Efficient Recognition of Telugu Characters Based on Critical Points Generated Using Morphological Methods

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Abstract

   A novel method for recognition of telugu character is proposed in this paper. The proposed method uses extraction of critical points of the characters based on grid and radial intersections analysis. The extracted critical points are classified based on the grid and radial lines, which helps in improving accuracy in recognition of characters. The algorithm is tested on various data sets and the results are satisfactory. The technique is a generic method in the sense that it is applicable for all Indian language scripts like Sanskrit, Hindi, Telugu, Kannada, Tamil, Malayalam, etc.

   Index Terms — Indian Languages, Grid based Intersecting Points Analysis, Radial Axis based Intersecting Points Analysis, Critical Points Analysis, Morphological Feature Extraction Methods, Optical Character Recognition.

1. Introduction

   Optical Character Recognition (OCR) is the mechanical or electronic conversion process of scanned printed or handwritten text images into computer-readable text format. It is a common method of digitization of printed/handwritten text documents. The digitized data can be electronically edited, searched, stored more compactly, displayed on-line, and also, it can be used for data extraction, language translation, text-to-speech conversion and data mining. OCR is used in many applications such as script recognition, language identification, postal processing, banking, and security check with the Authentication of Unique Identification Documents (for example, Aadhaar Card, Passport, PAN Card, Driving License, etc.) [1]. Nowadays, many organizations are giving high preference to OCR systems to minimize the human

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interactions for better performance and efficiency. OCR can be applied with the help of Pattern Recognition and/or Artificial Intelligence techniques to achieve accurate results. Generally, OCR system goes through various phases including: data collection, pre-processing, feature extraction, classification and post-processing [2].

The proposed approach is based on the existing approach "Recognition of Machine Printed Broken Characters based on Gradient Patterns and its Spatial Relationship" [3] that was developed to explore the geometrical and topological properties of 2D binary images. This method precisely determines the gradient-pattern from eight different view directions. To improve the accuracy in recognition of character, this method is extended, (i) by adding extra steps to grouping mechanism and view directions, and (ii) by maintaining two matrices for indifferent intersection point calculations.

The stages in a character recognition system [4] are in a pipeline fashion, i.e., each stage depends on the success of the previous stage in order to produce optimal/valid results. There are a number of factors that affect the accuracy of text recognized through OCR [5]. These factors include: scanner quality, scan resolution, type of printed or handwritten documents (laser printer or photocopied), paper quality, fonts used in the text, linguistic complexities, and dictionary used.

The use of preprocessing techniques [6] is to enhance a document image preparing it for the next stage in a character recognition system. In order to achieve higher recognition rates, it is essential to have an effective preprocessing stage makes the OCR system more robust [7] mainly through accurate image enhancement, noise removal, image thresholding, skew detection/correction, page segmentation, character segmentation, character normalization and morphological techniques.

On completion of preprocessing, the textual and non-textual document images are to perform page segmentation in order to separate text from halftone images, lines, and graphs. The result from the character segmentation stage provides isolated characters are normalized into a specific size; and are ready to be passed into the feature extraction stage. Then features are extracted from all characters with the same size in order to provide data uniformity.

2. Feature Extraction using Proposed Technique

The Recognition process consists of the following two sections:

A. Creation of boundary for an isolated character and then normalization.

B. Process the input image to find critical points in the following ways:
   1) 6-way and 10-way Grid based intersecting points Analysis.
   2) 8-way and 16-way Radial (Axis) based intersecting points Analysis.

Different data sets where tested using this algorithm. Initially, these data is scaled to normalize the size and create a boundary around each character. The images of the normalized characters are processed to generate characteristics vectors of features that are further used to classify the characters.

Initially, the technique has been demonstrated with a sample Telugu letter 'అ'/'A' as follows.

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A. Creation of boundary for an isolated character and then normalization

Figure 2.1 is an input image. After preprocessing the input image, the character is trimmed by identifying the boundary with dimensions. Later, the background color of the character is set to Black, and foreground color of it is set to White, for further analysis. Then, the size of the character is normalized (for example, 120X150) as shown in Figure 2.2.

Input Image
Figure 2.1

Normalized Image
Figure 2.2

Thinned Image
Figure 2.3

The thinned image is as shown in Figure 2.3 after applying morphological thinning methodology [8]. The same image is used for proposed feature extraction, i.e., determination of critical points in two ways.

B. Process the input image to determine the critical points in the following ways:

1) 6-way and 10-way Grid based Intersecting points Analysis:

The analysis is called as **6-way Grid based analysis**, as there are 3 horizontal grid lines and 3 vertical grid lines. The 6-way Grid based analysis starts by drawing additional 'horizontal lines on beside of the centrally located horizontal line, and vertical lines on beside of the centrally located vertical line' as shown in Figure 2.4(a). In case of vertical axis, E-1 is the middle point between top-right position and E; and E+1 is the middle point between E and bottom-right position; and it is vice versa for N-1 and N+1 that are related to horizontal axis; as shown in Figure 2.4(c).

Next, the skeleton image is generated with horizontal and vertical grid lines as shown in Figure 2.4(a). Then, the skeleton image is applied on input normalized character image with logical AND operation, as shown in Figure 2.4(c). After execution of the specified logical AND operation, the output image is generated with only intersection points, as shown in Figure 2.4(d). All the letters may not have intersection points for all the grid lines. And also, all the letters may have more intersection points for some grid lines. The variation between the nature of intersection points for each character letter indicates the feature. The proposed method is explored in the following two matrices that indicate the array of character feature vectors.

(a) Skeleton Image
(b) Normalized Input Image
(c) Applying 6-way Grid Analysis
(d) Output Image with Intersecting Points
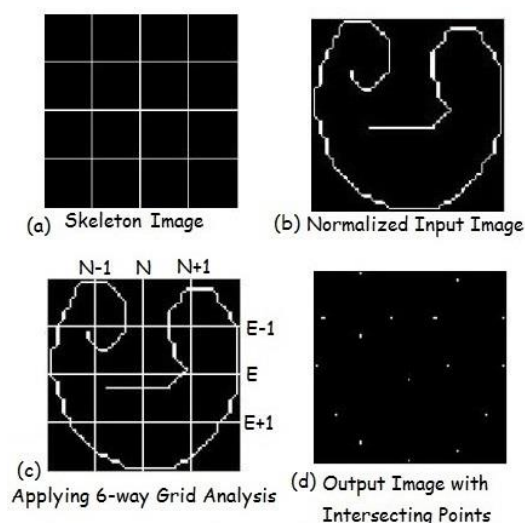
Figure 2.4

- Matrix-1 is having the intersection points.
- Matrix-2 is having the series of intersection points.

So, each Matrix will have M rows (records or feature vectors) and N columns. Where, M indicates the number of characters; and N indicates the number of grid lines 6. Each row represents the character. Each column represents the number of intersections for one grid line.

With 6-way grid based analysis, it is identified that there is a maximum possibility of getting duplicate rows in Matrix-1 and/or Matrix-2. To improve the accuracy in character recognition process, 6-way grid based analysis is extended to 10-way grid based analysis.

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The **10-way Grid based analysis** starts by drawing 5 horizontal and 5 vertical lines to prepare the Skeleton image, as shown in Figure 2.5(a).

In the Skeleton image (Figure 2.5(a)), the horizontal lines E-2, E-1, E, E+1, E+2 and the vertical lines N-2, N-1, N, N+1, N+2 are in equal distances; as shown in Figure 2.5(c). After execution of logical AND operation between skeleton image and normalized image as shown in Figure 2.5(c), the output image is generated with only intersection points as shown in Figure 2.5(d). The intersection points are captured in the form of two matrices, Matrix-1 with Intersection points and Matrix-2 with series of Intersection points.

(a) Skeleton Image (b) Normalized Input Image

(c) Applying 10-way Grid Analysis (d) Output Image with Intersecting Points

Figure 2.5

In this analysis, Matrix-1 and Matrix-2 are having M rows and N columns. Where, M indicates the number of characters; and N indicates the number of grid lines 10. The proposed method '10-way Grid based analysis' is verified with all Vowels and Consonants, Guninthas and Vaththus; and the details are listed in Annexure with Figure A.1.1 and A.1.2.

In Figure A.1.1, Matrix-1 values for Vowels, Consonants, Ka-Gunintham and Ka-Vaththu are given. In Figure A.1.2, Matrix-2 values for Vowels, Consonants, Ka-Gunintham and Ka-Vaththu are given.

The proposed method was tested with the following two test cases. Matrix-1 and Matrix-2 are inputs for these test cases. Matrix-1 and Matrix-2 values for 'all Vowels & Consonants and one set of Guninthas & Vaththus' are given in Annexure.

Test Case 1: Testing each Matrix itself for duplicate row values, as each row represents the intersection points for one character. With the execution of this test case, there is no duplicate row found in both Matrix-1 and Matrix-2.

