

STUDY ON THE OPTIMIZATIONS OF THE HOUGH TRANSFORM FOR IMAGE LINE DETECTION

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ABSTRACT

Skew detection for scanned documents is an important field of research, of great interest for both academic and commercial environments. The Hough transform has been established as the standard for accurate skew detection, thanks to its high accuracy and mathematical soundness. Unfortunately, this high accuracy comes with a high time penalty, and thus the search for speed improvements that do not reduce accuracy is on. The present article will present an impartial comparison of the proposed methods and point out each method strong and weak points.

Keywords: skew detection, deskew, Hough transform, OCR

1. INTRODUCTION

Thanks to technological development and the emergence of the Internet, both data supply and demand have grown considerably. One of the simplest ways of exchanging information is through the scanning and transfer of printed documents. Thanks to improvements in scanning technology, storage capacity, and Internet connectivity more and more digital documents are available online.

Many of these digital documents are then processed by OCR (Optical Character Recognition) and ICR (Intelligent Character Recognition) algorithms. These algorithms consist in translation of scanned images of handwritten, typewritten or printed text into machine-encoded text.

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For a proper processing of documents, the input to these algorithms should produce errors as small as possible. The causes for errors for these algorithms include skewed scanned documents, fuzzy and noisy images.

Skew detection and correction is a part of preprocessing stage [7] [8] [9] [10], stage which affects the performance of an OCR system significantly if not detected and corrected properly. A skew angle of a few degrees has a significant effect on these algorithms and thus it is important to accurately estimate and eliminate the effects of the skew.

The big problem of the skew algorithms is that usually an error free algorithm is time consuming, and a fast algorithm has a low accuracy, so usually it has to be “give-and-take” between these two problems.

Several skew detection and correction algorithms have been extensively discussed in the research literature.

The most popular strategies applied while developing these algorithms are: the projection-profile based, the Hough transform based, the nearest-neighborhood based, the morphological operation based, and the spatial cross correlation.

2. THE HOUGH TRANSFORM

The Hough transform can be used to detect lines at any orientation. One of the methods consists of mapping points in Cartesian space (xy) to sinusoidal curves in $(\rho\theta)$ space, via the transformation:

$$\rho = x \cos(\theta) + y \sin(\theta) \quad (1)$$

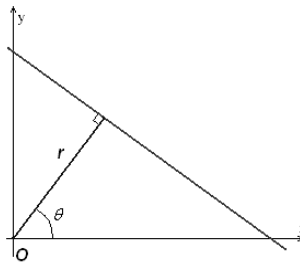


Fig. 1

We start with the equation for a straight line:

$$y = mx + b \quad (2)$$

This may be rewritten as:

$$y = \left(-\frac{\cos \theta}{\sin \theta} \right) x + \left(\frac{\rho}{\sin \theta} \right). \quad (3)$$

This is finally brought to:

$$\rho = x \cos(\theta) + y \sin(\theta). \quad (4)$$

Where

ρ : Length of the segment that starts in the origin and is perpendicular to our line

θ : Angle between ρ and ox

Each time a sinusoidal curve intersects another at a particular value of ρ and θ , the likelihood increases that a line corresponding to that (ρ, θ) coordinate value is present in the original image.

An accumulator array (consisting of R rows and T columns) is used to count the number of intersections at various ρ and θ values. Those cells in the accumulator array with the highest number of counts will correspond to lines in the original image.

The basic computational steps in the Hough transform are as follows:

```

for (x)
    for (y)
        if (pixel is black)
            for ( $\theta$ )
                 $\rho = x \cos(\theta) + y \sin(\theta)$ 
                increment accumulator array at  $(\rho, \theta)$ 

```

The maximum error when detecting the skew angle depends on the step with which θ is incremented. The number of lines, R, of the accumulator affects the way in which the Hough transform detects the lines; thus, in order to detect fine lines, R would need to be:

$$R = \sqrt{w^2 + h^2}, \quad (5)$$

where w : width, h : height.

