of tows of cropped image, k=4 is created. The set of pixel positions of w_k are defined as follows with the initial guess j=1, m=1.

Table 2. Proposed features and frame part identification of torn fragment.

Vertex of Polygon's Sides				fP_r	Features of Proposed System	
X1	Y1	X2	Y2		Euclidean Distance	Number of Sudden Changes in Contour Segment Ω
306	403	17	368	2.322	291	89
323	24	306	403	2.197	379	121
17	368	26	15	9.750	Frame Part	
26	15	323	24	8.969	Frame Part	
236	57	37	281	1.392	300	143
35	30	236	57	1.99	203	71
37	281	35	30	8.724	Frame Part	
8	407	23	26	2.048	381	131
137	437	8	407	1.706	132	56
142	29	137	437	18.50	Frame Part	
23	26	142	29	6.611	Frame Part	
11	322	217	93	1.384	308	143
217	93	430	126	2.038	216	77
49	519	11	322	23.20	Frame Part	
430	126	433	518	20.57	Frame Part	



SECTION - B (5x6=30 marks)
Answer all question choosing either (a) or (b)
(a) Compare and contrast the Time Sharing Systems and the Real - Time systems
(OR)
(b) Explain about resource.
(a) Discuss about buffering and explain various buffering techniques used.
(OR)
(b) Explain the factors in OS design.
(a) Explain Semaphores.
(OR)
(b) Explain Inter process communication

Figure 3. Reconstructed result of test image 1.

$$w_k = \left(\left(z_1, z_2\right) / 1 \le z_1 \le m,\ z_2 = j + \left(k - 1\right)\right) \tag{٨}$$

Where k= 1, 2, 3, 4, j= No. of column of cropped image. Window w slides over the entire image and calculates efficacy factor as follows:

$$Ef = \begin{cases} WC = \begin{cases} count + 1 & \text{if } \left(\begin{array}{l} \left(\sum w_1 < \left(m \times s\right)\right) and \\ \left(\sum w_2 = \sum w_3 = \sum w_4 = \left(m \times s\right)\right) \end{array}\right) \end{cases} \\ I_{bp} = \begin{cases} \left(m - \left(\sum w_1 / s\right)\right) & \text{if } \left(\begin{array}{l} \left(\sum w_1 < \left(m \times s\right)\right) and \\ \left(\sum w_2 = \sum w_3 = \sum w_4 = \left(m \times s\right)\right) \end{array}\right) \end{cases} \end{cases} \tag{9}$$

Initial values of *count* is zero and s= intensity value of white pixel. j gets incremented. The process is repeated from Equation 8 until the window slides over the entire image. EF is calculated for $cropI_{bw}$ and $cropR_{bw}$. A comparison is made between the Ef of $cropI_{bw}$ and $cropR_{bw}$ as mentioned in Table 3. WC values of $cropI_{bw}$ and $cropR_{bw}$ are same. I_{bp} of $cropI_{bw}$ and $cropR_{bw}$ are approximately equal. One or two variation in I_{bp} may occur due to scanning imperfection and pre-processing steps. Thus, Ef quantitatively favour the reconstructed results.

Table 3. Efficacy factor table.

Efficacy Factor			
WC		I_{bp}	
$Cropi_{bw}$	$Cropi_{bw}$	$Cropi_{bw}$	$Cropr_{bw}$
9	9	3	3
		4	4
		5	4
		2	2
		1	1
		5	5
		6	5
		2	2
		1	1

The result of proposed algorithm is compared with ELC [7] algorithm. Processing time taken to reconstruct the test image 2 by ELC and proposed algorithm are noted as 8.89sec and 7.551sec. Proposed algorithm converges fast. Fragments which has jigsaw edge segment as shown in Figure 4 will satisfy the matching criteria designed by ELC algorithm. Natural shredding shall not always generate shredded document of the type that can be reconstructed by the matching criteria suggested by ELC algorithm. So, the shredded document of test Reconstructed, though are matching document are not merged by the ELC algorithm, since they do not satisfy its matching criteria. The proposed algorithm's matching criteria and features are applicable for all kind of shreds and act as a general purpose reconstruction algorithm.

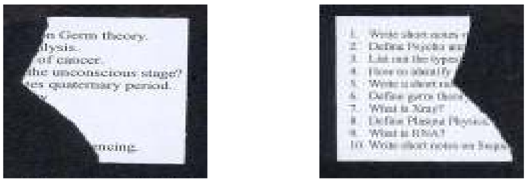
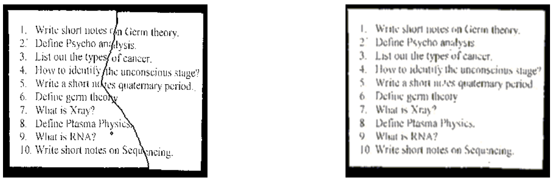


Figure 4. Test image 2.



a) Reconstructed result of ELC algorithm. b) Reconstructed result of proposed algorithm.

Figure 5. Reconstructed test image 2.

4. Conclusions

The proposed methodology enumerates a novel apictorial reconstruction technique for hand torn document using Euclidean distance and total number of sudden changes in contour orientation. Reconstructed result of hand torn fragment favours the method. Performance needs improvement in the case of excessive shear. Our future work will concentrate on the reconstruction of hand torn fragments from multiple pages.

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