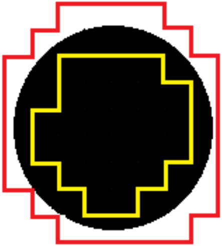
Introduction : Rough Set

- Rough set is an approximation of a crisp set in terms of a pair of sets for lower and upper approximations of the original set.
- It is easier to handle each of the approximating sets compared to the original crisp set.



Prior Work: Rough-Set

- Rough set — set the basic fundamentals Pawlak[1]
- While many problems has been tackled in rough set[2,3], its application in image processing has been explored less.
- Czajewski[4] use a discernibility matrix built on a reduced database for classification algorithms; average accuracy of 66.6%.

[1] Pawlak & Zdzislaw,"Rough sets", IJCIS-1982

[2] Thangavel,"Dimensionality reduction based on rough set theory", ASC-2009

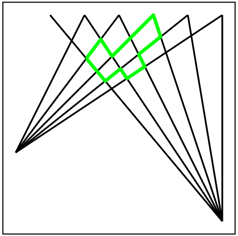
[3] Thangavel,"Application of rough set theory to feature selection for unsupervised clustering", Chemometrics and Intelligent Laboratory Systems-2002

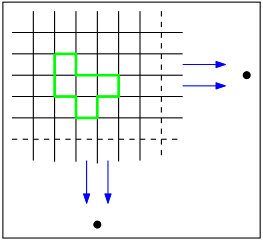
[4] Czajewski,"Rough Sets in Optical Character Recognition", RSCTC-1998

Definition

Definition (Rough-set Polygon)

A *Rough-set polygon* is a polygon which is constructed by two parametric families of straight lines with their centers at two points. Rectilinear polygons are a type of isothetic polygons with their centers lying at infinity.





For computational advantage, we consider only axes parallel polygons.

Object Approximation

Definition (Rough-set Semi-Reduct)

A *Rough-set semi-reduct* is the sub-optimal set of attributes, that are required for any classification system, without having any discrepancies.

Definition (Tight Upper Approximation)

A finite and minimal union of elementary sets, also called a composed set, containing X is called the *best tight upper approximation* of X in $\mathbb{A}$, denoted by $\overline{Apr}_{\mathbb{A}}(X)$.

Definition (Tight Lower Approximation)

The greatest composed set in $\mathbb{A}$ contained in X is called the *best tight lower approximation* of X in $\mathbb{A}$, denoted by $\underline{Apr}_{\mathbb{A}}(X)$.

Object Approximation

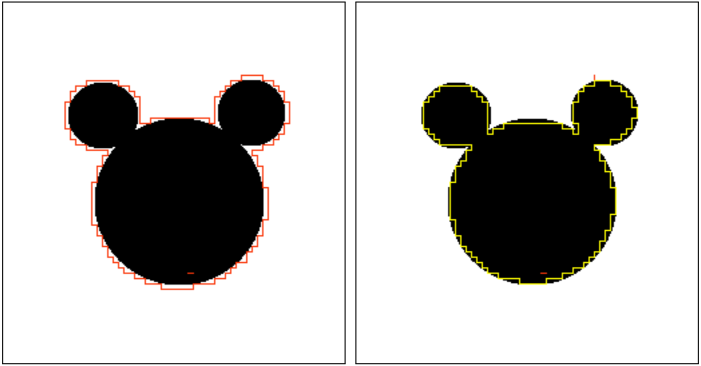


Figure: Upper and Lower approximations of the rough-set polygon of an object.

Tight Upper and Lower Approximations

- S is a 2D digital object and $\mathbb{G}$ a cellular grid.
- *Tight upper approximation* is given by $\overline{\mathcal{P}}_{\mathbb{G}}(S)$,
  and *tight lower approximation* is $\underline{\mathcal{P}}_{\mathbb{G}}(S)$ of S (induced by $\mathbb{G}$)
  where $\underline{\mathcal{P}}_{\mathbb{G}}(S)$ and $\underline{\mathcal{P}}_{\mathbb{G}}(S)$ can have multiple polygons.
- *Accuracy*, $\alpha_{\mathbb{G}}(S)$ of S is given by

$$\alpha_{\mathbb{G}}(S) = \frac{\operatorname{area}\left(\underline{\mathcal{P}}_{\mathbb{G}}(\mathrm{S})\right)}{\operatorname{area}\left(\overline{\mathcal{P}}_{\mathbb{G}}(\mathrm{S})\right)} \tag{1}$$

Rought-Set: Dependance on cell size

We use rough-sets in two stages[5]—

- For construction of upper and lower approximations of a 2D digital object.
- Defining the approximations of their attributes comprising the reduct.