I. Summary of Hough Transformation

The line detection in a binary image using the Hough transform algorithm can be summarized as follows:

- 1) Define the Hough transform parameters: $\rho_{\min}$, $\rho_{\max}$, $\theta_{\min}$, $\theta_{\max}$
- 2) Quantize the ρ - θ plane into cells by forming an accumulator cells array $A(\rho_i, \theta_i)$ where ρ_i is between $\rho_{\min}$ and $\rho_{\max}$, θ_i is between $\theta_{\min}$ and $\theta_{\max}$.
- 3) Initialize each element of an accumulator cells array A to zero.
- 4) For each black pixel in a binary image, perform the following:
 - a) For each value of calculate the corresponding ρ_i using the following equation:
 - b) $i = x * \cos\theta_i + y * \sin\theta_i$.
 - c) Round off the ρ_i value to the nearest interval value.
 - d) Increment the accumulator array element $A(\rho_i, \theta_i)$.
- 5) *Detect best line candidates as local maxima in the accumulator cell array.*

The computational performance of the Hough transform algorithm can be determined by analyzing equation (4). To increase the speed of the Hough transform, the amount of data points to be processed in a binary image should be reduced. This results in a sparsely populated Hough accumulator array from which we find an estimate of the skew angle to the nearest 1° using the realignment measure.

II. The pseudo code for the algorithm for a dataset reduced

Create a two-dimensional matrix Hough and initialize the values with zero

```

for  $i = 0$  to Number of Points selected - 1
  for  $\theta = 0$  to (Difference Range * step)
    Compute  $\rho = (y * \cos(\theta) + x * \sin(\theta))$ 
    Increment  $matrHough[\rho][\theta] += weight(pixel\ i)$ 
  next  $\theta$ 
next  $i$ 
Find the  $(\theta, \rho)$  pairs that have the highest count in the Hough matrix
Calculate the skew angle as an average of the  $\theta$ 
Rotate the image by - skew angle

```

3. COMPLEXITY OF THE HOUGH TRANSFORM

Algorithms based on the Hough transform are usually robust. The major problem is the necessary processing time; therefore this problem is solved by data reduction (minimizing the number of black pixels in the image that will be considered by the algorithm).

It is also necessary to keep in mind that documents may be affected by noise and that they may also contain pictures and tables. Several factors influence the speed and accuracy with which a skew angle is detected. The more data used the better results and the greater the processing time will be. It is also very important to remove images and noise from the data, as well as the algorithm's own inherent complexity.

This paper proposes an efficient data reduction method to enhance the performance of document skew estimation by using Hough transformation. The time complexity of Hough

transformation is $O(\theta N)$, where N is the number of black pixels in a document and θ is the skew estimation range. We might enhance the performance by reducing N or θ .

The proposed method uses an efficient data reduction method, which reduces the number of black pixels N , while retaining the skew angle of document. In order to show the superiority of the proposed method, we have also performed experiments with scanned documents, comparing the result with those of the usual data reduction methods: vertical run-length and connected component methods.

It is clear that the time complexity of the Hough transform is of the order $O(N\theta)$ where N is the number of image pixels (the algorithm uses binary documents and treats black pixels as image pixels), and θ is taken 90 for both parts of the slope.

The initial process of using every pixel on the page as data for the Hough transform algorithm leads to excellent results, as we can see in the section of experimental results, but is very time intensive, especially when one considers that for this application we are using A3 or A4 pages sampled at 300 dpi. Equivalent results can be obtained more efficiently by sub sampling the original document before using the Hough transform. [1]

4. OPTIMIZATIONS

Algorithms based on the Hough transform are very accurate; however they are very slow when applied to the entire image, making the way we choose the pixels to which this transform will be applied a very important part of any Hough transform based algorithm.

I. Accelerating the speed of the Hough transform

One of the most attractive features of the Hough transform is its simplicity. It has been retained the basic form of the Hough transform optimizing some steps in its implementation. The following features have been added to enhance the speed:

A. Integer Implementation

All calculations are performed using integer arithmetic, which increases the speed significantly. The accuracy of integer operations is maintained to the nearest integer results of float operations. This approach did not result in a significant speed up. [1]

B. Optimization of operations

Many repetitive operations, which fall under nested loops, are pre-computed and stored in the arrays. This reduces the number of calculations. Calculation of the functions "sin" and "cos" for the range of angles for which was performed Hough outside the main loop where the Hough matrix was formed. [1]

C. Use of pointers to access 2D array elements

Wherever necessary, pointers have been used to access elements of 2D array whose access otherwise is very time consuming. [1]

D. Use of reduced number of image pixels

In order to reduce image pixel significantly various methods of selecting points are used. This it is described in the next section.

E. Code modularization

The modularization of the code makes an easier change of the input datasets (for example instead of gray selection using all points or more points) but also the range of skew angle and the search step.

F. Translate a part of the image in origin

In order to translate the part of the image it is applied Hough transformation: for example for processing (500, 500, 1000, 1000), calculations should start from (0, 0, 500, 500), so as the matrix won't have dimensions 1000x1000.

