# Robust Skew Estimation Technique Based on Boundary Growing and Radon Transform

[1]Manjunath Aradhya V N*, [1]Hemantha Kumar G, [2]Shivakumara P

**Abstract**

Document image processing has become an increasingly important technology in the automation of office documentation tasks. Automatic document scanners such as text readers and OCR (Optical Character Recognition) systems are an essential component of those tasks. Hence, the problem in this field is that the document to be read is not always placed correctly on a flat bed scanner, resulting in a skewed document. Hence in this paper we present a new skew estimation technique for binary document images using boundary growing and Radon transform. This is required to enhance the ability of the document analysis system through Optical Character Recognition. The Boundary Growing (BG) is used to extract the text line from skewed document. The resultant extracted text line from the skewed document images are then applied for Radon transform for estimation of the skew angle. Several experiments have been conducted on various types of documents such as documents containing English Documents, Journals, Text-Book, Text with Picture, Text with Tables, Text with Graphs, Different Languages, Noisy Images, and Document with different fonts, Documents with different resolutions, to reveal the robustness of the proposed method. The experimental results revealed that the proposed method is accurate compared to the results of well-known existing methods.

**Keywords:** Optical Character Recognition (OCR), Skew Detection, Boundary Growing, Radon Transform, Document Processing,

## 1. INTRODUCTION

Over the past two decades, many researchers have attempted to solve the problem of skewed documents using various methods. The OCR system works well if the document is not skewed during the scanning process and its text lines are strictly horizontal, which is very unlikely and hence accurate estimation of skew angle is invariably involved in OCR based character recognition system to achieve good recognition rate (Yue Lu and Chew Lim Tan (2003), Liolios N et al (2002)). However, designing simple, efficient and an accurate OCR system which addresses skew estimation problem is still considered to be a challenging issue.

Existing skew estimation techniques are broadly classified into four models namely (a) Projection profile (b) Nearest neighbor clustering (c) Hough transform and (d) Interline cross correlation.

The horizontal projection profile, proposed by Hou (1983), is a histogram of the number of black pixels along the horizontal lines of a scanned document. For a script with horizontal text lines, the horizontal projection profiles have peaks at text lines positions and troughs between the successive text lines positions. To determine the skew angle of a document, the projection profile is computed at number of angles and for each angle, a

[1]Department of Studies in Computer Science, Manasagangotri, University of Mysore, Mysore-570006 India. *Email: mukesh_mysore@rediffmail.com

[2]Department of Computer Science, School of Computing, National university of Singapore (NUS), 3 Science, Drive 2, Singapore 117543.

measure of difference of peak and trough height is made. The maximum difference corresponds to the best alignment with the text line direction, which in turn determines the skew angle. Baird (1987) proposed modifications to this iterative approach for quick convergence.

Akiyama and Hagita (1990) have described an approach where the document is partitioned into vertical strips. The horizontal projection profiles are calculated for each strip and from the correlation of the profiles of the neighboring strips, the skew angle is determined. Although the proposed method is computationally inexpensive, it works well if the document is skewed within $\pm 10^0$.

Pavlidis and Zhau (1991) have proposed a method based on vertical projection profile of horizontal strips, which works well if the skew angle is small.

Yan (1993) has proposed cross correlation between the lines at fixed distances shifted by varying width of strips in a vertical direction. The correlation for all pairs of lines in the image is accumulated. The shift for which the accumulated cross correlation that becomes the maximum is used for skew angle estimation.

Hashizume et al, (1986) have proposed nearest neighbor clustering based approach to estimate skew angle of the document. In their methodology, all the connected components in the document were extracted and for each component, the direction angle of its nearest neighbor is estimated. A histogram of the direction angle is computed and the peak of which indicates the document skew angle.

The Hough Transform technique is used by Srihari and Govindaraju (1989) for skew detection. The basic method consists of mapping points in Cartesian space (x, y) to sinusoidal curves in $(\rho, \theta)$ space via the transformation $\rho = x\cos\theta + y\sin\theta$. Each time a sinusoidal curve intersects with another sinusoidal curve for a value of $\rho$, and $\theta$, there is likelihood that a line corresponding to that $((\rho, \theta)$ coordinate value is present in the original image. An accumulator array is used to count the number of intersections for various $\rho$, and $\theta$, values. The skew angle is then determined by the , values corresponding to the highest number of counts in the accumulator array.

In order to reduce the computational cost associated with processing of each pixel and also irrelevant data, Hinds et al, (1990) have proposed a method based on the length of black pixels to reduce the amount of data to be processed by a Hough transform. Since the aligned characters at the base line of a text line are sufficient enough to compute skew angle, Le et al, (1994) have considered the bottom pixels of each character to transform the data to Hough space. However, irrelevant pixels such as lowermost pixels of the characters viz., *g, j, p, q* and *y* that are below the base line, lowermost pixels of the dots of the characters like *i* and *j*, and punctuations marks were considered for transformation purpose which may result in error in line approximation. Pal and Chaudhuri (1996) have proposed an improved method to overcome the drawback of the method proposed by Le et al, (1994).

Hull J J, (1998) has proved that the document must contain some amount of text in order to estimate the skew angle. Based on distributions of pixels of text, the orientation of the text line is computed.

Hence, there is a need to develop new algorithms, which takes less time and gives better accuracy in estimating skew angle for skewed document.

In this paper, we have proposed an algorithm based on boundary growing approach and Radon transform to estimate accurately skew angles for skewed documents. The boundary growing approach is used to extract text lines present in the scanned document image and the extracted text line is subjected to Radon transform to estimate the skew angles accurately. Radon transform are used to extract the representations of the images as it permits to globally detect lineal singularities in an image, which are the most important source of information in these images [Jain A.K., 2002]. Hence, Radon transform helps us in estimating the skew angle accurately. The approaches assume the fact that the space between the text lines is greater than the space between the words and the characters. The proposed method works on all types of documents.