Test Case 2: The test execution steps are as follows.
- Selected 'X' as an Unknown character.
- For the character 'X', Vector-1 and Vector-2 values are calculated; and are listed in below Table 1. Here, Vector-1 row values are named as X-Vector-1; and Vector-2 row values are named as X-Vector-2.

Table 1: Vector-1 and Vector-2 values for the Unknown character 'X'.

	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2	Telugu Character
X-Vector-1	1	1	2	5	8	11	13	15	17	19	స
X-Vector-2	2	2	3	9	14	19	21	24	26	30	

- Verify the X-Vector-1 row with all rows of Matrix-1 values of 'Vowels, Consonants, Guninthas and Vaththus'. Few of them are listed in Figure A.1.1.
- In this example, the X-Vector-1 row is matched with only one row. The matched row is related to the character **'స'/'SA'**. If the unknown character is not identified with X-Vector-1, then, it is required to check with X-Vector-2 with all rows of Matrix-2 values of 'Vowels, Consonants, Guninthas and Vaththus'; and are listed in Figure A.1.2.

Thus, both 'Test Case 1' and 'Test Case 2' are passed successfully.

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2) 8-way and 16-way Radial (Axis) based Intersecting points Analysis:

The initial **8-way Radial based analysis** starts by drawing radial lines from the center of the image for every 45° to prepare the Skeleton Image as shown in Figure 2.6(a). Here, the Radial Axis is 45°. The Skeleton image is having the 8 Radial lines in 8 directions from center of the image, such as East, East-North, North, North-West, West, West-South, South, and South-East; as specified the notations in Figure 2.6(d). Now, the skeleton image is applied on the Normalized input image with logical AND operation as shown in Figure 2.6(d). Then, the output image is generated with the Intersection points for each radial line as shown in Figure 2.6(e). Two matrices Matrix-1 and Matrix-2 are generated with the proposed method.

(a) Preparing Skeleton Image
(b) Skeleton Image
(c) Normalized Input Image

(d) Applying 8-way Radial based Analysis
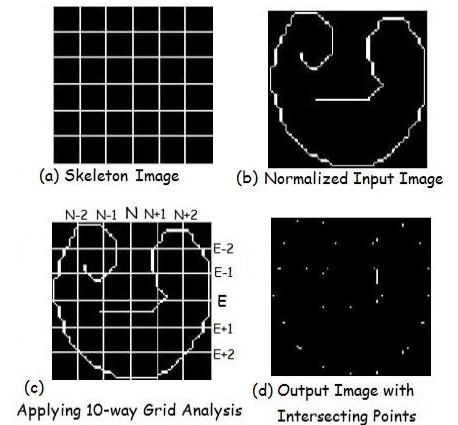(e) Output Image with Intersecting Points

Figure 2.6

In this analysis, Matrix-1 and Matrix-2 will have M rows and N columns. Where, M indicates the number of characters; and N indicates the number of Radial lines 8.

The 8-way Radial based analysis is identified that there is a maximum possibility of getting duplicate rows in Matrix-1 and/or Matrix-2. To improve the accuracy in character recognition process, 8-way Radial based analysis is extended to 16-way Radial based analysis.
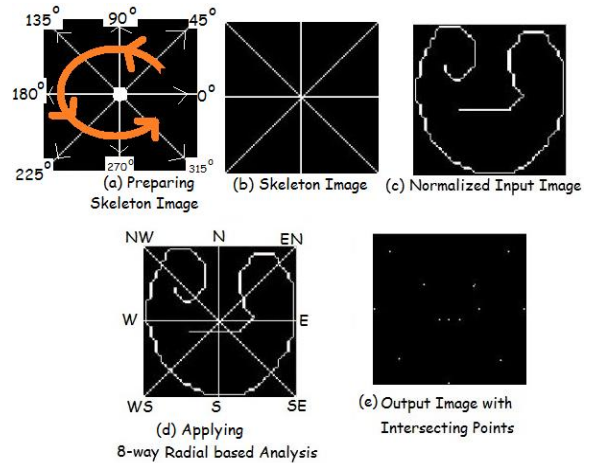
The **16-way Radial based analysis** starts by drawing radial lines from the center of the image for every 22.5^o to prepare the Skeleton Image as shown in Figure 2.7(a). In this example case, the Radial Axis is 22.5^o.

(a) Skeleton Image
(b) Normalized Input Image

(c) 16-way Radial based Analysis
(d) Output Image with Intersecting Points

Figure 2.7

In the Skeleton image (Figure 2.7(a)), 16 Radial lines are drawn with notations as shown in Figure 2.7(c). After execution of logical AND operation between skeleton image and normalized image as shown in Figure 2.7(c), the output image is generated with only intersection points as shown in Figure 2.7(d). Intersection points are captured in the form of two matrices, where Matrix-1 is having the intersection points, and Matrix-2 is having only the series of intersection points.

In this analysis, Matrix-1 and Matrix-2 are having M rows and N columns, where, M indicates the number of characters; and N indicates the number of Radial lines 16. The proposed method '16-way Radial based analysis' is verified with all Vowels and Consonants, Guninthas and Vaththus; and the details are listed in Annexure with Figure A.2.1 and A.2.2.
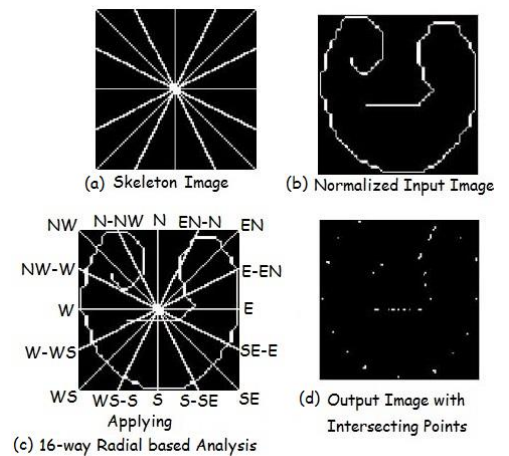
In Figure A.2.1, Matrix-1 values for Vowels, Consonants, Ka-Gunintham and Ka-Vaththu are given. In Figure A.2.2, Matrix-2 values for Vowels and Consonants, Ka-Gunintham and Ka-Vaththu are given.

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The proposed method is tested with the following two Test Cases. Matrix-1 and Matrix-2 are inputs for these Test Cases. Matrix-1 and Matrix-2 values for 'all Vowels & Consonants and one set of Guninthas & Vaththus' are given in Annexure.

Test Case 1: Testing each Matrix itself for duplicate row values, as each row represents the intersection points for one character. With the execution of this test case, there is no duplicate row found in both Matrix-1 and Matrix-2.

Test Case 2: The test execution steps are as follows.
- Selected 'Y' as an Unknown character.
- For this character, Vector-1 and Vector-2 values are calculated; and are listed in below Table 2. Here, Vector-1 row values are named as Y-Vector-1; and Vector-2 row values are named as Y-Vector-2.

Table 2: Vector-1 and Vector-2 values for the Unknown character 'Y'.

	E	E-EN	EN	EN-N	N	N-NW	NW	NW-W	W	W-WS	WS	WS-S	S	S-SE	SE	SE-E	Telugu Character
Y-Vector-1	1	11	6	12	7	13	8	14	9	15	9	16	10	17	10	18	ర
Y-Vector-2	2	23	18	24	19	27	20	29	21	30	21	32	22	33	22	38	

- Verify the Y-Vector-1 row with all rows of Matrix-1 values of 'Vowels, Consonants, Guninthas and Vaththus'. Few of them are listed in Figure A.2.1.
- In this example, the Y-Vector-1 row is matched with only one row. The matched row is related to the character **'ర'/'RA'**. If the unknown character is not identified with Y-Vector-1, then, it is required to check with Y-Vector-2 with all rows of Matrix-2 values of 'Vowels, Consonants, Guninthas and Vaththus'; and are listed in Figure A.2.2.

Thus, both 'Test Case 1' and 'Test Case 2' are passed successfully for the proposed method.

3. Algorithm

Main Procedure:

Requirement: Determination of Intersection points for all input character images.
1. INPUT: Set of character images with INPUT_IMGS array.
2. Initialization Part:-
   OUTPUT_INT as matrix;
   OUTPUT_INT_SER matrix;
3. for i=1 to sizeOf(INPUT_IMGS)
   a) COL_INPUT_IMG ← INPUT_IMGS(i).
   b) NORM_BW_IMG ← procedure call PreProcessInputImage(COL_INPUT_IMG).
   c) [ROW_INT ROW_INT_SER] ← procedure call GetIntersectionsArrays(NORM_BW_IMG).
   d) OUTPUT_INT(i) ← ROW_INT.
   e) OUTPUT_INT_SER(i) ← ROW_INT_SER.
   f) Exit for-loop.
4. Display OUTPUT_INT and OUTPUT_INT_SER matrix values.
5. Exit.