II. Methods of data reduction for efficient skew estimation

As explained in the previous section, the time complexity of Hough transformation for a document is $O(\theta N)$. Therefore skew estimation algorithm using Hough transformation can be improved by N or θ . There have been several investigation to reduce N .

One is called the run-length encoding method. It uses vertical runs of a document, and makes the end points of each run have the length of the run and any other points have 0. This method has very low reduction rate because it only reduces the thickness of characters into one pixel for even a less skewed document and has the difficulty at accurate skew estimation. This was implemented by attributing an incremented pound for each new black pixel (x, y) that was discovered in the vertical run of the document. [4]

Another method used frequently collects the center or middle points of the base line of connected components encompassed rectangle. In this method, all points of one text line generally come together as a line, thereby having high reduction rate.

However this algorithm takes too much time to obtain connected components and requires much space and reduces a horizontal line which is a single connected component and is critical to estimate skew of table-form document into a point. This was achieved by calculating the center of the bounding rectangle of each connected component. [4]

Another method of reduction is selection of the contour. Practically, the selection of the contours was realized by summing all segments of the connected components at the boundary (the most right, the most left, the lowest, and the highest).

One of the best data reduction method was selecting the bottom pixels, practically, the last row of pixels of a connected component. The objects bottom pixels are black pixels that belonged to the last black run-lengths in the bottom row of the object. Figure 3 shows an object of a binary image and its object bottom pixels. These black pixels belong to the last two black run-lengths in row. [7]

The fastest method of point reduction is BAG algorithm (block adjacency graph) [1]. This method calculates the middle point for each block of bonding boxes (each word). This is rather a precise method for reduction of points, but the errors are bigger than *Bottom pixels* or *Middle points* for every bounding box.

Some other methods of reduction of data are resampling and the selection of a significant rectangle. These are described below.

III. Downsampling

The first step was to apply the following filter:

- delete everything that is less than 5 pixels height (the minimum space for representing the simplest letter: "e")
- delete everything that is less than $\frac{x_{dpi}}{50.8}$ (the minimum space for representing the smallest readable character: 0.5 mm)

The resolution of the document image was reduced from 300 to 75 dots per inch (dpi) in order to increase the speed of our skew detection procedure. After that, the ratio between time and accuracy of the angle it is observed. [5]

IV. Selection of a significant rectangle from the image

Selection of an area from the image that contains only text, preferably long lines of text, should be enough to find out the skew angle after applying the algorithm only on this area.

The evident advantage is that this area is 10% from the height of the image which means speed up to 10X. The problem is whether the area is significant and contains only text. This will reduce the time needed for processing the input image.

In conclusion, by methods of data reduction, the number of black pixels is significantly reduced as compared to the original image. (For typical text documents digitized at 300 pixels per inch, we observe a reduction in the black pixel count by slightly more than a factor of two.

This reduction factor increases with the non-text area populations, and is typically a factor of 1 for average newspaper pages with a mixture of pictures and text).

5. TEST EXECUTION

The next table presents the results of the execution using different pictures with different skew angles and different methods of point selection. The columns have the following header:

- the first column is the name of the picture
- the second column represents the resolution of the picture which is directly proportional with the processing time
- the third column is the correct skew angle of the processed image

- the rest of the columns represent the results obtained for the following methods of selection: all points selected, grayscale selection, entities contour selection, middle square selection, bottom row selection

For each method of point selection it can be chosen the sensitivity of the Θ angle. In addition, the skew angle can be calculated in one or multiples steps. This increases the speed of the execution, but may decrease the correctness.

The tests are executed in two steps: the first step uses a bigger angle (one degree) and the second step uses an angle refined.

Each row of the table describes the results obtained for a different picture. Downsampled $n\%$ means that the previous picture was down sampled with a certain degree and all the tests were executed again on this picture.

The aim is to decrease the speed and to verify if the calculation of the angle remains accurate.

The angle Θ and the error $\Delta\Theta$ are expressed in degrees. T means the time of the execution and is expressed in milliseconds.