The organization of the paper is as follows. We present proposed methodologies and their algorithmic models in section 2. Experimental results are reported in section 3. We give a comparative study of the proposed method with the well-known existing methods in section 4. Discussion based on experimental results is given in section 5. Conclusion is reached at the end.

## 2. PROPOSED METHOD

This section presents the proposed methodology that is based on BG, and Radon transform to determine the skew angle of the scanned document. The method has two stages. In the first stage, using BG the method extracts the skewed text line of the scanned documents. In the second stage, the extracted text line using BG is subjected to Radon Transform to estimate skew angle. The block diagram of the proposed methodology is given in Fig. 1. In the following subsections, each stage is explained in detail.

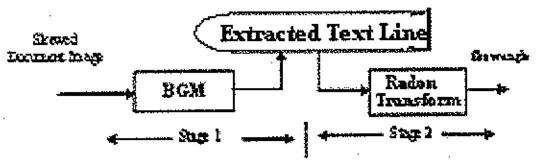



**Fig. 1 Block diagram of the proposed model for skew angle estimation**

### *2.1 Boundary Growing Method (BGM)*

The method begins with fixing the boundaries for character in the document using the concept of connected component labeling Fig. 3 (b). Fig. 3(a) shows the original image. The boundary for each character is fixed by scanning the document column-wise and the centroid of bounding box of a character is computed when the character is found (Fig 2). The boundary of a character is allowed to reach pixel of the neighbor-character. This procedure repeats till end of the text line. The end of the text line is decided by the space between the lines and words and characters. The height (H) of each boundary of characters (Fig. 2) in the text line is computed. The average height (AVH) is computed which is defined as the ratio of sum of heights of characters to the number of characters in the document. The height of the character is reduced to average height when the height of character is larger than the average height. Some characters whose height is less than average height are ignored ($H(c_i) = 0$) in the algorithm 1). This procedure is repeated for all the text lines present in the document. The height normalized scanned document image is shown in Fig. 3 (c). However, AVH of the characters depends on the number of characters present in the text line and their sizes. Fig. 3(d) shows the BG applied for height normalized document. This procedure is repeated for two or three text lines to estimate skew angle of the whole document. The extracted text line using Boundary Growing (Fig. 3(e)) is then applied for Radon transform to estimate the skew angle accurately.

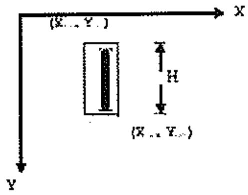



**Fig. 2 Rectangle is fixed using ($X_{min}$, $Y_{min}$) and ($X_{max}$, $Y_{max}$) coordinates of a character**

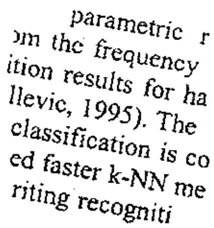



**Fig 3 (a) Skewed text Image Fig 3 (b) boundary fixed**

**Fig 3 (c) Height normalized Skewed document**

**Fig 3(d) BG applied for height normalized document**


**Fig 3 (e) extracted text line**

The detailed algorithm of the proposed method is as shown below.

**Algorithm 1: Boundary Growing Method**

**Input**: Skewed text document

**Output**: Text Line

**Method**

**[Normalization of heights of each character]**

(a) Identify the black pixel of i[th] character, say $c_i$ of the document by scanning the document column-wise.

(b) Fix the rectangular boundary, say B for $c_i$. Let ($X_{min}$, $Y_{min}$) and ($X_{max}$, $Y_{max}$) be the lowermost and uppermost coordinates of the fixed rectangular boundary (Fig. 3).

(c) Compute the centroid C (x, y) for the rectangular boundary B using the coordinates of the character $c_i$, where $x = \dfrac{x_{min} + x_{max}}{2}, y = \dfrac{y_{min} + y_{max}}{2}$

(d) Compute the height of $c_i$ i.e $H_i = abs(Y_{min} - Y_{max})$

(e) Repeat the steps from (a) to (d) till end of the characters in the document.

(f) Compute the average height i.e.,

$$AVH = \frac{\sum_{i=1}^{n} H_i}{n}$$

where n is the number of characters processed.

(g) Obtain the Height normalized character say ($H(c_i)$) of i[th] character.

$$H(c_i) = \begin{cases} 0 & if\ H_i << AVH \quad \forall\, i = 1..n \\ AVH & if\ H_i \geq AVH \quad \forall\, i = 1..n \end{cases}$$

as (if Height of the character is too less compared to the average height then we won't consider for the skew estimation. That is represented symbolically by $H(c_i) = 0$.

**[Extraction of text line from height normalized document image by Boundary Growing]**

(h) Repeat the steps (a) to (d).

(i) Neighbor character of $c_i$ say $c_j$ pixel position is obtained by incrementing corners of B both in X and Y direction.

(j) Repeat the steps (h) to (i) till end of the line.

**Algorithm ends**

This procedure is repeated for two to three text lines in order to find mean skew angle using radon transform.

***2.2 Radon Transform***

The Radon transform of a function f(x,y), denoted as g(s, ,), is defined as its line integral along a line inclined at an angle , from the y-axis and at a distance s from the origin.