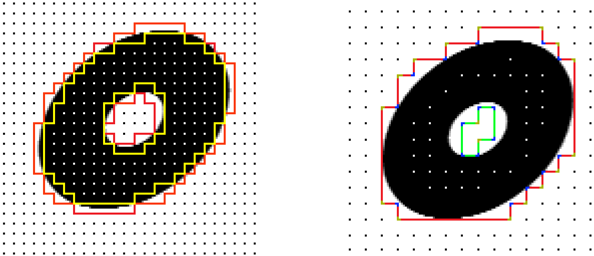


Figure: Cell-size 6×6 (nearer to the crisp-set) and 9×9 (more approximation).

[5] Pawlak & Zdzislaw,"Rough sets", IJCIS-1982

Character Spotting

This work makes the following novel contributions:

- An unsupervised algorithm for the retrieval of characters.
- An efficient spotting mechanism using inverse Hough transform.

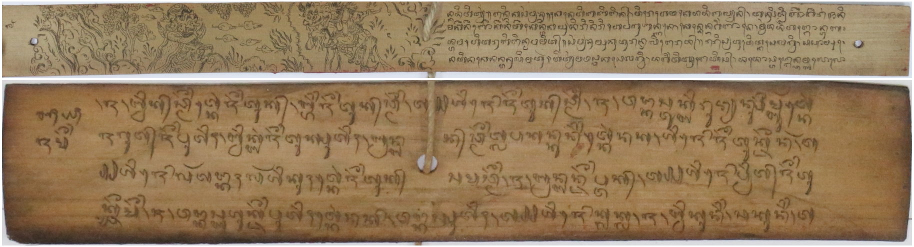
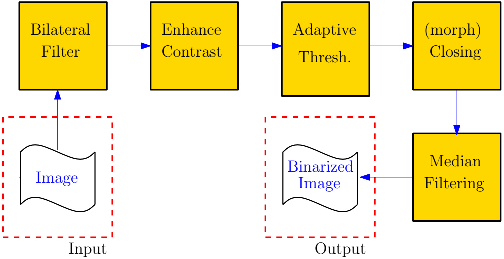


Figure: Sample palm leaf images from the data set.

Challenge— Binarization

Binarization

- Bilateral filtering [6]
- Contrast enhancement
- Adaptive thresholding [7]
- Morphological closing operation [8]
- Median filtering



[6] C. Tomasi, R. Manduchi, "Bilateral filtering for gray and color images", ICCV-1998
[7] D. Bradley, Roth , "Adaptive Thresholding using the Integral Image", JGT
[8] Serra, Jean, "Image Analysis and Mathematical Morphology", 1983

Bilateral Filtering

- Non-linear filter
- Preserves the edges
- Reduces the noise

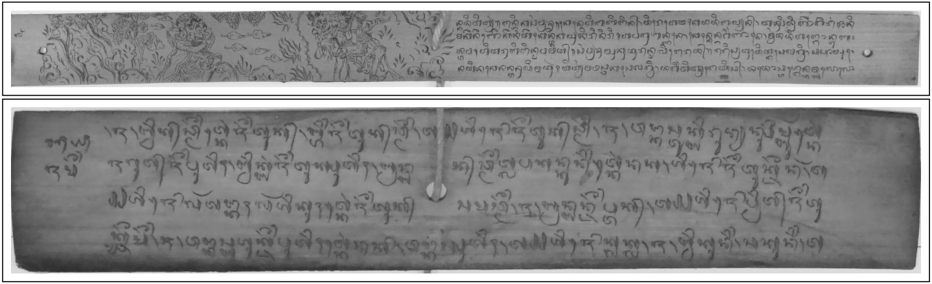


Figure: Applying bilateral filter on palm leaf images shown in Fig. 3.

Contrast Enhancement.

$$f(x) = \alpha x + \beta \quad (2)$$

α - Gain; (controls contrast).
β - Bias; (controls brightness).
x - intensity at a point.