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Procedure 1 : PreProcessInputImage(COL_IMG):

Requirement: Pre-process the input image.

1. BW_IMG ← ConvertToBW(COL_IMG).
2. BW_IMG ← Inversion(BW_IMG).
3. BW_IMG ← Trim(BW_IMG).
4. BW_IMG ← Normalize(BW_IMG).
5. BW_IMG ← Thinning (BW_IMG).
6. Return BW_IMG.

Procedure 2 : GetIntersectionsArrays(BW_IMG):

Requirement: Calculation of No. of Intersection points for the processed image.

1. Prepare the Skeleton Image SK_IMG based on the selected technique (i.e., 6-way Grid based Analysis (or) 10-way Grid based Analysis (or) 8-way Radial based Analysis (or) 16-way Radial based Analysis (or) any other) by drawing '6/10 Grid or 8/16 Radial lines'.
2. INT_IMG ← SK_IMG (logical AND) BW_IMG.
3. X_ROW_INT ← 'No. of intersection points' of INT_IMG for each Grid/Radial line.
4. X_ROW_INT_SER ← 'Series of No. intersection points' of INT_IMG for each Grid/Radial line.
5. Return X_ROW_INT and X_ROW_INT_SER row values.

4. Efficiency Evaluation

The proposed methodologies of 'Critical Points Analysis' are extended with additional enhancements to improve the accuracy and efficiency in character recognition process. The methods became suitable for all kind of characters like Vowels, Consonants, Guninthas and Vathus.

There is a possibility of extending the proposed feature extraction 'Critical Points Analysis' process further to improve the accuracy. It can be achieved by adding additional horizontal and vertical grid lines; and by adding additional radial lines after further minimizing the radial axis. The specified testing scenarios are telecasting with the high degree of accuracy and efficiency in character recognition.

Telugu Character 'JA'

(a) Gautami Font   (b) Vani Font   (c) Vajram Font
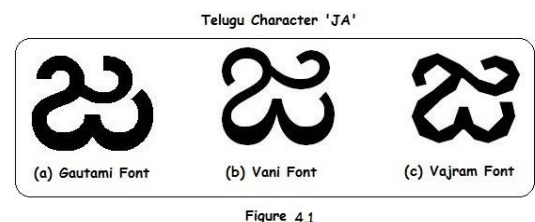
Figure 4.1

The proposed method is also verified with a character image 'జ'/'JA' with different fonts as shown in the Figure 4.1.

The proposed 10-way Grid based Analysis results are listed in Table 3; and 16-way Radial based Analysis results are listed in Table 4. The variation between Feature Vector-1 values of the character image is very minor, and vice versa in case of Feature Vector-2. The variation can be vanished by considering additional feature extraction like mean value of the all intersection points, finding intersection points at region-wise and coordinate-wise, and length of the character.

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Table 3: 10-way Grid based Analysis

10-way Grid based Analysis											
Feature Vector-1 values for the Telugu Character 'JA' fonts (Gautami, Vani and Vajram)											
File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
'Ja-Font-Gautami.JPG'	జ	2	4	6	8	12	15	18	19	22	23
'Ja-Font-Vani.JPG'	జ	3	7	8	11	15	17	20	22	24	27
'Ja-Fonts-Vajram.JPG'	జ	4	7	8	10	14	16	19	21	23	26
Feature Vector-2 values for the Telugu Character 'JA' fonts (Gautami, Vani and Vajram)											
File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
'Ja-Font-Gautami.JPG'	జ	2	9	13	15	20	23	26	29	33	34
'Ja-Font-Vani.JPG'	జ	3	7	8	11	15	17	20	26	30	34
'Ja-Fonts-Vajram.JPG'	జ	6	11	12	14	18	23	26	28	32	37

Table 4: 16-way Radial based Analysis

16-way Radial based Analysis																	
Feature Vector-1 values for the Telugu Character 'JA' fonts (Gautami, Vani and Vajram)																	
File Name	Telugu Character	E	EN	N	NW	W	WS	S	SE	E-EN	EN-N	N-NW	NW-W	W-WS	WS-S	S-SE	SE-E
'Ja-Font-Gautami.JPG'	జ	1	3	4	5	6	7	8	9	11	13	17	18	19	20	21	22
'Ja-Font-Vani.JPG'	జ	0	2	3	3	4	4	6	7	11	13	15	17	18	19	20	21
'Ja-Fonts-Vajram.JPG'	జ	0	1	2	4	5	5	6	7	9	11	12	14	15	16	17	18
Feature Vector-2 values for the Telugu Character 'JA' fonts (Gautami, Vani and Vajram)																	
File Name	Telugu Character	E	EN	N	NW	W	WS	S	SE	E-EN	EN-N	N-NW	NW-W	W-WS	WS-S	S-SE	SE-E
'Ja-Font-Gautami.JPG'	జ	1	3	4	5	8	9	11	12	17	20	30	31	33	35	37	39
'Ja-Font-Vani.JPG'	జ	0	3	5	5	6	6	10	11	25	29	32	36	38	40	42	44
'Ja-Fonts-Vajram.JPG'	జ	0	1	2	4	5	5	6	7	12	15	18	21	23	26	28	29

For efficiency evaluation, four printed and hand-written similar Telugu characters ('NA', 'PA', 'VA' and 'SA': Figure 4.2) are considered for comparison; and the report is listed at Annexure Figure A.3.

The comparison report is generated with the combination of three types of feature extraction techniques, i.e., Connected Components Analysis [9] and Closed Regions (Holes) Analysis [10] at Figure A.3(a); and Critical Points Analysis at Figure A.3(b & c).

(a) Telugu printed characters

(i) 'NA'   (ii) 'PA'   (iii) 'VA'   (iv) 'SA'

(b) Telugu hand-written characters

(i) 'NA'   (ii) 'PA'   (iii) 'VA'   (iv) 'SA'
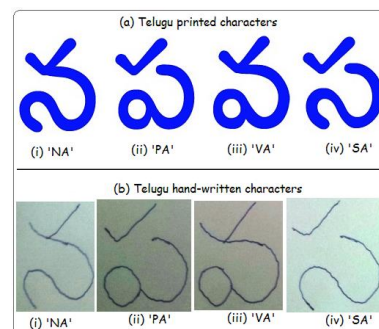
Figure 4.2

5. Conclusion

The proposed Critical Points Analysis would provide the OCR system with high degree of accuracy and efficiency with the combination of other morphological methods like Connected Components Analysis and Closed Regions (Holes) Analysis. These methods are validated for the printed and hand-written characters. The entire OCR system would give 100% result for printed characters and 92% result for hand-written characters, by using these methods.

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Annexure

RESULTS

10-way Grid based Analysis

Figure A.1.1: Matrix-1 values

(a) Matrix-1 for Vowels

	File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
	'V01_a.jpg'	అ	4	9	12	14	16	17	21	23	27	29
	'V02_aa.jpg'	ఆ	4	9	12	14	16	18	21	23	25	27
	'V03_i.jpg'	ఇ	3	5	6	8	11	13	16	18	20	23
	'V04_ee.jpg'	ఈ	2	4	7	11	15	18	21	24	25	27
V	V05_u.jpg	ఉ	1	2	6	9	12	13	15	18	20	23
O	'V06_oo.jpg'	ఊ	2	5	7	12	15	18	21	26	27	30
W	'V07_aRu.jpg'	ఋ	5	9	13	17	24	27	28	29	30	31
E	'V08_aRoo.jpg'	ౠ	7	13	17	21	28	28	28	29	31	32
L	'V09_e.jpg'	ఎ	1	2	3	6	9	10	12	14	16	18
S	V10_ae.jpg	ఏ	1	3	4	5	8	10	12	14	16	17
	'V11_ai.jpg'	ఐ	3	4	7	10	13	16	18	18	20	22
	'V12_o.jpg'	ఒ	2	3	5	7	10	12	15	16	17	18
	'V13_oa.jpg'	ఓ	1	3	5	7	10	12	16	18	19	20
	'V14_ow.jpg'	ఔ	3	6	8	10	13	15	19	21	23	26
	V15_am.jpg	అం	6	13	18	22	26	29	32	33	37	39
	'V16_aha.jpg'	అః	6	13	16	20	24	27	29	31	31	35