Mathematically, it is written as

$$g(s,\theta) = Rf = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x,y)\delta(x\cos\theta + y\sin\theta - s)dxdy, \quad -\infty<s<\infty,\ 0<=,< \quad (1)$$

The symbol *R*, denoting the Radon transform operator, is also called the projection operator. The function g(s, θ), the radon transform operator of *f(x, y)*, is the one-dimensional projection of f(x, y) at an angle θ. In the rotated coordinate system (s, u), where

$s = x \cos \theta + y \sin \theta$ $\quad$ $x = s \cos \theta - u \sin \theta$

Or

$u = -x \sin \theta + y \cos \theta$ $\quad$ $y = s \sin \theta + u \cos \theta$ $\quad$ (2)

Equation 1 can be expressed as

$$g(s,\theta) = \int_{-\infty}^{\infty} f(s\cos\theta - u\sin\theta, s\sin\theta + u\cos\theta)du, \quad -\infty<s<\infty, 0<=\theta<q \quad (3)$$

The quantity g(s, θ) is also called a ray-sum, since it represents the summation of f(x,y) along a ray at a distance s and an angle θ.

The radon transform maps the spatial domain (x, y) to the domain (s, θ). Each point in the (s, θ) space corresponds to a line in the spatial domain (x, y). Note that (s, θ) are not the polar coordinates of (x, y). In fact, if (r, ø) are the polar coordinates of (x, y), that is,

$x = r \cos ø, \quad y = r \sin ø$ $\quad$ (4)

Then from equation 4

$s = r \cos (\theta - ø)$ $\quad$ (5)

For a fixed point (r, ø), this equation gives the locus of all the points in (s, θ), which is a sinusoid curve.

The algorithm to estimate the skew angle is as follows.

**Algorithm 2: Skew angle estimation**

**Input**: Text Line

**Output**: Skew angle

**Method**

1. For i = 1 to r (r = the number of text lines).

$$(X_l, Y_l) = \left\{ \begin{array}{l} \forall\ l = 1..\ p,\ where\ p\ \ is\ the\ number\ of\ Pixel \\ coordinates\ present\ in\ the\ line\ L_i. \end{array} \right\}$$

(a) Compute the slope angle $\theta_i$ of the i[th] line using equation (3) considering ($X_l$, $Y_l$) as input.

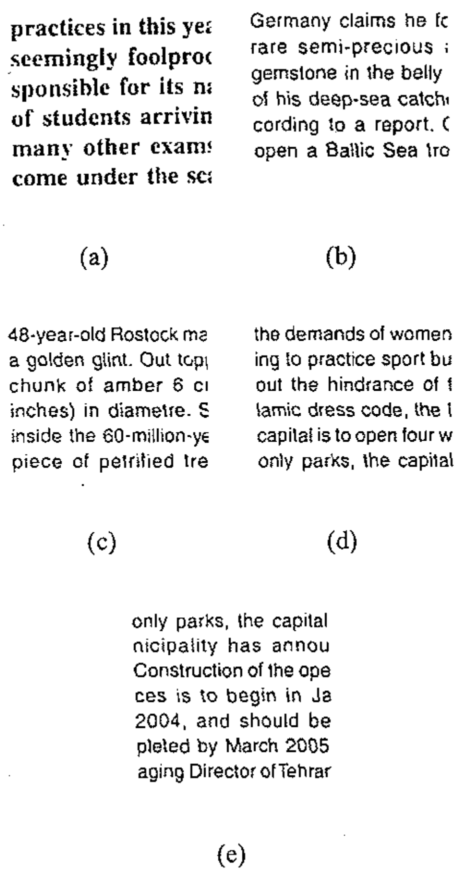
Next i;

2. Compute the skew angle as $\frac{\sum_{i=1}^{r} \theta_i}{r}$ where r is number of lines considered to estimate the skew angle.

**Algorithm ends**

## 3. EXPERIMENTAL RESULTS

This section presents the results of the experiments conducted to study the performance of the proposed method. All the methods are implemented on a PIV machine with 256 MB RAM, 1.4 GHz, under Turbo-C environment. We have considered different skewed documents from different sources like journals, textbooks, newspapers and the like. For experimentation purpose 20 documents, with eight true skew angles are considered. Some of the sample images are shown in Fig. 4(a) to 4(e). Obtained Mean Skew Angle (M), Standard Deviation (SD) and Mean Computing Time (CT) taken by the proposed methodology for these 20 documents are reported in Table 1. To further establish the suitability of our method for document analysis and understanding purpose, documents with noise, documents with different resolutions, different textbook documents and the like are also considered as shown in Fig.



practices in this yea
seemingly foolproc
sponsible for its na
of students arrivin
many other exams
come under the sca

(a)

Germany claims he fc
rare semi-precious a
gemstone in the belly
of his deep-sea catch
cording to a report. C
open a Baltic Sea tro

(b)

48-year-old Rostock ma
a golden glint. Out top
chunk of amber 6 ci
inches) in diametre. S
inside the 60-million-ye
piece of petrified tre

(c)

the demands of women
ing to practice sport bu
out the hindrance of t
lamic dress code, the t
capital is to open four w
only parks, the capital

(d)

only parks, the capital
nicipality has annou
Construction of the ope
ces is to begin in Ja
2004, and should be
pleted by March 2005
aging Director of Tehrar

(e)

**Fig. 4 Different sample scanned text document images.**

**Table 1 Estimated Skew angle, standard deviation and mean time taken by the proposed method**

| True angle | Proposed Method | | |
|---|---|---|---|
| | Mean | Standard deviation | Mean Time (Secs) |
| 3 | 3.200 | 0.102 | 0.95 |
| 5 | 4.855 | 0.336 | 0.98 |
| 10 | 10.025 | 0.317 | 0.88 |
| 15 | 15.425 | 0.305 | 0.95 |
| 20 | 20.00 | 0.376 | 0.90 |
| 30 | 29.750 | 0.475 | 0.94 |
| 40 | 40.10 | 0.236 | 0.99 |
| 45 | 45.005 | 0.255 | 0.95 |

## 4. COMPARATIVE STUDY

A comparative study with certain existing methods is carried out to establish the superiority of our method in terms of accuracy and efficiency. The scanned text document images (Fig. 4(a)-(e)), with different skew angles say 3, 5, 10, 15, 20, 30, and 45 degrees is actually considered as an input to the proposed method as well as to the existing methods. The mean, standard deviation and computing time obtained using the proposed method and the other methods are reported in Table 2 (a) and Table 2 (b).