Img. Name	Img. Res.	Skew	BAG selection (1;0.01)	Img. Name	Img. Res.	Skew	BAG selection (1;0.01)
true 0040 0.4	1180 X 1968	-0.4	$\Theta=-0.19$ $\Delta\Theta=0.21$ T=0.67	truea 0040 5.0	1312 X 2044	-5.0	$\Theta=-5.01$ $\Delta\Theta=0.01$ T=0.57
true 0040 0.7	1190 X 1974	-0.7	$\Theta=-0.67$ $\Delta\Theta=0.03$ T=0.64	truea 0040 8.6	1446 X 2112	-8.6	$\Theta=-8.79$ $\Delta\Theta=0.19$ T=0.60
true 0040 1.0	1200 X 1980	-1.0	$\Theta=-0.95$ $\Delta\Theta=0.05$ T=0.64	truea 0042 3.0	1814 X 2240	-3.0	$\Theta=-3.18$ $\Delta\Theta=0.18$ T=0.5
true 0040 1.32	1210 X 1986	1.32	$\Theta=1.32$ $\Delta\Theta=0$ T=0.53	truea 0042 4.4	1864 X 2324	-4.4	$\Theta=-4.75$ $\Delta\Theta=0.35$ T=0.51
truea 0040 3.0	1266 X 2018	-3.0	$\Theta=-2.79$ $\Delta\Theta=0.21$ T=0.57	truea 0042 5.0	1886 X 2340	-5.0	$\Theta=-5.13$ $\Delta\Theta=0.13$ T=0.51
truea 0040 4.4	1312 X 2044	-4.4	$\Theta=-4.4$ $\Delta\Theta=0$ T=0.60	truea 0042 8.6	2010 X 2430	-8.6	$\Theta=-8.4$ $\Delta\Theta=0.2$ T=0.56

Table 1. Execution results for BAG point reduction

Img. Name	Im g. Res	Ske w	All points (1;0.01)	Gray (1;0.01)	Gray (1;0.5)	Gray (1;0.1)	Conto ur (1;0.01)	Middle square (1;0.01)	Botto m row (1;0.01)
true 0040 0.4	118 0 X 196 8	-0.4	$\Theta=0.02$ $\Delta\Theta=0.42$ $T=15.89$	$\Theta=-0.39$ $\Delta\Theta=0.01$ $T=9.84$	$\Theta=-0.4$ $\Delta\Theta=0$ $T=4.11$	$\Theta=-0.4$ $\Delta\Theta=0$ $T=3.39$	$\Theta=-0.39$ $\Delta\Theta=0.01$ $T=29.51$	$\Theta=-0.39$ $\Delta\Theta=0.01$ $T=1.07$	$\Theta=-0.40$ $\Delta\Theta=0$ $T=1.89$
Down - sampl ed 25%	295 X 492	-0.4	$\Theta=-0.31$ $\Delta\Theta=0.09$ $T=1.62$	$\Theta=-0.52$ $\Delta\Theta=0.12$ $T=1.79$	$\Theta=-0.5$ $\Delta\Theta=0.1$ $T=0.60$	$\Theta=-0.5$ $\Delta\Theta=0.1$ $T=0.48$	$\Theta=-0.61$ $\Delta\Theta=0.21$ $T=2.18$	$\Theta=-0.42$ $\Delta\Theta=0.02$ $T=0.12$	$\Theta=-0.61$ $\Delta\Theta=0.21$ $T=0.32$
true 0040 0.7	119 0 X 197 4	-0.7	$\Theta=0.02$ $\Delta\Theta=0.72$ $T=17.68$	$\Theta=-0.68$ $\Delta\Theta=0.02$ $T=10.21$	$\Theta=-0.75$ $\Delta\Theta=0.05$ $T=4.65$	$\Theta=-0.7$ $\Delta\Theta=0$ $T=3.62$	$\Theta=-0.04$ $\Delta\Theta=0.66$ $T=31.95$	$\Theta=-0.68$ $\Delta\Theta=0.02$ $T=0.92$	$\Theta=-0.04$ $\Delta\Theta=0.66$ $T=2.20$
Down - sampl ed 25%	298 X 494	-0.7	$\Theta=-0.62$ $\Delta\Theta=0.08$ $T=1.76$	$\Theta=-0.6$ $\Delta\Theta=0.1$ $T=1.79$	$\Theta=-0.6$ $\Delta\Theta=0.1$ $T=0.60$	$\Theta=-0.6$ $\Delta\Theta=0.1$ $T=0.48$	$\Theta=-0.63$ $\Delta\Theta=0.07$ $T=2.26$	$\Theta=-0.72$ $\Delta\Theta=0.02$ $T=0.14$	$\Theta=-0.66$ $\Delta\Theta=0.04$ $T=0.34$
true 0040 1.0	120 0 X 198 0	-1.0	$\Theta=0.02$ $\Delta\Theta=1.02$ $T=18.92$	$\Theta=-1.03$ $\Delta\Theta=0.03$ $T=9.95$	$\Theta=-0.95$ $\Delta\Theta=0.05$ $T=4.07$	$\Theta=-0.9$ $\Delta\Theta=0.10$ $T=3.43$	$\Theta=-1.03$ $\Delta\Theta=0.03$ $T=29.67$	$\Theta=-1.03$ $\Delta\Theta=0.03$ $T=0.92$	$\Theta=-0.97$ $\Delta\Theta=0.03$ $T=1.93$
Down - sampl ed 25%	300 X 495	-1.0	$\Theta=-0.82$ $\Delta\Theta=0.18$ $T=1.62$	$\Theta=-1.1$ $\Delta\Theta=0.1$ $T=1.78$	$\Theta=-1.1$ $\Delta\Theta=0.1$ $T=0.62$	$\Theta=-1.1$ $\Delta\Theta=0.1$ $T=0.48$	$\Theta=-0.99$ $\Delta\Theta=0.01$ $T=2.37$	$\Theta=-0.96$ $\Delta\Theta=0.04$ $T=0.12$	$\Theta=-1.15$ $\Delta\Theta=0.15$ $T=0.37$
true 0040 1.32	121 0 X 198 6	1.32	$\Theta=0.02$ $\Delta\Theta=1.3$ $T=20.51$	$\Theta=1.34$ $\Delta\Theta=0.02$ $T=10.04$	$\Theta=1.35$ $\Delta\Theta=0.03$ $T=4.29$	$\Theta=1.4$ $\Delta\Theta=0.08$ $T=3.64$	$\Theta=-0.04$ $\Delta\Theta=1.36$ $T=30.17$	$\Theta=1.34$ $\Delta\Theta=0.02$ $T=0.89$	$\Theta=-0.04$ $\Delta\Theta=1.36$ $T=2.03$