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(b) Matrix-1 for Consonants

	File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
	'C01_ka.jpg'	క	1	3	5	6	8	12	14	17	21	23
	'C02_kha.jpg'	ఖ	4	6	10	14	15	19	22	25	26	28
	'C03_ga.jpg'	గ	1	3	5	7	9	9	11	12	14	14
	'C04_gha.jpg'	ఘ	2	4	6	10	11	14	16	18	19	21
	'C05_injna.jpg'	ఙ	3	5	6	8	11	14	17	19	21	24
	'C06_ca.jpg'	చ	1	3	4	6	9	12	13	14	15	18
	'C07_Cha.jpg'	ఛ	2	3	5	8	8	11	12	14	16	18
	'C08_ja.jpg'	జ	3	6	7	9	12	15	18	20	22	25
	'C09_jha.jpg'	ఝ	2	6	10	15	15	17	20	21	23	24
	'C10_ini.jpg'	ఞ	4	5	7	9	12	15	18	20	21	22
	'C11_Tta.jpg'	ట	1	4	8	10	13	14	17	17	18	20
	'C12_Ttha.jpg'	ఠ	1	3	5	8	10	12	15	18	21	24
C	'C13_Dda.jpg'	డ	1	3	4	5	8	10	13	15	18	22
O	C14_Ddha.jpg	ఢ	2	4	5	8	9	11	13	19	23	27
N	'C15_nna.jpg'	ణ	4	6	8	12	15	18	20	21	24	26
S	'C16_ta.jpg'	త	1	4	8	14	16	18	22	24	29	33
O	'C17_tha.jpg'	థ	2	4	7	10	11	13	16	18	21	24
N	'C18_da.jpg'	ద	1	3	5	7	10	12	15	16	19	22
A	'C19_dha.jpg'	ధ	2	4	6	9	10	12	14	16	19	22
N	'C20_na.jpg'	న	1	3	4	7	10	13	15	18	21	23
T	'C21_pa.jpg'	ప	1	3	4	7	10	13	15	17	19	21
S	'C22_pha.jpg'	ఫ	2	3	4	7	8	11	14	16	18	19
	'C23_ba.jpg'	బ	3	5	7	9	12	15	18	19	20	21
	'C24_bha.jpg'	భ	2	5	7	10	10	13	15	16	18	20
	'C25_ma.jpg'	మ	2	3	5	9	13	16	18	20	21	23
	'C26_ya.jpg'	య	1	3	7	11	17	19	21	23	26	27
	'C27_ra.jpg'	ర	1	3	5	7	9	11	14	16	19	21
	'C28_la.jpg'	ల	3	8	10	12	14	15	18	19	20	22
	'C29_Lla.jpg'	ళ	1	3	7	9	11	13	18	21	23	26
	'C30_va.jpg'	వ	2	4	5	8	11	14	16	19	22	24
	'C31_Sa.jpg'	శ	1	4	5	8	10	11	13	17	20	24
	'C32_sha.jpg'	ష	2	4	5	8	12	14	16	18	20	21
	'C33_ssa.jpg'	స	1	1	2	5	8	11	13	15	17	19
	'C34_ha.jpg'	హ	1	5	8	11	14	17	19	22	22	25
	'C35_Rra.jpg'	ఱ	4	9	12	14	17	20	23	25	29	31
	'C36_Ksha.jpg'	క్ష	2	4	5	7	7	9	14	18	22	24

(c) Matrix-1 for Ka-Gunintham

	File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
	'Ka01_ka.jpg'	క	1	3	4	5	6	9	12	15	18	21
K	'Ka02_kaa.jpg'	కా	4	7	8	9	11	13	16	19	20	22
A	'Ka03_ki.jpg'	కి	3	4	6	7	8	10	13	18	23	26
-	'Ka04_kee.jpg'	కీ	1	2	4	5	6	9	12	17	23	26
G	'Ka05_ku.jpg'	కు	1	4	6	8	10	14	17	20	21	23
u	'Ka06_koo.jpg'	కూ	1	7	11	13	15	16	21	22	24	25
n	'Ka07_kru.jpg'	కృ	2	4	6	9	12	15	18	21	22	24
i	'Ka08_kroo.jpg'	కౄ	2	5	9	12	15	18	22	23	24	25
n	'Ka09_ke.jpg'	కె	1	3	4	5	7	11	15	19	23	28
t	'Ka10_kea.jpg'	కే	1	2	4	5	6	10	14	18	22	28
h	'Ka11_kai.jpg'	కై	1	2	3	5	6	11	15	20	24	29
a	'Ka12_ko.jpg'	కొ	3	4	6	7	8	11	15	19	20	22
m	Ka13_koa.jpg'	కో	2	5	7	8	9	13	16	20	22	24
	Ka14_kau.jpg'	కౌ	3	5	6	7	9	12	16	20	21	23
	Ka15_kam.jpg'	కం	2	4	7	10	14	19	22	22	23	25
	Ka16_kah.JPG'	కః	2	4	7	8	12	15	18	21	21	25

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(d) Matrix-1 for Ka-Vaththu

	File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
K A - V a t h t h u	'KaVt01_KKa.jpg'	క్క	5	7	9	11	13	16	19	19	22	24
	'KaVt02_KKha.jpg'	క్ఖ	2	3	5	8	12	17	25	30	34	39
	'KaVt03_KGa.jpg'	క్గ	3	4	6	6	8	10	15	19	23	29
	'KaVt04_KGha.jpg'	క్ఘ	3	4	6	8	12	17	21	26	30	35
	'KaVt05_KInjna.jpg'	క్ఙ	2	3	5	5	7	12	19	24	28	33
	'KaVt06_KCa.jpg'	క్చ	3	5	8	9	11	13	16	17	19	21
	'KaVt07_KCha.jpg'	క్ఛ	2	4	7	8	10	13	17	18	20	22
	'KaVt08_KJa.jpg'	క్జ	4	5	6	6	8	13	19	24	29	34
	'KaVt09_KJha.jpg'	క్ఝ	2	3	5	8	12	15	21	25	32	37
	'KaVt10_KIni.jpg'	క్ఞ	3	4	6	7	9	12	18	23	29	33
	'KaVt11_KTta.jpg'	క్ట	3	4	6	6	9	15	20	23	28	33
	'KaVt12_KTtha.jpg'	క్ఠ	3	4	6	6	8	10	15	19	24	30
	'KaVt13_KDda.jpg'	క్డ	2	3	5	5	6	10	16	21	26	32
	'KaVt14_KDdha.jpg'	క్ఢ	2	3	5	7	8	12	18	24	29	35
	'KaVt15_KNna.jpg'	క్ణ	3	4	6	6	8	14	19	22	28	35
	'KaVt16_KTa.jpg'	క్త	3	4	5	7	7	11	13	17	20	26
	'KaVt17_KTha.jpg'	క్థ	2	3	5	7	9	14	17	22	26	31
	'KaVt18_KDa.jpg'	క్ద	3	4	6	6	8	13	18	22	27	33
	'KaVt19_KDha.jpg'	క్ధ	2	3	5	7	9	13	18	24	29	34
	'KaVt20_KNa.jpg'	క్న	3	5	7	8	10	12	16	18	21	22
	'KaVt21_KPa.jpg'	క్ప	3	5	8	9	10	13	16	16	18	20
	'KaVt22_KPha.jpg'	క్ఫ	2	4	7	8	11	14	17	17	19	21
	'KaVt23_KBa.jpg'	క్బ	2	4	7	8	10	14	17	17	20	22
	'KaVt24_KBha.jpg'	క్భ	3	5	8	10	12	14	16	16	18	20
	'KaVt25_KMa.jpg'	క్మ	4	6	9	12	13	16	19	19	23	26
	'KaVt26_KYa.jpg'	క్య	5	7	10	11	13	17	19	23	26	28
	'KaVt27_KRa.jpg'	క్ర	2	3	4	6	8	10	13	17	21	25
	'KaVt28_KLa.jpg'	క్ల	2	3	4	4	8	10	15	19	23	29
	'KaVt29_KLla.jpg'	క్ళ	3	6	9	11	13	18	21	22	25	28
	'KaVt30_KVa.jpg'	క్వ	5	7	9	10	11	14	18	19	22	25
	'KaVt31_KSa.jpg'	క్శ	3	5	8	9	12	15	17	21	22	24
	'KaVt32_KSha.jpg'	క్ష	2	3	4	6	6	7	11	15	18	19
	'KaVt33_KSsa.jpg'	క్స	3	6	9	10	11	14	17	17	18	20
	'KaVt34_Kha.jpg'	క్హ	2	3	4	4	7	11	15	20	24	29
	KaVt35_KSRra.jpg'	క్క్ష	2	3	4	4	11	17	23	28	34	39