It is observed from Table 2 (a) and Table 2(b) that the skew angle estimation obtained by the proposed methodology is better than the existing methods Akiyama and Hagita (1990), Pavlidis and Zhau (1992), Hashizume et al, (1986), Srihari and Govindaraju (1989), Le et al, (1994), Pal and Chaudhuri (1996), Yan, (1993) and Lu and Tan, (2003) with respect to mean (M). It is also observed that the proposed method is better with respect to the standard deviation that varies from 0.1 to 0.4. The variations in standard deviation (SD) of the other methods namely Akiyama and Hagita (1990) is (0.99 to 2.86), Pavlidis and Zhau (1992) is (0.76 to 3.25), Hashizume et al, (1986) is (0.5 to 1.5), Srihari and Govindaraju (1989) is (0.3 to 1.45), Le et al, (1994) is (0.35 to 0.85), Pal and Chaudhuri (1996) is (0.3 to 1.42), Yan, (1993) is (0.63-1.04) and Lu and Tan, (2003) is (0.51-0.95), which reveals that the proposed method is better compared to existing methods.

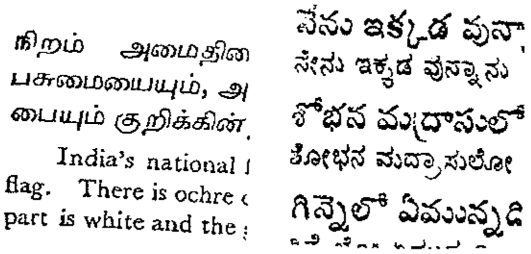
From Table 2 (a) and Table 2(b), one can notice that the proposed method is efficient as it takes less computing time (~1 Secs) compared to the other methods.

The above discussion revealed that the proposed method is precise and efficient compared to the existing methods.

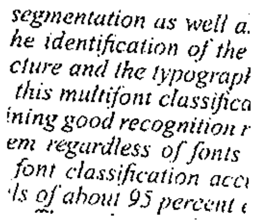
## 5. DISCUSSIONS

The simplicity, generality, and applicability of the proposed method considering special cases comprising of different document images namely language documents, journals, document with different resolutions, synthetic text documents, newspaper cuttings, and noisy documents, is discussed in this section.

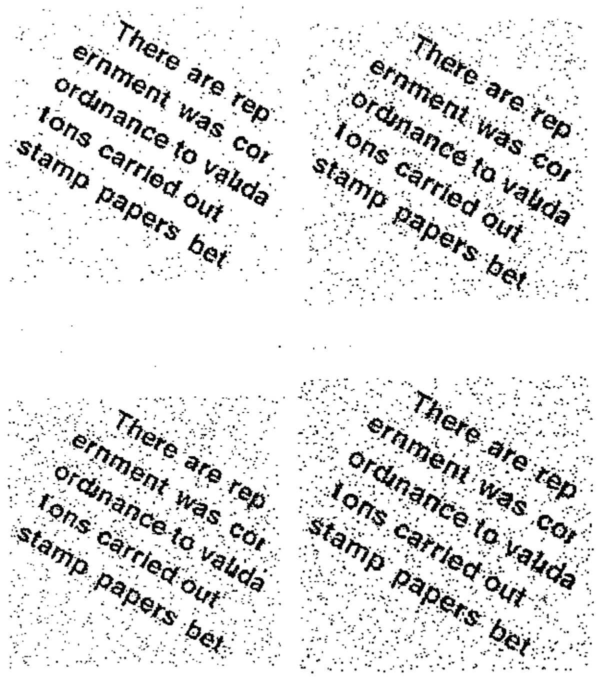
Experiments are conducted on different types of documents as shown in Fig. 5 (a) to Fig. 5 (d) and the computed skew angles using the proposed methods as well as the existing methods are given in Table 3.