Img. Name	Im g. Res	Ske w	All points (1;0.01)	Gray (1;0.01)	Gray (1;0.5)	Gray (1;0.1)	Conto ur (1;0.01)	Middle square (1;0.01)	Botto m row (1;0.01)
Down - sampl ed 25%	303 X 497	1.32	$\Theta=1.39$ $\Delta\Theta=0.07$ $T=1.59$	$\Theta=1.19$ $\Delta\Theta=0.13$ $T=1.81$	$\Theta=1.15$ $\Delta\Theta=0.17$ $T=0.6$	$\Theta=1.2$ $\Delta\Theta=0.12$ $T=0.46$	$\Theta=1.32$ $\Delta\Theta=0$ $T=2.21$	$\Theta=1.36$ $\Delta\Theta=0.04$ $T=0.14$	$\Theta=1.31$ $\Delta\Theta=0.01$ $T=0.28$
truea 0040 3.0	126 6 X 201 8	-3.0	$\Theta=-3.0$ $\Delta\Theta=0$ $T=13.15$	$\Theta=-2.79$ $\Delta\Theta=0.21$ $T=10.0$	$\Theta=-3.05$ $\Delta\Theta=0.05$ $T=4.25$	$\Theta=-2.9$ $\Delta\Theta=0.1$ $T=3.51$	$\Theta=-2.96$ $\Delta\Theta=0.04$ $T=28.09$	$\Theta=-2.98$ $\Delta\Theta=0.02$ $T=0.87$	$\Theta=-3.04$ $\Delta\Theta=0.04$ $T=1.70$
Down - sampl ed 25%	317 X 505	-3.0	$\Theta=-3.2$ $\Delta\Theta=0.2$ $T=1.81$	$\Theta=-3.09$ $\Delta\Theta=0.09$ $T=1.87$	$\Theta=-3.1$ $\Delta\Theta=0.1$ $T=0.65$	$\Theta=-3.1$ $\Delta\Theta=0.1$ $T=0.51$	$\Theta=-2.61$ $\Delta\Theta=0.39$ $T=2.82$	$\Theta=-2.93$ $\Delta\Theta=0.07$ $T=0.125$	$\Theta=-2.62$ $\Delta\Theta=0.38$ $T=0.29$
truea 0040 4.4	131 2 X 204 4	-4.4	$\Theta=-2.7$ $\Delta\Theta=1.7$ $T=13.37$	$\Theta=-4.38$ $\Delta\Theta=0.02$ $T=10.31$	$\Theta=-4.45$ $\Delta\Theta=0.05$ $T=4.35$	$\Theta=-4.40$ $\Delta\Theta=0$ $T=3.59$	$\Theta=-4.38$ $\Delta\Theta=0.02$ $T=28.42$	$\Theta=-4.39$ $\Delta\Theta=0.01$ $T=0.89$	$\Theta=-4.38$ $\Delta\Theta=0.02$ $T=1.71$
Down - sampl ed 25%	328 X 511	-4.4	$\Theta=-4.41$ $\Delta\Theta=0.01$ $T=1.68$	$\Theta=-4.33$ $\Delta\Theta=0.07$ $T=1.92$	$\Theta=-4.35$ $\Delta\Theta=0.05$ $T=0.64$	$\Theta=-4.3$ $\Delta\Theta=0.1$ $T=0.5$	$\Theta=-2.3$ $\Delta\Theta=2.1$ $T=2.23$	$\Theta=-4.41$ $\Delta\Theta=0.01$ $T=0.12$	$\Theta=-4.46$ $\Delta\Theta=0.06$ $T=0.25$
truea 0040 5.0	131 2 X 204 4	-5.0	$\Theta=-5.71$ $\Delta\Theta=0.71$ $T=13.36$	$\Theta=-5.01$ $\Delta\Theta=0.01$ $T=10.56$	$\Theta=-5.00$ $\Delta\Theta=0$ $T=4.45$	$\Theta=-5.0$ $\Delta\Theta=0$ $T=3.68$	$\Theta=-5.01$ $\Delta\Theta=0.01$ $T=28.89$	$\Theta=-5.01$ $\Delta\Theta=0.01$ $T=0.90$	$\Theta=-5.01$ $\Delta\Theta=0.01$ $T=1.68$
Down - sampl ed 25%	333 X 514	-5.0	$\Theta=-4.97$ $\Delta\Theta=0.03$ $T=1.67$	$\Theta=-5.02$ $\Delta\Theta=0.02$ $T=1.85$	$\Theta=-5.0$ $\Delta\Theta=0$ $T=0.64$	$\Theta=-5.0$ $\Delta\Theta=0$ $T=0.5$	$\Theta=-4.9$ $\Delta\Theta=0.01$ $T=2.31$	$\Theta=-5.07$ $\Delta\Theta=0.07$ $T=0.12$	$\Theta=-4.91$ $\Delta\Theta=0.1$ $T=0.23$