Figure A.1.2: Matrix-2 values

(a) Matrix-2 for Vowels

	File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
V O W E L S	'V01_a.jpg'	అ	4	10	13	17	20	22	26	28	43	47
	'V02_aa.jpg'	ఆ	6	11	18	21	24	29	35	37	39	43
	'V03_i.jpg'	ఇ	6	10	12	16	21	24	27	37	40	44
	'V04_ee.jpg'	ఈ	2	5	8	12	18	21	25	32	33	47
	V05_u.jpg'	ఉ	2	3	70	74	78	79	81	84	86	95
	'V06_oo.jpg'	ఊ	2	5	17	22	25	28	34	39	40	43
	'V07_aRu.jpg'	ఋ	5	9	13	17	24	32	33	34	40	41
	'V08_aRoo.jpg'	ౠ	7	13	17	21	28	31	66	72	74	75
	'V09_e.jpg'	ఎ	1	3	5	12	17	18	20	22	24	28
	V10_ae.jpg'	ఏ	2	5	6	8	14	28	30	32	34	36
	'V11_ai.jpg'	ఐ	6	8	15	21	34	39	41	44	47	49
	'V12_o.jpg'	ఒ	3	4	8	12	22	26	30	37	38	40
	'V13_oa.jpg'	ఓ	2	6	10	14	18	20	24	29	30	31
	'V14_ow.jpg'	ఔ	4	22	24	27	30	40	44	46	48	51
	V15_am.jpg'	అం	6	13	18	22	26	32	36	45	50	53
	'V16_aha.jpg'	అః	6	13	16	20	24	28	31	34	34	38

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(b) Matrix-2 for Consonants

	File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
C O N S O N A N T S	'C01_ka.jpg'	క	3	8	14	15	21	25	30	33	37	51
	'C02_kha.jpg'	ఖ	7	11	17	23	25	29	32	53	54	56
	'C03_ga.jpg'	గ	1	7	11	16	19	21	24	25	30	31
	'C04_gha.jpg'	ఘ	2	5	7	11	12	15	17	19	20	22
	'C05_injna.jpg'	ఙ	3	5	7	10	16	19	22	24	26	29
	'C06_ca.jpg'	చ	2	7	8	11	16	19	20	22	27	30
	'C07_Cha.jpg'	ఛ	5	8	13	17	17	20	21	23	26	28
	'C08_ja.jpg'	జ	4	7	12	16	22	27	31	33	36	39
	'C09_jha.jpg'	ఝ	3	9	13	18	18	22	25	26	28	29
	'C10_ini.jpg'	ఞ	4	5	13	15	18	21	25	35	36	38
	'C11_Tta.jpg'	ట	2	5	13	17	22	25	28	37	38	40
	'C12_Ttha.jpg'	ఠ	1	9	11	18	20	22	26	29	32	37
	'C13_Dda.jpg'	డ	1	5	6	8	13	15	18	20	24	28
	'C14_Ddha.jpg'	ఢ	2	9	11	16	17	20	25	33	37	41
	'C15_nna.jpg'	ణ	4	6	8	13	17	23	27	31	34	36
	'C16_ta.jpg'	త	2	5	9	19	24	28	32	34	39	52
	'C17_tha.jpg'	థ	5	7	13	18	22	24	27	33	36	40
	'C18_da.jpg'	ద	1	8	11	15	20	22	25	34	37	41
	'C19_dha.jpg'	ధ	5	9	13	18	22	24	26	47	50	53
	'C20_na.jpg'	న	2	8	9	13	18	21	23	26	30	32
	'C21_pa.jpg'	ప	2	5	7	12	17	20	22	25	27	32
	'C22_pha.jpg'	ఫ	3	4	6	12	14	17	20	23	25	28
	'C23_ba.jpg'	బ	5	9	16	20	26	31	35	37	38	39
	'C24_bha.jpg'	భ	2	5	8	12	12	15	18	19	21	23
	'C25_ma.jpg'	మ	2	3	5	9	13	17	20	23	24	26
	'C26_ya.jpg'	య	1	3	7	11	18	20	22	24	30	31
	'C27_ra.jpg'	ర	1	4	7	12	16	22	27	29	33	35
	'C28_la.jpg'	ల	3	12	16	19	23	30	34	35	36	38
	'C29_Lla.jpg'	ళ	1	5	11	14	17	19	25	28	30	33
	'C30_va.jpg'	వ	3	9	11	15	21	26	29	33	36	38
	'C31_Sa.jpg'	శ	2	5	8	11	17	18	20	24	32	36
	'C32_sha.jpg'	ష	2	17	18	21	27	32	35	37	39	40
	'C33_ssa.jpg'	స	2	2	3	9	14	19	21	24	26	30
	'C34_ha.jpg'	హ	1	44	47	50	53	56	58	61	61	65
	'C35_Rra.jpg'	ఱ	5	11	15	17	20	23	27	30	34	36
	'C36_Ksha.jpg'	క్ష	4	10	11	13	13	19	24	28	34	36

(c) Matrix-2 for Ka-Gunintham

	File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
K A - G u n i n t h a m	'Ka01_ka.jpg'	క	1	3	4	5	6	9	15	18	21	25
	'Ka02_kaa.jpg'	కా	4	7	8	9	11	13	16	21	22	25
	'Ka03_ki.jpg'	కి	7	10	15	18	20	22	25	30	37	47
	'Ka04_kee.jpg'	కీ	15	17	21	23	25	28	31	36	43	50
	'Ka05_ku.jpg'	కు	1	4	6	8	10	14	17	20	21	23
	'Ka06_koo.jpg'	కూ	1	27	31	48	50	51	57	58	61	72
	'Ka07_kru.jpg'	కృ	3	5	8	13	17	22	25	29	31	33
	'Ka08_kroo.jpg'	కౄ	2	29	33	36	39	42	46	50	52	54
	'Ka09_ke.jpg'	కె	1	5	6	7	11	15	19	23	27	32
	'Ka10_kea.jpg'	కే	3	5	9	12	15	19	23	27	33	39
	'Ka11_kai.jpg'	కై	3	4	7	30	46	52	56	61	65	70
	'Ka12_ko.jpg'	కొ	4	5	7	12	14	20	24	29	45	47
	Ka13_koa.jpg'	కో	20	24	32	34	35	41	44	48	60	62
	Ka14_kau.jpg'	కౌ	3	5	6	7	9	12	16	26	27	29
	Ka15_kam.jpg'	కం	2	4	7	10	14	19	25	25	32	34
	Ka16_kah.JPG'	కః	2	4	7	8	15	18	21	25	25	29

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(d) Matrix-2 for Ka-Vaththu

File Name	Telugu Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
'KaVt01_KKa.jpg'	క్క	6	9	11	15	17	20	25	25	32	34
'KaVt02_KKha.jpg'	క్ఖ	3	4	14	17	21	28	36	44	48	54
'KaVt03_KGa.jpg'	క్గ	6	7	14	14	18	24	29	33	37	43
'KaVt04_KGha.jpg'	క్ఘ	3	9	12	27	31	36	40	45	50	55
'KaVt05_KInjna.jpg'	క్ఞ	3	4	13	13	23	29	37	42	46	51
'KaVt06_KCa.jpg'	క్చ	17	20	25	26	28	31	35	36	38	40
'KaVt07_KCha.jpg'	క్ఛ	2	7	12	13	15	18	22	23	25	27
'KaVt08_KJa.jpg'	క్జ	10	11	12	12	24	29	35	40	45	50
'KaVt09_KJha.jpg'	క్ఝ	9	18	23	49	54	64	70	74	86	91
'KaVt10_KIni.jpg'	క్ఞ	30	32	40	42	46	50	56	61	68	72
'KaVt11_KTta.jpg'	క్ట	34	37	47	47	63	69	76	79	85	90
'KaVt12_KTtha.jpg'	క్ఠ	15	18	23	23	26	44	49	54	59	65
'KaVt13_KDda.jpg'	క్డ	5	8	10	10	12	16	22	27	32	38
'KaVt14_KDdha.jpg'	క్ఢ	3	4	17	20	22	27	33	39	44	50
'KaVt15_KNna.jpg'	క్ణ	15	18	27	27	29	35	40	43	49	56
'KaVt16_KTa.jpg'	క్త	6	8	11	41	41	45	50	54	65	72
'KaVt17_KTha.jpg'	క్థ	8	18	28	44	48	55	58	63	67	72
'KaVt18_KDa.jpg'	క్ద	21	22	32	32	35	40	46	50	55	61
'KaVt19_KDha.jpg'	క్ధ	3	4	14	17	21	25	31	37	42	47
'KaVt20_KNa.jpg'	క్న	5	7	9	10	17	20	24	26	29	30
'KaVt21_KPa.jpg'	క్ప	7	10	13	14	15	18	21	21	23	25
'KaVt22_KPha.jpg'	క్ఫ	2	4	10	11	14	17	20	20	23	25
'KaVt23_KBa.jpg'	క్బ	2	5	8	9	14	18	21	21	25	27
'KaVt24_KBha.jpg'	క్భ	18	24	27	39	41	44	49	49	52	54
'KaVt25_KMa.jpg'	క్మ	21	23	28	31	32	35	38	38	42	45
'KaVt26_KYa.jpg'	క్య	7	10	13	14	17	21	23	27	30	35
'KaVt27_KRa.jpg'	క్ర	2	3	4	10	12	25	28	32	37	41
'KaVt28_KLa.jpg'	క్ల	6	8	10	10	15	34	39	43	47	53
'KaVt29_KLla.jpg'	క్ళ	8	16	22	27	29	34	37	38	41	44
'KaVt30_KVa.jpg'	క్వ	8	12	14	15	16	19	23	25	29	32
'KaVt31_KSa.jpg'	క్స	20	26	29	30	43	46	48	52	54	56
'KaVt32_KSha.jpg'	క్శ	2	3	4	6	6	7	12	16	21	22
'KaVt33_KSsa.jpg'	క్ష	6	15	18	19	20	23	26	26	28	30
'KaVt34_Kha.jpg'	క్హ	2	3	6	6	10	19	23	28	34	39
KaVt35_KSRra.jpg'	క్ష్ర	4	7	8	8	32	38	44	49	55	60