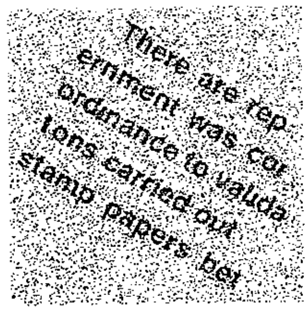



(a) Samples of different language document images

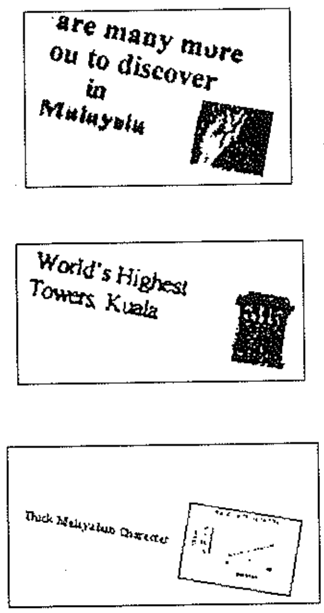



(b) Samples from different journal paper documents




(c) Samples of noisy image

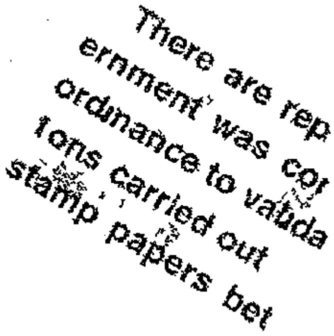



**(d) Different text with picture documents**

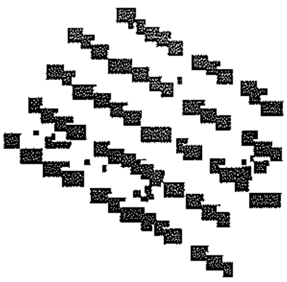
**Fig. 5 Different document images**

However the proposed method fails if the noise in the document increases. This is because of average height method, which removes only small dots. To illustrate this we have conducted experiments and shown in Fig. 6 and Fig. 7. Based on experimental results we have tabulated the values in Table 7 and the graphical representation is shown in Fig. 8. From Table 7 and Fig. 8, it is noticed that the proposed method works for the noise documents up to 0.05 level densities but not beyond.

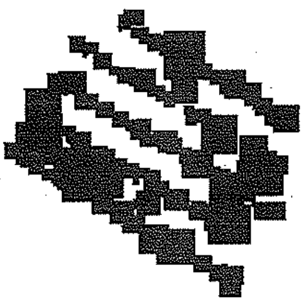
(a) A document with 0.06 noise density



(b) Noise less image

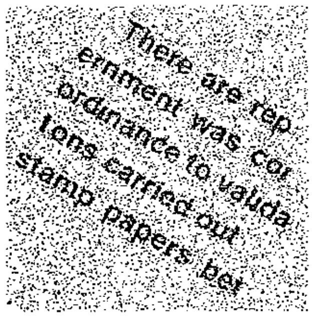


(c) Height normalized document

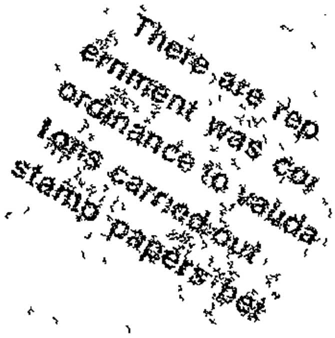


(d) BGM fails

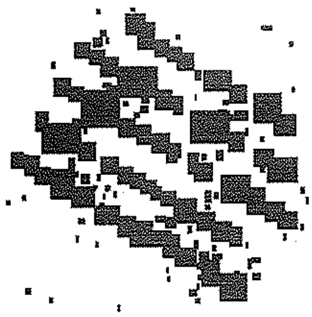
**Fig. 6 BGM fails for 0.06 level noise density document**



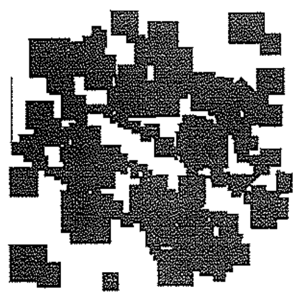
(a) 0.07 noise density



(b) Noise less image



(c) Height normalized document



(d) BGM fails

**Fig. 7 BGM fails for 0.07 level noise density document**

**Table 7 Performance of the proposed method with different noise densities**

| Noise Density | Known Angle | Computed Angle | Performance (%) | Remarks |
|---|---|---|---|---|
| 0.01 | 30 | 30.05 | 99.83 | Algorithm Works |
| 0.02 | 30 | 30.12 | 99.60 | |
| 0.03 | 30 | 30.02 | 99.93 | |
| 0.04 | 30 | 29.54 | 98.4 | |
| 0.05 | 30 | 29.96 | 99.8 | |
| 0.06 | 30 | 14.02 | 46.73 | Performance Degrades |
| 0.07 | 30 | 14.89 | 49.63 | |

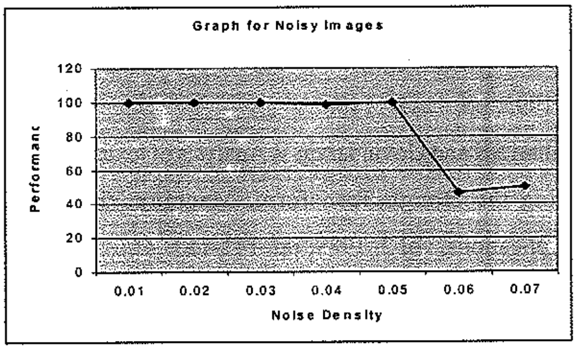



**Fig. 8 The method fails after 0.05 level noise densities**

An experiment has also been conducted on different resolution documents and the performance of the proposed method does not degrade even for different resolution document. The computed skew angle using the proposed method and other methods is given in Table 4. The overall summary of the discussion is given in Table 5 and Table 6.

From Table 5 and 6 it is observed that the proposed method is suitable and superior when we compared with the existing methods in terms of relative error, variations and time. This is mainly because of the following the advantages.

- The method ignores some characters like dot, comma and colon using average height method.
- It converts the height of the capital letter to an average height of the character in the text line since the skew angle is estimated based on average height of the characters.
- The method uses only two or three text lines in estimating the skew angles and the method considers one text line at a time to estimate the skew angle instead of considering coordinates of all the characters of the whole document.
- The method is language and size independent.

## 6. CONCLUSION

In summary, an efficient and novel methodology to estimate skew angle is presented in this paper. The proposed methods work based on boundary growing and Radon transform. To study the performance of the proposed method we used decision parameters such as Mean Skew angle, Standard Deviation and Mean time. The experimental results revealed that the proposed method gives better results for all types of documents compared to results of existing methods.

## References

Akiyama T and Hagita N, Automated entry system for printed documents, Pattern Recognition, Vol. 23, No. 11, 1990, pp 1141-1158.