Img. Name	Im g. Res	Ske w	All points (1;0.01)	Gray (1;0.01)	Gray (1;0.5)	Gray (1;0.1)	Conto ur (1;0.01)	Middle square (1;0.01)	Botto m row (1;0.01)
truea 0040 8.6	144 6 X 211 2	-8.6	$\Theta=-7.0$ $\Delta\Theta=1.6$ T=13.6	$\Theta=-8.61$ $\Delta\Theta=0.01$ T=11.34	$\Theta=-8.6$ $\Delta\Theta=0$ T=4.84	$\Theta=-8.6$ $\Delta\Theta=0$ T=4.04	$\Theta=-8.61$ $\Delta\Theta=0.01$ T=28.54	$\Theta=-8.62$ $\Delta\Theta=0.02$ T=0.92	$\Theta=-8.61$ $\Delta\Theta=0.01$ T=1.64
Down - sampl ed 25%	362 X 528	-8.6	$\Theta=-7.91$ $\Delta\Theta=0.69$ T=1.67	$\Theta=-8.51$ $\Delta\Theta=0.09$ T=1.87	$\Theta=-8.5$ $\Delta\Theta=0.1$ T=0.67	$\Theta=-8.5$ $\Delta\Theta=0.1$ T=0.54	$\Theta=-8.45$ $\Delta\Theta=0.15$ T=2.34	$\Theta=-8.53$ $\Delta\Theta=0.07$ T=0.12	$\Theta=-8.58$ $\Delta\Theta=0.02$ T=0.20
truea 0042 3.0	181 4 X 224 0	-3.0	$\Theta=-4.4$ $\Delta\Theta=1.4$ T=30.15	$\Theta=-2.98$ $\Delta\Theta=0.02$ T=13.28	$\Theta=-3.0$ $\Delta\Theta=0$ T=5.90	$\Theta=-3.0$ $\Delta\Theta=0$ T=4.96	$\Theta=-3.06$ $\Delta\Theta=0.06$ T=24.28	$\Theta=-3.05$ $\Delta\Theta=0.05$ T=0.75	$\Theta=-2.97$ $\Delta\Theta=0.03$ T=1.65
Down - sampl ed 25%	454 X 572	-3.0	$\Theta=-4.4$ $\Delta\Theta=1.4$ T=2.81	$\Theta=-3.06$ $\Delta\Theta=0.06$ T=2.31	$\Theta=-3.05$ $\Delta\Theta=0.05$ T=0.84	$\Theta=-2.9$ $\Delta\Theta=0.1$ T=0.64	$\Theta=-3.11$ $\Delta\Theta=0.11$ T=3.45	$\Theta=-3.25$ $\Delta\Theta=0.25$ T=0.18	$\Theta=-3.12$ $\Delta\Theta=0.12$ T=0.32
truea 0042 4.4	186 4 X 232 4	-4.4	$\Theta=-5.71$ $\Delta\Theta=1.31$ T=30.43	$\Theta=-4.39$ $\Delta\Theta=0.01$ T=13.98	$\Theta=-4.4$ $\Delta\Theta=0$ T=6.17	$\Theta=-4.4$ $\Delta\Theta=0$ T=5.14	$\Theta=-4.46$ $\Delta\Theta=0.06$ T=24.15	$\Theta=-4.45$ $\Delta\Theta=0.05$ T=0.75	$\Theta=-4.46$ $\Delta\Theta=0.06$ T=1.57
Down - sampl ed 25%	466 X 581	-4.4	$\Theta=-5.71$ $\Delta\Theta=1.31$ T=2.78	$\Theta=-4.47$ $\Delta\Theta=0.07$ T=2.34	$\Theta=-4.45$ $\Delta\Theta=0.05$ T=0.84	$\Theta=-4.3$ $\Delta\Theta=0.01$ T=0.65	$\Theta=-4.43$ $\Delta\Theta=0.03$ T=3.28	$\Theta=-4.57$ $\Delta\Theta=0.17$ T=0.17	$\Theta=-4.43$ $\Delta\Theta=0.03$ T=0.36
truea 0042 5.0	188 6 X 234 0	-5.0	$\Theta=-6.17$ $\Delta\Theta=1.17$ T=30.40	$\Theta=-5.0$ $\Delta\Theta=0$ T=14.03	$\Theta=-5.0$ $\Delta\Theta=0$ T=6.28	$\Theta=-5.0$ $\Delta\Theta=0$ T=5.25	$\Theta=-5.0$ $\Delta\Theta=0$ T=24.31	$\Theta=-5.07$ $\Delta\Theta=0.07$ T=0.76	$\Theta=-5.08$ $\Delta\Theta=0.08$ T=1.54