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16-way Radial based Analysis

Figure A.2.1: Matrix-1 values

(a) Matrix-1 for Vowels

File Name	Telugu Character	E	E-EN	EN	EN-N	N	N-NW	NW	NW-W	W	W-WS	WS	WS-S	S	S-SE	SE	SE-E
'V01_a.jpg'	అ	2	15	4	18	4	20	6	21	7	23	9	25	11	27	13	29
'V02_aa.jpg'	ఆ	2	15	4	15	4	17	6	20	7	22	9	24	11	26	13	28
'V03_i.jpg'	ఇ	1	11	2	12	3	13	4	15	4	18	6	19	7	19	10	20
'V04_ee.jpg'	ఈ	2	14	2	15	4	16	5	17	6	19	8	21	10	23	13	27
'V05_u.jpg'	ఉ	2	13	3	14	4	15	5	16	7	17	8	18	10	19	13	21
'V06_oo.jpg'	ఊ	1	11	2	11	4	11	6	13	7	14	7	17	10	19	10	21
'V07_aRu.jpg'	ఋ	2	15	3	16	3	18	5	21	7	23	10	25	11	26	13	28
'V08_aRoo.jpg'	ౠ	2	20	6	23	7	24	10	27	12	29	14	31	15	33	17	35
'V09_e.jpg'	ఎ	1	5	1	6	2	6	2	6	2	9	3	11	4	12	4	13
'V10_ae.jpg'	ఏ	1	9	2	10	3	11	4	12	4	12	6	14	7	15	8	16
'V11_ai.jpg'	ఐ	1	9	1	10	2	11	3	11	5	13	6	15	7	16	8	17
'V12_o.jpg'	ఒ	1	5	1	5	1	7	2	9	3	10	3	11	5	12	5	13
'V13_oa.jpg'	ఓ	0	9	0	9	0	10	3	10	5	14	6	15	8	16	9	17
'V14_ow.jpg'	ఔ	0	13	2	14	3	18	6	22	8	28	8	29	10	30	11	31
'V15_am.jpg'	అం	2	15	3	15	4	16	7	19	10	20	12	21	12	21	13	23
'V16_aha.jpg'	అః	1	18	4	18	5	20	8	23	10	26	11	27	12	28	15	31

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(b) Matrix-1 for Consonants

	File Name	Telugu Character	E	E-EN	EN	EN-N	N	N-NW	NW	NW-W	W	W-WS	WS	WS-S	S	S-SE	SE	SE-E
C O N S O N A N T S	'C01_ka.jpg'	క	1	14	3	16	4	17	7	18	8	19	9	21	11	23	13	23
	'C02_kha.jpg'	ఖ	1	12	2	13	4	15	5	15	7	17	8	19	10	20	11	21
	'C03_ga.jpg'	గ	1	11	5	12	6	13	7	14	8	15	9	15	9	15	10	16
	'C04_gha.jpg'	ఘ	2	11	3	12	4	14	5	14	5	16	6	18	7	19	9	21
	'C05_injna.jpg'	ఙ	0	9	1	12	2	14	4	16	5	17	6	18	7	19	8	20
	'C06_ca.jpg'	చ	1	6	1	7	2	7	2	7	2	7	3	8	4	9	5	10
	'C07_Cha.jpg'	ఛ	1	8	2	9	3	9	3	9	4	10	5	11	6	13	7	14
	'C08_ja.jpg'	జ	0	11	2	12	3	14	5	16	6	17	7	18	8	19	9	20
	'C09_jha.jpg'	ఝ	2	10	3	11	3	12	3	14	5	16	7	17	8	19	8	21
	'C10_ini.jpg'	ఞ	1	12	3	14	4	15	5	16	6	18	7	20	9	21	10	22
	'C11_Tta.jpg'	ట	1	8	1	8	1	9	3	11	6	12	6	13	7	14	7	15
	'C12_Ttha.jpg'	ఠ	1	11	3	12	4	13	5	14	6	15	7	16	9	17	10	18
	'C13_Dda.jpg'	డ	0	8	1	9	2	10	3	11	4	12	4	13	5	15	7	17
	C14_Ddha.jpg'	ఢ	0	12	1	14	2	17	2	18	3	19	4	20	10	21	11	23
	'C15_nna.jpg'	ణ	1	10	2	11	3	12	4	13	5	14	6	15	6	17	9	20
	'C16_ta.jpg'	త	2	11	3	12	4	13	4	13	6	16	9	18	10	19	10	22
	'C17_tha.jpg'	థ	1	12	2	14	3	16	5	16	7	17	7	18	10	19	11	20
	'C18_da.jpg'	ద	1	9	2	10	3	13	4	14	5	15	6	16	7	17	8	18
	'C19_dha.jpg'	ధ	1	9	1	11	2	13	3	14	4	15	5	16	7	17	8	18
	'C20_na.jpg'	న	1	9	2	10	4	11	5	11	5	13	7	14	8	15	8	16
	'C21_pa.jpg'	ప	1	6	2	6	3	7	3	10	3	14	3	16	4	17	5	18
	'C22_pha.jpg'	ఫ	1	8	2	9	3	10	3	10	3	12	5	14	6	15	7	16
	'C23_ba.jpg'	బ	1	7	1	7	1	9	3	11	4	12	5	13	6	14	6	15
	'C24_bha.jpg'	భ	1	11	5	11	5	11	7	13	8	14	9	15	10	16	10	17
	'C25_ma.jpg'	మ	2	10	3	11	4	13	6	13	6	15	7	16	8	18	9	20
	'C26_ya.jpg'	య	1	9	2	10	3	11	3	12	5	14	6	17	7	18	9	20
	'C27_ra.jpg'	ర	1	11	6	12	7	13	8	14	9	15	9	16	10	17	10	18
	'C28_la.jpg'	ల	1	7	2	7	2	9	3	14	4	15	4	16	5	17	6	18
	'C29_Lla.jpg'	ళ	1	13	3	14	4	14	5	16	8	17	9	19	11	20	12	21
	'C30_va.jpg'	వ	1	9	2	10	4	12	5	12	5	14	7	16	8	17	8	18
	'C31_Sa.jpg'	శ	1	13	5	14	6	15	6	15	6	17	6	18	9	21	12	22
	'C32_sha.jpg'	ష	1	7	2	8	4	9	4	11	4	13	5	15	6	16	6	17
	'C33_ssa.jpg'	స	1	7	2	7	3	8	4	10	4	12	5	14	6	15	6	16
	'C34_ha.jpg'	హ	3	11	5	13	7	15	8	17	8	19	9	20	10	21	11	22
	'C35_Rra.jpg'	ఱ	2	13	4	16	4	18	4	21	5	23	7	25	9	27	11	29
	'C36_Ksha.jpg'	క్ష	0	9	0	11	1	13	2	14	3	14	5	16	7	18	8	19