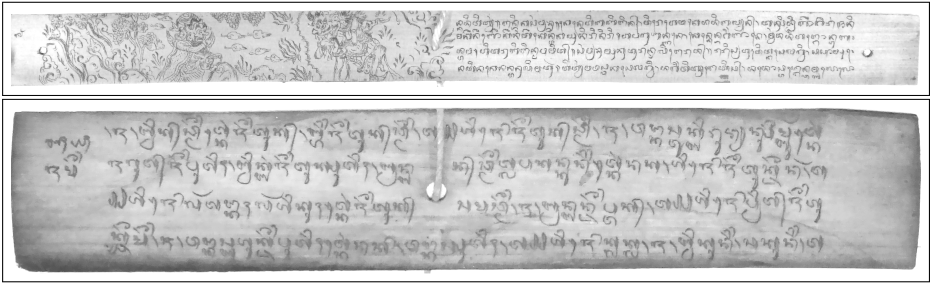
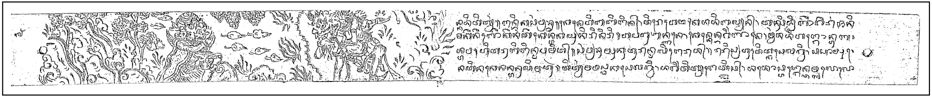
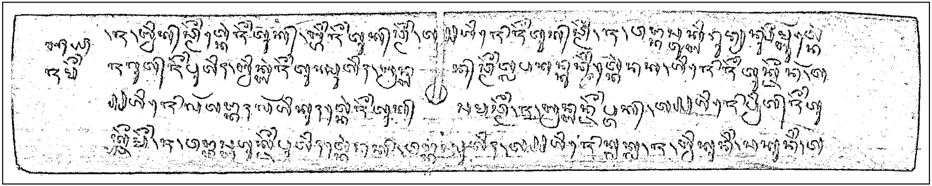


Figure: Increasing contrast on the pre-processed image shown in fig:bilateral. The values of α and β have chosen to be 1.5 and 10.

Adaptive Thresholding

- For each pixel, a threshold value is to be calculated.
- Lot of gradient difference— an adaptive thresholding!
- Image is divided into multiple overlapping sub-images.

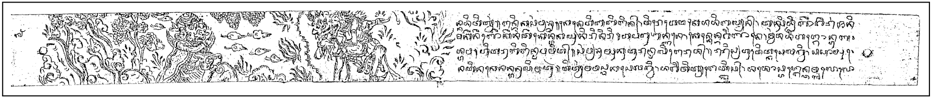


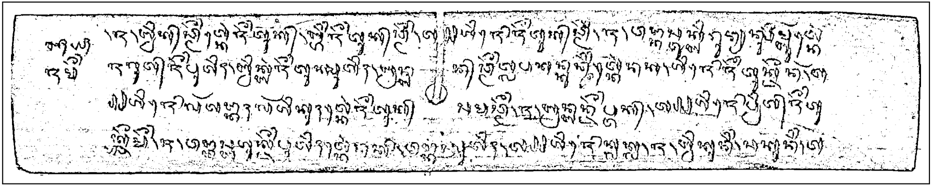


Morphological Closing

- For gaps and holes filling.
- Erosion of the dilation of that image.

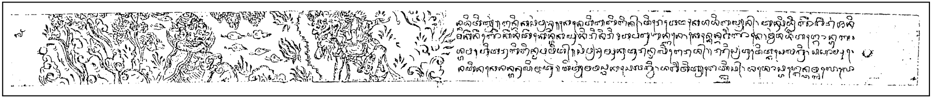
$$A \bullet B = (A \oplus B) \ominus B, \tag{3}$$

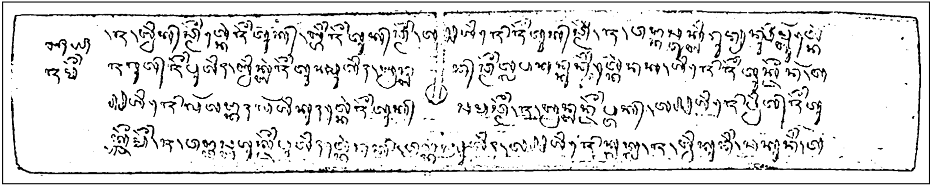




Median Filtering

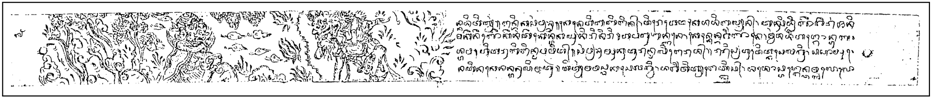
- For the removal of spurious noises.