Img. Name	Im g. Res	Ske w	All points (1;0.01)	Gray (1;0.01)	Gray (1;0.5)	Gray (1;0.1)	Conto ur (1;0.01)	Middle square (1;0.01)	Botto m row (1;0.01)
Down - sampl ed 25%	472 X 585	-5.0	$\Theta=-5.71$ $\Delta\Theta=0.71$ $T=2.78$	$\Theta=-5.07$ $\Delta\Theta=0.07$ $T=2.34$	$\Theta=-4.91$ $\Delta\Theta=0.15$ $T=0.85$	$\Theta=-4.91$ $\Delta\Theta=0.17$ $T=0.67$	$\Theta=-5.16$ $\Delta\Theta=0.16$ $T=3.34$	$\Theta=-5.17$ $\Delta\Theta=0.17$ $T=0.17$	$\Theta=-5.02$ $\Delta\Theta=0.02$ $T=0.34$
truea 0042 8.6	2010 X 2430	-8.6	$\Theta=-8.13$ $\Delta\Theta=0.47$ $T=31.15$	$\Theta=-8.59$ $\Delta\Theta=0.01$ $T=14.73$	$\Theta=-8.6$ $\Delta\Theta=0$ $T=6.57$	$\Theta=-8.6$ $\Delta\Theta=0$ $T=5.59$	$\Theta=-8.58$ $\Delta\Theta=0.02$ $T=25.01$	$\Theta=-8.65$ $\Delta\Theta=0.05$ $T=0.76$	$\Theta=-8.73$ $\Delta\Theta=0.13$ $T=1.45$
Down - sampl ed 25%	503 X 608	-8.6	$\Theta=-9.46$ $\Delta\Theta=0.86$ $T=2.87$	$\Theta=-8.55$ $\Delta\Theta=0.05$ $T=2.45$	$\Theta=-8.55$ $\Delta\Theta=0.05$ $T=0.90$	$\Theta=-8.71$ $\Delta\Theta=0.11$ $T=0.71$	$\Theta=-8.66$ $\Delta\Theta=0.06$ $T=3.37$	$\Theta=-8.65$ $\Delta\Theta=0.05$ $T=0.17$	$\Theta=-8.66$ $\Delta\Theta=0.06$ $T=0.29$