(c) Matrix-1 for Ka-Gunintham

	File Name	Telugu Character	E	E-EN	EN	EN-N	N	N-NW	NW	NW-W	W	W-WS	WS	WS-S	S	S-SE	SE	SE-E
K A - G u n i n t h a m	'Ka01_ka.jpg'	క	0	10	2	11	3	12	4	13	5	14	6	16	8	18	9	19
	'Ka02_kaa.jpg'	కా	0	11	1	12	2	13	4	14	5	15	7	16	9	16	9	16
	'Ka03_ki.jpg'	కి	1	14	3	17	6	18	7	19	8	20	9	22	11	24	13	24
	'Ka04_kee.jpg'	కీ	1	12	2	15	6	16	6	16	7	17	8	19	10	21	12	21
	'Ka05_ku.jpg'	కు	1	10	1	10	2	12	3	13	4	14	6	16	8	17	9	18
	'Ka06_koo.jpg'	కూ	3	13	5	13	5	14	5	17	6	18	7	20	8	21	9	22
	'Ka07_kru.jpg'	కృ	1	8	1	8	2	9	3	10	4	10	5	11	7	14	7	15
	'Ka08_kroo.jpg'	కౄ	3	14	5	14	5	15	6	16	7	18	9	18	11	19	12	20
	'Ka09_ke.jpg'	కె	0	13	2	15	4	17	5	18	6	19	8	21	10	23	12	26
	'Ka10_kea.jpg'	కే	1	15	3	18	5	20	7	21	8	22	9	24	11	26	13	26
	'Ka11_kai.jpg'	కై	1	16	4	19	7	22	9	24	9	25	12	28	14	30	15	31
	'Ka12_ko.jpg'	కొ	1	12	3	15	5	17	6	19	7	20	9	22	11	24	11	24
	Ka13_koa.jpg'	కో	1	12	3	13	5	13	7	14	8	15	9	17	11	19	11	19
	Ka14_kau.jpg'	కౌ	0	9	1	12	3	13	3	14	4	15	5	17	7	17	7	17
	Ka15_kam.jpg'	కం	2	8	2	8	2	9	5	10	6	11	7	13	7	16	8	18
	Ka16_kah.JPG'	కః	2	11	2	12	4	13	5	14	6	15	7	17	9	20	11	20

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(d) Matrix-1 for Ka-Vaththu

	File Name	Telugu Character	E	EN	N	NW	W	WS	S	SE	E-EN	EN-N	N-NW	NW-W	W-WS	WS-S	S-SE	SE-E
	'KaVt01_KKa.jpg'	క్క	1	2	2	4	5	5	5	5	6	7	8	11	11	11	13	16
	'KaVt02_KKha.jpg'	క్ఖ	1	1	3	5	6	11	14	16	17	19	22	22	25	27	27	30
	'KaVt03_KGa.jpg'	క్గ	1	5	7	9	10	13	15	17	18	20	23	24	25	29	31	32
	'KaVt04_KGha.jpg'	క్ఘ	1	3	5	7	8	11	14	16	17	20	22	22	23	25	27	33
	'KaVt05_KInjna.jpg'	క్ఙ	1	4	6	7	8	12	15	17	19	21	24	27	28	32	35	36
	'KaVt06_KCa.jpg'	క్చ	1	2	2	5	7	7	8	8	9	9	10	13	13	13	14	15
	'KaVt07_KCha.jpg'	క్ఛ	1	2	2	5	7	7	8	9	10	11	12	15	15	15	17	18
	'KaVt08_KJa.jpg'	క్జ	1	3	5	7	7	11	14	17	18	20	22	25	27	31	34	35
	'KaVt09_KJha.jpg'	క్ఝ	1	3	5	7	8	10	12	14	15	18	20	20	23	25	28	31
	'KaVt10_KIni.jpg'	క్ఞ	1	3	5	7	8	10	14	17	18	21	24	24	27	30	33	35
K	'KaVt11_KTta.jpg'	క్ట	1	2	4	6	7	10	12	15	16	19	22	25	26	30	32	33
A	'KaVt12_KTtha.jpg'	క్ఠ	1	4	6	8	9	12	15	17	18	20	23	23	24	27	30	31
-	'KaVt13_KDda.jpg'	క్డ	1	3	5	7	8	10	13	17	19	21	24	25	26	29	32	33
V	'KaVt14_KDdha.jpg'	క్ఢ	1	3	5	7	8	10	14	18	19	21	24	24	25	26	27	28
a	'KaVt15_KNna.jpg'	క్ణ	1	2	4	6	7	9	11	15	16	18	21	21	22	25	29	30
t	'KaVt16_KTa.jpg'	క్త	1	4	6	8	8	10	12	14	15	17	19	21	22	24	27	28
h	'KaVt17_KTha.jpg'	క్థ	1	3	5	6	7	10	13	16	17	19	21	21	22	23	24	25
t	'KaVt18_KDa.jpg'	క్ద	1	3	5	7	8	11	14	17	18	20	22	26	27	30	33	34
h	'KaVt19_KDha.jpg'	క్ధ	1	4	6	7	8	10	14	17	18	20	23	24	25	26	27	28
u	'KaVt20_KNa.jpg'	క్న	1	2	2	4	5	5	7	8	9	10	12	15	15	15	18	19
	'KaVt21_KPa.jpg'	క్ప	1	2	2	4	6	6	6	7	8	8	11	13	15	15	16	17
	'KaVt22_KPha.jpg'	క్ఫ	1	2	2	5	7	7	7	7	8	9	11	13	13	13	15	16
	'KaVt23_KBa.jpg'	క్బ	1	2	2	5	7	7	7	7	8	8	10	12	12	12	15	16
	'KaVt24_KBha.jpg'	క్భ	1	2	2	4	6	6	6	8	8	9	12	12	12	16	17	
	'KaVt25_KMa.jpg'	క్మ	1	2	2	5	7	7	7	10	11	12	14	17	18	18	20	22
	'KaVt26_KYa.jpg'	క్య	2	5	8	10	11	12	13	17	18	19	21	23	24	24	26	26
	'KaVt27_KRa.jpg'	క్ర	0	0	1	2	3	5	7	9	9	11	13	14	15	17	19	20
	'KaVt28_KLa.jpg'	క్ల	1	4	6	8	8	9	11	14	15	17	20	23	24	27	29	30
	'KaVt29_KLla.jpg'	క్ళ	1	2	3	6	8	8	8	9	10	10	12	13	14	14	19	20
	'KaVt30_KVa.jpg'	క్వ	1	2	2	5	6	6	7	8	9	11	12	15	15	15	16	17
	'KaVt31_KSa.jpg'	క్స	1	2	6	8	9	9	9	11	12	12	14	16	18	18	21	22
	'KaVt32_KSha.jpg'	క్శ	1	3	5	5	5	5	7	8	7	8	10	11	11	13	15	16
	'KaVt33_KSsa.jpg'	క్ష	1	2	2	5	7	7	7	7	8	8	10	11	12	12	13	14
	'KaVt34_Kha.jpg'	క్హ	1	3	5	7	7	9	12	16	17	20	22	22	23	26	28	31
	KaVt35_KSRra.jpg'	క్ఱ	1	3	5	7	7	9	12	14	15	17	19	19	20	24	28	29

Figure A.2.2: Matrix-2 values

(a) Matrix-2 for Vowels

	File Name	Telugu Character	E	E-EN	EN	EN-N	N	N-NW	NW	NW-W	W	W-WS	WS	WS-S	S	S-SE	SE	SE-E
	'V01_a.jpg'	అ	2	18	5	30	5	34	7	37	8	41	10	46	12	51	14	54
	'V02_aa.jpg'	ఆ	6	20	8	20	8	24	10	31	11	35	13	40	15	45	17	49
	'V03_i.jpg'	ఇ	2	25	3	27	12	29	14	33	14	40	16	42	18	44	22	50
V	'V04_ee.jpg'	ఈ	2	19	2	20	8	23	10	24	11	27	13	30	15	35	18	43
O	V05_u.jpg	ఉ	39	76	40	78	42	80	43	81	70	83	71	84	73	85	76	90
W	'V06_oo.jpg'	ఊ	6	25	7	27	9	30	12	34	18	36	18	42	21	47	21	50
E	'V07_aRu.jpg'	ఋ	2	15	3	16	3	20	5	23	7	25	10	29	11	30	13	33
L	'V08_aRoo.jpg'	ౠ	2	28	7	36	10	37	13	42	15	46	19	54	22	58	24	60
S	V09_e.jpg	ఎ	2	6	2	7	3	7	3	7	3	18	4	21	5	22	5	23
	V10_ae.jpg	ఏ	1	11	2	12	3	13	5	14	5	14	7	17	8	18	9	21
	'V11_ai.jpg'	ఐ	2	15	2	17	4	19	5	19	10	23	12	28	13	31	14	34
	'V12_o.jpg'	ఒ	2	13	2	13	2	16	3	21	5	24	5	25	13	28	13	31
	'V13_oa.jpg'	ఓ	0	19	0	19	0	24	7	29	11	48	12	49	17	51	19	54
	'V14_ow.jpg'	ఔ	0	15	2	22	3	30	6	37	8	50	8	51	10	52	11	53
	'V15_am.jpg'	అం	2	24	3	24	12	26	15	31	18	34	20	38	20	38	21	41
	'V16_aha.jpg'	అః	1	22	4	22	6	28	11	34	13	45	14	46	15	47	18	52