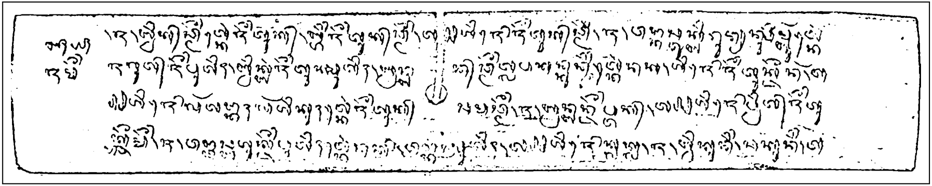


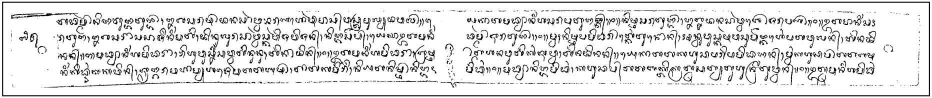


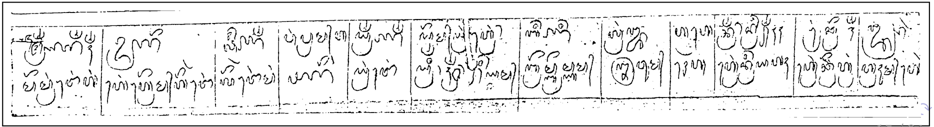
Binarization and Segmentation

More samples of binarized leafs—









Binarization and Segmentation

Figure: Results of character segmentation for the inscription image.

Proposed Methodology

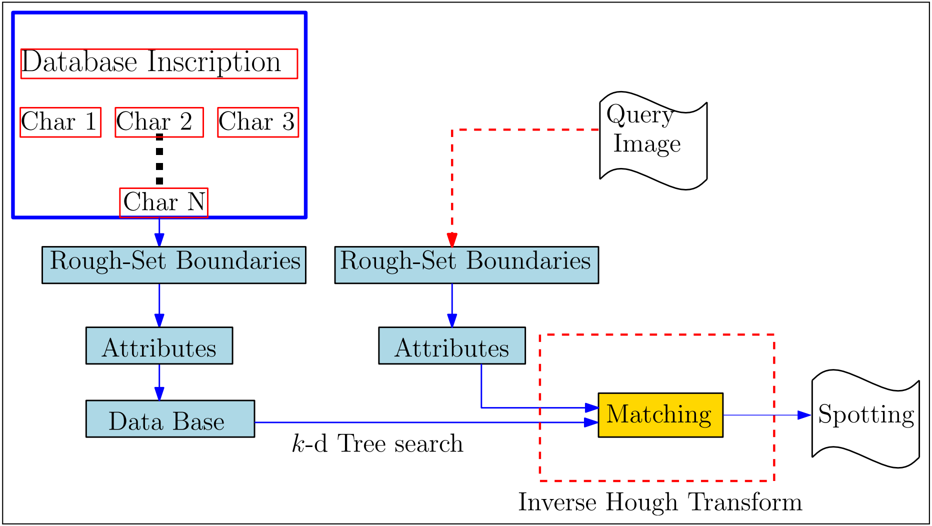


Figure: Pipeline of the proposed symbol spotting method.

Attributes for Spotting of Characters

- Number of polygons
- Number of Holes
- Euler Number Approximation (EN)
- Position of Holes (PoH)
- Directional Changes
- Vertical Directional Changes (VDC)
- Horizontal Directional Changes (HDC)
- Perimeter Components— Vertical ratio (VR), Horizontal ratio (HR), Edge Ratio (ER)
- Concavities (3-tuple)
- Hull Concavities

Number of polygons

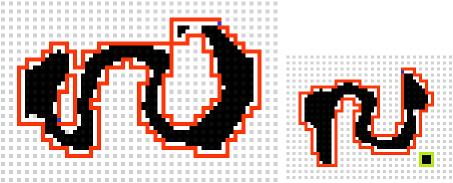


Illustration of continuity breakage in glyph images.

Number of Holes

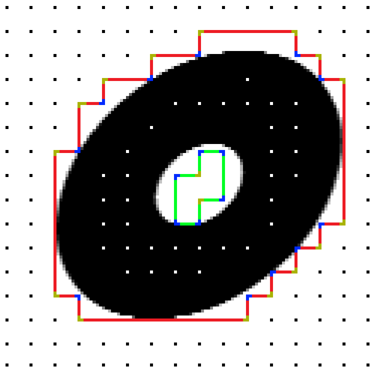


Illustration of $\measuredangle 90^\circ$ and $\measuredangle 270^\circ$ in holes and primary polygons.