Table 2. Execution Results

Image name	true 0009 8.6	true 0009 8.6 (downsampled)	test001 3.5
Image resolution	3422 X 4228	685 X 846	5380 X 7306
Skew angle	-8.6	-8.6	-3.5
All points selected Θ selection: 1 and 0.01	$\Theta=-8.59$ $\Delta\Theta=0.01$ $T=65.71$	$\Theta=-8.13$ $\Delta\Theta=0.47$ $T=4.89$	$\Theta=-1.34$ $\Delta\Theta=2.16$ $T=305.28$
Grayscale selection Θ selection: 1 and 0.01	$\Theta=-8.6$ $\Delta\Theta=0$ $T=81.34$	$\Theta=-8.63$ $\Delta\Theta=0.03$ $T=1.89$	$\Theta=-3.5$ $\Delta\Theta=0$ $T=106.25$
Grayscale selection Θ selection: 1 and 0.05	$\Theta=-8.6$ $\Delta\Theta=0$ $T=28.70$	$\Theta=-8.65$ $\Delta\Theta=0.05$ $T=0.75$	$\Theta=-3.5$ $\Delta\Theta=0$ $T=42.03$
Grayscale selection Θ selection: 1 and 0.1	$\Theta=-8.6$ $\Delta\Theta=0$ $T=22.36$	$\Theta=-8.6$ $\Delta\Theta=0$ $T=0.60$	$\Theta=-3.5$ $\Delta\Theta=0$ $T=34.78$
Contour selection Θ selection: 1 and 0.01	$\Theta=-8.6$ $\Delta\Theta=0$ $T=102.09$	$\Theta=-8.63$ $\Delta\Theta=0.03$ $T=2.79$	$\Theta=-3.61$ $\Delta\Theta=0.11$ $T=173.70$
Middle square selection Θ selection: 1 and 0.01	$\Theta=-8.6$ $\Delta\Theta=0$ $T=1.85$	$\Theta=-8.51$ $\Delta\Theta=0.01$ $T=0.09$	$\Theta=-3.6$ $\Delta\Theta=0.1$ $T=5.42$

Image name	true 0009 8.6	true 0009 8.6 (downsampled)	test001 3.5
Bottom row selection Θ selection: 1 and 0.01	$\Theta=-8.6$ $\Delta\Theta=0$ $T=1.93$	$\Theta=-8.6$ $\Delta\Theta=0$ $T=0.20$	$\Theta=-3.6$ $\Delta\Theta=0.1$ $T=11.42$
BAG points selection Θ selection: 1 and 0.01	$\Theta=-8.62$ $\Delta\Theta=0.02$ $T=1.21$		$\Theta=-3.73$ $\Delta\Theta=0.23$ $T=4.92$

Table 3. Execution Results

I. Example of point-reduction strategies



Fig. 2 – Grayscale point-reduction



Fig. 3 – Middle point-reduction

6. CONCLUSIONS AND FUTURE WORK

A complete Hough transform based skew detection system is presented and analyzed for its time complexity. The system has two phases: a pre-processing stage that reduces the number of image pixels and a processing stage that employs the Hough transform for skew detection. The two major issues of the Hough transform, slow speed and high memory requirement, are addressed. The overall speed of skew detection is enhanced by using a preprocessing stage where the number of image pixels is greatly reduced using methods described above.

Hough transform in $\rho - \theta$ space is a very powerful algorithm for calculating skew angle. The precision of the angle is very good, in the most of the cases the error is less than 0.05 degrees. The speed of the algorithm is increased by reducing the points used, by executing the algorithm in two steps with different levels for θ , by down sampling the picture.

After implementing the optimizations described in section 4, we concluded that the best practice to obtain the lower error in the shorter time is to downsample the picture and to reduce the points, only keeping the middle of each entity. By downsampling a picture to 25%, the time of execution drops up to ten times. By choosing only the middle points of the entities and not all points, the speed increases up to 15 times. By decreasing the sensitivity of the angle, the speed will increase, but the error will increase too.

The weakness of Hough algorithm is felt for documents that contain big pictures or black background. We implemented an algorithm that removes the pictures and determine a representative rectangle for the picture, so in the future; this will permit to run the Hough algorithm only on one specific rectangle, not for the entire picture. As future work, the speed of extracting rectangular from picture will be optimized.

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