Baird H.S, The Skew Angle of Printed Documents, Proceedings of Conference Society of Photographic Scientists and Engineers, Rocherster, New York, 1987, pp 14-21.

Hashizume A Yeh P S and Cosenfeld A, A Method of Detecting the Orientation of Aligned Components, Pattern Recognition Letters, Vol. 4, April 1986, pp 125-132.

Hinds, S. C, Fisher J L and D'Amato D P, A Document Skew detection method using run-length encoding and the Hough transform. In Proc. International conference on Pattern Recognition, Volume I, 1990, pp 464-468.

Hou H S, Digital document processing. New York, John Wiley, 1983.

Hull J J, Document image skew detection: Survey and annotated bibliography, Document Analysis System II, J J Hull, S L Taylor, Ed. World Scientific, pp 40-64, 1998.

Jain A.K., Fundamentals of Digital Image Processing, Prentice-Hall of India, 2002.

Le D S, Thoma G R and Wechsler H, Automatic page orientation and skew angle detection for binary document images. Pattern Recognition 27, 1994, pp 1325-1344.

Liolios, Fakotakis N and Kokkimakis G, On the generalization of the form identification and skew detection problem, Pattern Recognition 35, 2002, pp 253-264.

Liu j, Lee C.M, Shu R.B, An efficient method for the skew normalization of a document image. 11th International conference on Pattern Recognition, 1992, pp. 152-155.

O'Gorman L, The document spectrum for page layout analysis, IEEE Transactions on Pattern Analysis and machine Intelligence, No 15, vol 11, 1993, pp. 1162-1173.

Pal U and Chaudhuri B. B, An Improved document skew angle estimation technique, Pattern Recognition Letters, Vol. 17, 1996, pp 899-904.

Pavlidis T and Zhou J, Page segmentation by white streams, Proceedings of first International Conference on Document Analysis and Recognition (ICDAR), France, September 30, October 2, 1991, pp 945-953.

Postl W, Detection of linear oblique structures and skew scan in digitized documents. Proceedings 8th International Conference on Pattern Recognition, 1986, pp. 687-689.

Smith R, A simple and efficient skew detection algorithm via text row accumulation, Proceedings 3rd International Conference on Document Analysis and Recognition, vol 2, 1995, pp. 1145-1148.

Srihari SN and Govindaraju V, Analysis of textual images using the Hough Transform, Machine Vision and Applications, vol 2, 1989, pp. 141-153.

Yan, H. Skew correction of document images using interline cross-correlation, Computer Vision, Graphics, and Image Processing 55, 1993, pp 538-543.

Yue Lu and Chew Lim Tan, A nearest neighbor chain based approach to skew estimation in document images, Pattern Recognition Letters 24, 2003, pp 2315-2323.

**Table 2 (a) Computed mean, standard deviation and computing time using proposed method and the other methods to measure Accuracy, consistency and efficiency**

| True angle in degrees | Akiyama & Hagita (1990) | | | Pavlidis & Zhau (1992) | | | Hashizume et al (1986) | | | Srihari and Govindaraju (1989) | | | Le et al. (1994) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | CT (s) | M | SD | CT (s) | M | SD | CT (s) | M | SD | CT (s) | M | SD | CT (s) |
| 3 | 7.3 | 2.86 | 1.16 | 3.15 | 0.761 | 1.28 | 3.54 | 0.545 | 2.2 | 3.2 | 0.3 | 13.66 | 3.150 | 0.365 | 2.32 |
| 5 | 8.04 | 2.12 | 1.16 | 5.28 | 1.543 | 1.28 | 4.8 | 0.649 | 2.15 | 5.59 | 0.548 | 14.06 | 5.35 | 0.426 | 2.31 |
| 10 | 12.19 | 1.761 | 1.16 | 11.2 | 1.949 | 1.28 | 8.05 | 1.246 | 1.83 | 12.88 | 1.456 | 13.13 | 10.125 | 0.416 | 2.21 |
| 15 | 15.94 | 1.44 | 1.16 | 14.76 | 2.135 | 1.28 | 15.82 | 1.14 | 1.95 | 15.72 | 0.826 | 11.19 | 15.18 | 0.496 | 2.42 |
| 20 | 22.6 | 1.562 | 1.16 | 19.14 | 3.13 | 1.28 | 20.78 | 0.901 | 1.96 | 18.9 | 0.749 | 12.04 | 20.17 | 0.398 | 2.10 |
| 30 | 32.7 | 1.769 | 1.16 | 27.5 | 2.256 | 1.28 | 27.8 | 1.469 | 2.03 | 30.02 | 0.994 | 11.36 | 30.5 | 0.856 | 2.61 |
| 40 | 40.2 | 2.02 | 1.16 | 36.2 | 2.866 | 1.28 | 43.19 | 1.558 | 2.01 | 40.9 | 0.618 | 11.17 | 40.21 | 0.358 | 2.68 |
| 45 | 45.9 | 0.99 | 1.16 | 46.16 | 3.257 | 1.28 | 45.95 | 0.6449 | 2.03 | 45.3 | 0.462 | 10.5 | 45.15 | 0.926 | 2.59 |