- Blue - $\measuredangle 270^\circ$
- Yellow - $\measuredangle 90^\circ$

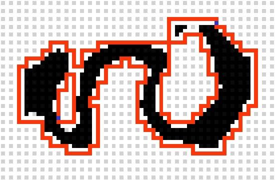
Definition (Hole polygon)

Some of the characters cover the entire region inside the cover, while some characters have voids inside them. These void covers are called as the lower boundary or a hole polygon.

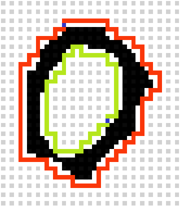
The Euler number(EN) is calculated as—

$$EN = 2 - n \tag{4}$$

where n = total number of polygons in $\overline{\mathcal{P}}_{\mathbb{G}}(S)$.



$n = 1$, EN=1



$N = 2$, EN=0

Relative Hole Positions

Definition (Hole position)

A hole position is given by the centroid of the hole w.r.t to the centroid of the containing polygon.

The hole centroid (c), is found in the local coordinate with the top left vertex of the character as the reference point.

The relative position (PoH) of each hole polygon is determined by comparing its center c with the top-left vertex v_0 of the outer polygon in $\overline{\mathcal{P}}_{\mathbb{G}}(S)$.

Directional Changes

Definition (U-turn)

U-turn is defined by a vertex sequence where two consecutive vertices are of type $\langle 270^\circ, 270^\circ \rangle$ or $\langle 90^\circ, 90^\circ \rangle$.

Definition (Vertical Direction Change (VDC))

When we start traversing along the upper boundary of the rough set perimeter of the object from the top left corner, the number of times we encounter a directional 'U-turns' in the vertical direction (ex 1 to 3, or 3 to 1) is defined as vertical direction change (VDC).

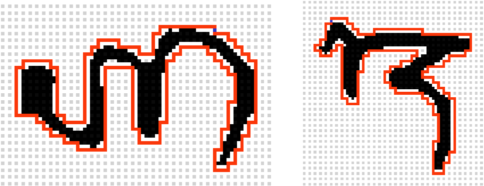
Similarly we have Horizontal direction change (HDC).

Directional Changes

Definition (Vertical Ratio (VR))

The sum of the perimeter components along ‘Up’ and ‘Down’ are calculated separately, and their ratios are found. This ratio is referred to as the *vertical ratio* (VR).

Similarly, the sum of the perimeter components along ‘Left’ and ‘Right’ are calculated separately, and their ratios are found. This ratio is referred to as the *horizontal ratio* (HR).



VDC=10; HDC=4 VDC=6; HDC=8

Figure: Illustration of VDC & HDC.

Edge Ratio

- Horizontal Perimeter Component (HPC)- For each polygon in $\overline{\mathcal{P}}_{\mathbb{G}}(S)$, we define horizontal perimeter component (HPC) as the sum of the lengths of its horizontal edges.
- Vertical Perimeter Component (VPC)- For each polygon in $\overline{\mathcal{P}}_{\mathbb{G}}(S)$, we define vertical perimeter component (VPC) as the sum of the lengths of its vertical edges.
- Edge Ratio (ER)- The ratio VPC:HPC, discretized to the nearest value in $\{\frac{1}{2}, 1, 2\}$, is called edge ratio (ER).

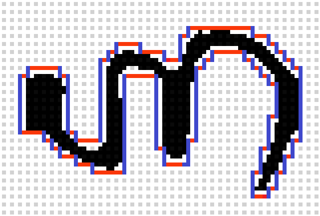


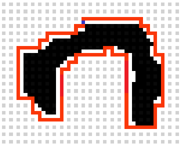
Figure: ER=2; VR=1; HR=1.

Concavities

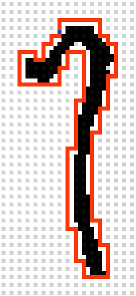
Definition (Concavity)

Concavity is defined as two consecutive vertices of type 270° (without considering the type intermediate 180° vertices).

Types of concavities— left (L), right (R), upward (U), and downward (B)



⟨U,+2,3⟩



⟨U,−1,1⟩

Concavities

Defined in 3-tuple format $\langle$ Orientation, Position, Depth $\rangle$

- Sometimes due to binarization errors, noise in boundaries of the objects, we find the presence of external noise.
- Leads to unwanted erroneous small concavities.
- Also, different glyphs leads to different covers, and hence different concavities. Solution— Hull concavities.

Hull Concavities[9]

Definition (Orthogonal Hull)

An orthogonal hull is a polygon with some degenerate edges connecting extreme vertices in each coordinate direction.

Four types of concavities — left, right, upward, and downward. In this type of concavity, all the spare noise concavities are more or less removed.

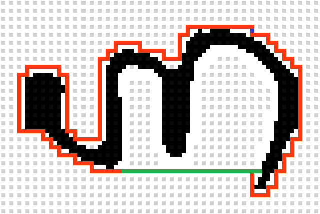
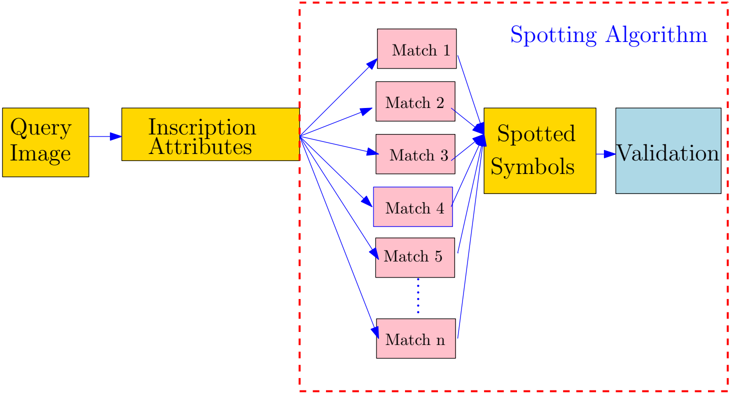


Figure: Upward Hull-Concavity.

[9] Arindam Biswas *et al.*," A linear-time combinatorial algorithm to find the orthogonal hull of an object on the digital plane", Information Sciences-2012

Symbol Spotting

- 11-attributes corresponding to every primary polygon in the image.
- ⟨ number of polygons, number of holes, Euler number, position of holes, VDC, HDC, edge ratio, VR, HR, concavity tuple, hull-concavity orientation ⟩



Symbol Spotting— Dataset

- Balinese inscription pages [10]
- Contains 133 distinct glyph symbols.
- Each inscription image has size 3000×500 pixels on average.
- An image having 'n' polygons will have $n \times 13$ number of attributes.

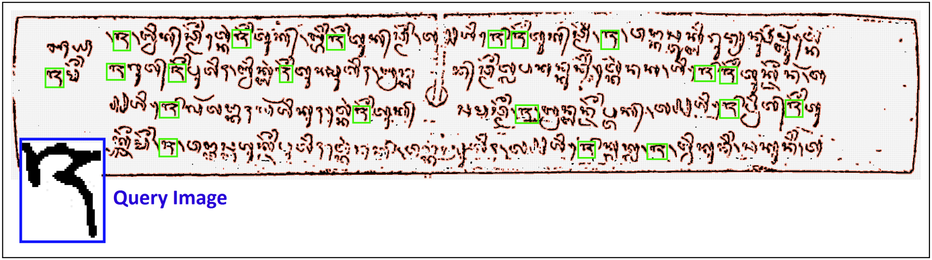
[10] M. W. A. Kesiman and S. Prum and J. C. Burie and J. M. Ogier,"Study on feature extraction methods for character recognition of Balinese script on palm leaf manuscript images", ICPR-2016

Spotting using Inverse Hough Transform

- 2 dimensional k-d tree: Edge ratios and VDC.
- $\mathcal{O}(\log n)$ time complexity, as compared to a linear search.
- With the nearest matches found, the rest of the remaining polygons are compared, which lie in a window of $\pm\varepsilon$ pixels from the bounding box of the biggest polygon.
- For our experimentation, the value of ε is taken as 50.
- 25% of the size of the query image as the overlapping area.

Results

- CPU time of 0.498 secs is achieved for the experimentation.
- An overall accuracy of 74.47% is achieved, when the algorithm is run on 20 query images.
- The CPU time is achieved on a computing platform having of 64-bit Intel ® Core ™ i5-4210U processor, with 8GB RAM.



Results—Analysis

- The performance of the system can be further improved by having an improved binarization technique.
- Most symbols that are failed to get spotted are observed to be the ones which lie mainly along the boundary edges.
- A few symbols resemble each other so closely that they are difficult to distinguish.
- Some characters also loose their connectivity and their curvature broken due to errors in binarization and cropping of the query images.
- Main advantage of the grid polygon approximation method is its reduced time complexity.
- When used for some large scale process, it saves us a huge amount of time.

Thank You