**Table 2 (b) Continuation to Table 2 (a)**

| True angles in degree | Pal and Chaudhari (1996) | | | Yan (1993) | | | Lu and Tan (2003) | | | Proposed Method | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | CT (s) | M | SD | CT (s) | M | SD | CT (s) | M | SD | CT (s) |
| 3 | 3.128 | 0.348 | 2.12 | 3.439 | 0.9488 | 2.49 | 3.868 | 0.819 | 2.28 | 3.200 | 0.102 | 0.95 |
| 5 | 5.68 | 0.451 | 1.98 | 5.0955 | 1.0401 | 2.48 | 5.7124 | 0.958 | 2.31 | 4.855 | 0.336 | 0.98 |
| 10 | 10.17 | 0.425 | 2.38 | 10.191 | 0.8201 | 2.492 | 10.7363 | 0.798 | 2.22 | 10.025 | 0.317 | 0.88 |
| 15 | 15.72 | 0.51 | 2.12 | 15.358 | 0.936 | 2.501 | 15.5330 | 0.517 | 2.29 | 15.425 | 0.305 | 0.95 |
| 20 | 20.11 | 0.722 | 2.38 | 20.439 | 0.8376 | 2.685 | 20.97 | 0.801 | 2.58 | 20.00 | 0.376 | 0.90 |
| 30 | 30.32 | 1.42 | 2.18 | 30.847 | 0.9717 | 2.48 | 30.174 | 0.521 | 2.58 | 29.750 | 0.475 | 0.94 |
| 40 | 40.42 | 0.719 | 2.17 | 40.382 | 0.846 | 2.369 | 39.474 | 0.664 | 2.40 | 40.10 | 0.236 | 0.99 |
| 45 | 45.2 | 0.86 | 2.32 | 44.422 | 0.6399 | 2.589 | 45.927 | 0.530 | 2.69 | 45.005 | 0.255 | 0.95 |

**Table 3 Computed mean skew angle for different documents with $10^0$ true skew angles**

| Cases | Existing methods | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Akiyama & Hagita (1990) | Pavlidis & Zhau (1992) | Hashizume et al (1986) | Srihari and Govindaraju (1989) | Le et al. (1994) | Pal and Chaudhari (1996) | Yan (1993) | Lu and Tan (2003) | Proposed method |
| Different Language | 39.11 | 43 | 24 | 11 | 11.5 | 11.5 | 7.63 | 10.963 | 10.001 |
| Noise | 27 | 31 | 0 | 11 | 9.5 | 9.5 | 11.921 | 9.236 | 10.21 |
| Text Book | 29 | 25 | 12.1 | 10.5 | 11 | 10.5 | 10.326 | 10.459 | 10.02 |
| Journal | 3.58 | 2.7 | 35 | 12 | 10.5 | 11 | 11.021 | 10.679 | 9.99 |
| Text with Picture | 71 | 81 | 0 | 45 | 1.7 | 38 | 16.796 | 14.719 | 11.23 |

**Table 4 Computed skew angles using proposed and existing methods for different dpis of $23^0$**

| Resolution | Existing methods | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Akiyama & Hagita (1990) | Pavlidis & Zhau (1992) | Hashizume et al (1986) | Srihari and Govindaraju (1989) | Le et al. (1994) | Pal and Chaudhari (1996) | Yan (1993) | Lu and Tan (2003) | Proposed method |
| 75 | 22.12 | 23 | 90 | 18.5 | 23 | 23.5 | 26.75 | 23.96 | 22.86 |
| 100 | 46 | 45 | 21 | 17.5 | 22.5 | 23.5 | 24.21 | 23.02 | 23.14 |
| 150 | 29 | 38 | 21 | 4.5 | 23 | 23 | 21.65 | 22.89 | 23.65 |
| 300 | 41 | 44 | 19 | 22.5 | 23 | 23 | 26.08 | 23.86 | 23.12 |
| 400 | 75 | 90 | 0 | 48 | 22.5 | 23.5 | 24.06 | 23.59 | 23.44 |

**Table 5 Summarized performance of the proposed methods and existing methods for different types of document images**

| Methods | Text Images | | | Different languages | | | Noise Image | | | Synthetic images | | | Text books | | | Journal images | | | Text with Picture Doc. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Relative error% | SD | ACT (s) | Relative error % | SD | CT (s) | Relative error % | SD | CT (s) | Relative error % | SD | CT (s) | Relative error % | SD | CT (s) | Relative error % | SD | CT (s) | Relative error % | SD | CT (s) |
| Akiyama and Hagita (1990) | 32.07 | 0.99-2.86 | 1.16 | 291 | 3.9 | 1.71 | 170 | 3.89 | 1.69 | 350 | 4.6 | 1.69 | 190 | 1.71 | 1.9 | 64.2 | 5.12 | 1.8 | 610 | 5.6 | 2.26 |
| Pavlidis and Zhau (1992) | 6.1 | 0.70-3.2 | 1.28 | 330 | 4.4 | 1.69 | 210 | 2.36 | 1.7 | 20 | 2.4 | 1.6 | 150 | 4.46 | 7 | 73 | 6.6 | 1.9 | 710 | 2.6 | 2.01 |
| Hashizume et al., (1986) | 8.5 | 0.5-1.5 | 2.03 | 140 | 2.33 | 2.41 | 100 | 1.87 | 2.1 | 10 | 1.01 | 2.01 | 21 | 1.49 | 1.96 | 250 | 8.6 | 1.82 | 100 | 2.25 | 2.9 |
| Srihari and Govindaraju (1989) | 7.5 | 0.3-1.45 | 12.13 | 10 | 0.89 | 13.6 | 10 | 0.82 | 13.1 | 0 | 0.42 | 12.9 | 5 | 0.61 | 12.1 | 20 | 0.56 | 12.23 | 350 | 2.23 | 13.9 |
| Le et al., (1994) | 2.2 | 0.35-0.85 | 2.405 | 15 | 0.65 | 2.67 | 5 | 0.54 | 2.67 | 5 | 0.3 | 2.79 | 10 | 0.56 | 1.99 | 5 | 0.45 | 2.9 | 83 | 5.6 | 3.00 |
| Pal and Chaudhuri (1996) | 3.42 | 0.3-1.42 | 2.2 | 10 | 0.33 | 2.8 | 5 | 0.42 | 2.39 | 0 | 0.2 | 2.41 | 5 | 0.36 | 2.54 | 10 | 0.39 | 2.53 | 280 | 4.69 | 2.24 |
| Yan (1993) | 3.543 | 0.63-1.04 | 2.50 | 23.7 | 4.215 | 2.49 | 19.12 | 1.256 | 2.501 | 2.16 | 0.798 | 2.48 | 3.2 | 0.758 | 2.49 | 10.2 | 1.0125 | 2.44 | 67.96 | 5.369 | 2.65 |
| Lu and Tan (2003) | 7.63 | 0.51-2.69 | 2.41 | 9.6 | 1.024 | 2.321 | 7.64 | 0.891 | 2.24 | 2.06 | 0.714 | 2.23 | 4.59 | 0.652 | 2.20 | 6.79 | 0.689 | 2.34 | 47.19 | 3.124 | 2.51 |
| Proposed Method | 2.04 | 0.1-0.4 | 0.95 | 3.012 | 0.51 | 0.94 | 2.60 | 0.13 | 0.94 | 1.1 | 0.01 | 0.97 | 2.25 | 0.24 | 0.99 | 1.45 | 0.31 | 0.98 | 5.36 | 2.35 | 1.10 |

**Table 6 Summarized performance of the proposed method and existing method for different resolution documents**

| Methods | 75 DPI | | | 100 DPI | | | 150 DPI | | | 300 DPI | | | 400 DPI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Relative error % | S.D | CT (s) | Relative error % | S.D | CT (s) | Relative error % | S.D | CT (s) | Relative error % | S.D | CT (s) | Relative error % | S.D | CT (s) |
| Akiyama and Hagita (1990) | 3.82 | 3.45 | 1.68 | 100 | 4.47 | 1.71 | 26.08 | 3.79 | 1.6 | 78.26 | 2.79 | 1.6 | 226 | 4.41 | 1.69 |
| Pavlidis and Zhau (1992) | 0 | 4.47 | 1.69 | 100 | 3.97 | 1.68 | 65.21 | 2.69 | 1.91 | 91.3 | 2.05 | 1.71 | 291 | 2.25 | 1.71 |
| Hashizume et al., (1986) | 291.3 | 7.1 | 2.1 | 8.69 | 2.5 | 2.62 | 8.69 | 1.89 | 2.73 | 17.39 | 2.26 | 2.76 | 100 | 3.16 | 2.79 |
| Srihari and Govindaraju (1989) | 19.56 | 2.1 | 10.33 | 23.9 | 1.9 | 10.11 | 80.04 | 2.23 | 10.91 | 2.17 | 0.89 | 12.69 | 108 | 3.51 | 16.14 |
| Le et al., (1994) | 0 | 0.61 | 2.91 | 2.17 | 0.75 | 2.89 | 0.35 | 0.5 | 12.61 | 3.28 | 0.51 | 2.89 | 2.17 | 0.61 | 2.8 |
| Pal and Chaudhuri (1996) | 2.17 | 0.48 | 2.58 | 2.17 | 0.4 | 2.37 | 0.15 | 0.75 | 2.31 | 3.25 | 0.23 | 2.1 | 2.17 | 0.5 | 2.3 |
| Yan (1993) | 16.30 | 2.013 | 2.425 | 5.2 | 0.98 | 2.5 | 5.86 | 0.589 | 2.49 | 13.39 | 0.689 | 2.51 | 4.6 | 1.023 | 2.59 |
| Lu and Tan (2003) | 4.17 | 0.568 | 2.314 | 0.08 | 0.651 | 2.30 | 0.47 | 0.356 | 2.48 | 3.7 | 0.702 | 2.35 | 2.5 | 0.799 | 2.30 |
| Proposed Method | **0.54** | **0.11** | **0.86** | **0.33** | **0.23** | **0.90** | **0.51** | **0.12** | **0.98** | **2.01** | **0.32** | **0.96** | **2.01** | **0.22** | **0.99** |

**V. N. Manjunath Aradhya** obtained M.S in Computer Systems from the University of Mysore, Mysore in the year 2004. He has published around 25 research papers in various Journals, International and National Conference proceedings. Currently he is working has a Research Scholar in Department of Studies in Computer Science, University of Mysore, Mysore. He is working on Development of Universal OCR for Indian and Foreign Languages. His areas of Interest are Pattern Recognition, Digital Image Processing, Document Image Analysis, and Biometrics.

**G. Hemantha Kumar** obtained M.Sc and Ph.D in Computer Science from the University of Mysore in the year 1988 and 1998 respectively. He has published around 130 research papers in various Journals, international and National Conference proceedings. He has successfully guided two Ph.D candidates and two M.Sc Tech (by research) candidates. Currently he is guiding 6 Ph.D candidates and 4 M.Sc Technology by research candidates. He has delivered talk at many Universities in India and Abroad. His research focuses on Pattern Recognition and Image Processing, Document analysis, Speech Processing, Computer Network and Simulation. He is currently Reader and Chairman at Department of Studies in Computer Science, University of Mysore, Mysore.

**P. Shivakumara** obtained M.Sc, M.Sc Tech (by research) and Ph.D in Computer Science from the University of Mysore in the year 1998, 2001 and 2005 respectively. He has published around 90 research papers in various Journals, International and National Conference proceedings. Currently he is working has a Post Doctoral Research Fellow in National University of Singapore, Singapore. His research interest focuses on Pattern Recognition and Image Processing, Document Analysis, and Multimedia.