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(b) Matrix-2 for Consonants

	File Name	Telugu Character	E	E-EN	EN	EN-N	N	N-NW	NW	NW-W	W	W-WS	WS	WS-S	S	S-SE	SE	SE-E
C O N S O N A N T S	'C01_ka.jpg'	క	3	25	6	31	7	32	11	34	14	35	15	37	17	40	21	40
	'C02_kha.jpg'	ఖ	2	37	3	45	9	48	11	48	15	54	17	61	33	63	34	65
	'C03_ga.jpg'	గ	1	27	13	31	14	37	15	38	18	41	21	41	21	41	23	46
	'C04_gha.jpg'	ఘ	2	12	3	13	4	15	5	15	5	18	6	22	7	23	9	26
	'C05_injna.jpg'	ఙ	0	12	1	19	2	25	4	29	6	31	7	33	8	34	9	38
	'C06_ca.jpg'	చ	1	6	1	7	2	7	2	7	2	7	3	8	4	9	5	12
	'C07_Cha.jpg'	ఛ	2	13	3	14	4	14	4	14	7	15	8	17	9	21	10	23
	'C08_ja.jpg'	జ	0	18	3	19	4	23	6	27	11	30	12	32	13	34	14	37
	'C09_jha.jpg'	ఝ	2	12	3	14	3	15	3	18	5	21	7	22	8	25	8	27
	'C10_ini.jpg'	ఞ	1	28	3	31	5	33	6	34	13	37	14	40	22	41	23	43
	'C11_Tta.jpg'	ట	2	23	2	23	2	41	6	44	12	47	12	48	22	49	22	52
	'C12_Ttha.jpg'	ఠ	1	15	3	17	4	24	5	25	6	29	8	30	10	31	12	36
	'C13_Dda.jpg'	డ	0	9	1	14	2	16	3	17	4	20	4	22	5	30	7	34
	C14_Ddha.jpg'	ఢ	0	15	1	18	2	25	2	26	4	27	5	28	13	30	14	34
	'C15_nna.jpg'	ణ	1	15	2	17	6	19	7	21	8	23	9	25	9	31	12	40
	'C16_ta.jpg'	త	2	11	3	13	4	20	4	20	6	27	9	31	10	32	10	39
	'C17_tha.jpg'	థ	2	19	3	25	4	30	7	35	11	37	11	39	17	41	18	43
	'C18_da.jpg'	ద	2	20	3	22	4	31	5	34	6	37	7	38	16	39	18	42
	'C19_dha.jpg'	ధ	2	31	2	35	3	39	4	40	6	42	7	44	28	46	29	49
	'C20_na.jpg'	న	1	9	2	10	4	17	5	17	5	23	7	24	8	25	8	28
	'C21_pa.jpg'	ప	2	8	3	8	5	11	5	17	5	27	5	32	6	33	7	36
	'C22_pha.jpg'	ఫ	2	10	3	11	5	12	5	12	5	15	7	20	8	22	9	24
	'C23_ba.jpg'	బ	2	16	2	16	2	23	5	27	10	30	11	32	13	34	13	37
	'C24_bha.jpg'	భ	1	13	5	13	5	13	7	17	9	18	11	19	12	21	12	22
	'C25_ma.jpg'	మ	2	15	3	16	4	19	9	19	9	22	10	24	12	28	13	31
	'C26_ya.jpg'	య	2	10	2	11	3	11	3	19	5	22	6	39	7	40	9	43
	'C27_ra.jpg'	ర	2	23	18	24	19	27	20	29	21	30	21	32	22	33	22	38
	'C28_la.jpg'	ల	2	10	3	10	3	13	4	28	6	31	6	32	7	35	9	38
	'C29_Lla.jpg'	ళ	1	15	3	16	4	16	5	22	10	25	11	33	13	34	14	35
	'C30_va.jpg'	వ	2	12	3	13	6	16	7	16	7	22	10	26	11	27	11	30
	'C31_Sa.jpg'	శ	3	24	13	25	14	26	14	26	14	34	14	35	17	39	23	41
	'C32_sha.jpg'	ష	1	7	2	9	4	10	4	13	4	15	5	19	6	20	6	22
	'C33_ssa.jpg'	స	1	9	2	9	3	11	4	13	4	20	5	24	7	25	7	28
	'C34_ha.jpg'	హ	3	13	5	16	7	20	8	23	8	26	9	27	10	30	11	32
	'C35_Rra.jpg'	ఱ	3	19	6	29	6	32	6	38	7	44	9	48	12	52	14	57
	'C36_Ksha.jpg'	క్ష	0	10	0	13	1	18	2	21	3	24	5	27	7	31	9	36

(c) Matrix-2 for Ka-Gunintham

	File Name	Telugu Character	E	E-EN	EN	EN-N	N	N-NW	NW	NW-W	W	W-WS	WS	WS-S	S	S-SE	SE	SE-E
K A - G u n i n t h a m	'Ka01_ka.jpg'	క	0	11	2	12	3	13	4	14	5	15	6	19	8	23	9	24
	'Ka02_kaa.jpg'	కా	0	14	1	15	2	17	4	18	5	20	7	22	11	22	11	22
	'Ka03_ki.jpg'	కి	3	18	6	22	9	23	10	24	12	26	13	28	15	30	17	30
	'Ka04_kee.jpg'	కీ	2	20	3	24	7	33	8	35	10	36	11	40	13	44	15	44
	'Ka05_ku.jpg'	కు	1	12	1	12	2	21	3	22	4	25	6	27	8	28	9	30
	'Ka06_koo.jpg'	కూ	3	15	7	15	7	17	7	23	8	26	9	31	10	33	11	35
	'Ka07_kru.jpg'	కృ	1	11	1	11	3	13	4	14	6	18	7	20	9	27	9	29
	'Ka08_kroo.jpg'	కౄ	3	20	5	20	5	21	6	22	7	26	11	26	15	27	16	29
	'Ka09_ke.jpg'	కె	0	17	2	20	4	23	5	27	6	30	8	33	10	37	12	48
	'Ka10_kea.jpg'	కే	1	19	3	26	5	30	7	31	10	32	11	35	13	38	15	38
	'Ka11_kai.jpg'	కై	3	24	6	29	9	35	11	42	11	43	18	47	20	50	21	52
	'Ka12_ko.jpg'	కొ	1	14	3	21	6	26	7	36	8	38	10	41	12	48	12	48
	Ka13_koa.jpg'	కో	5	22	8	23	10	25	12	29	15	31	16	34	18	39	18	39
	Ka14_kau.jpg'	కౌ	0	21	1	27	8	29	8	30	9	31	10	34	13	34	13	34
	Ka15_kam.jpg'	కం	2	8	2	8	2	9	5	10	6	12	7	15	7	32	8	35
	Ka16_kah.JPG'	కః	2	11	2	12	4	13	5	14	6	17	7	20	9	24	11	24

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(d) Matrix-2 for Ka-Vaththu

	File Name	Telugu Character	E	EN	N	NW	W	WS	S	SE	E-EN	EN-N	N-NW	NW-W	W-WS	WS-S	S-SE	SE-E
K	'KaVt01_KKa.jpg'	క్క	1	2	2	4	5	5	5	5	7	8	9	14	14	14	18	22
A	'KaVt02_KKha.jpg'	క్ఖ	3	3	5	7	14	19	25	27	30	35	40	40	45	50	53	62
-	'KaVt03_KGa.jpg'	క్గ	3	9	11	15	19	23	25	28	31	34	38	43	46	52	54	57
V	'KaVt04_KGha.jpg'	క్ఘ	2	4	6	8	9	12	15	17	18	22	25	25	28	32	35	50
a	'KaVt05_KInjna.jpg'	క్ఞ	2	5	7	8	15	21	24	26	32	36	43	52	55	60	63	66
t	'KaVt06_KCa.jpg'	క్చ	1	2	2	9	13	13	14	14	15	15	18	23	23	23	25	27
h	'KaVt07_KCha.jpg'	క్ఛ	1	2	2	5	9	9	10	11	12	14	15	22	22	22	25	27
t	'KaVt08_KJa.jpg'	క్జ	1	3	5	7	7	11	14	19	22	26	33	44	47	52	56	59
h	'KaVt09_KJha.jpg'	క్ఝ	2	4	6	8	11	13	15	17	18	23	26	26	31	36	47	59
u	'KaVt10_KIni.jpg'	క్ఞ	2	4	6	8	14	16	20	25	26	30	34	34	45	52	56	68
	'KaVt11_KTta.jpg'	క్ట	3	4	6	8	15	18	20	23	26	30	34	43	46	53	55	58
	'KaVt12_KTtha.jpg'	క్ఠ	1	4	6	8	12	17	20	22	24	27	30	30	33	36	40	43
	'KaVt13_KDda.jpg'	క్డ	1	3	5	7	8	10	13	17	22	26	31	42	43	47	51	52
	'KaVt14_KDdha.jpg'	క్ఢ	6	8	10	12	19	21	25	29	32	34	39	39	42	46	52	55
	'KaVt15_KNna.jpg'	క్ణ	2	3	5	7	14	16	18	22	25	28	31	31	34	38	43	46
	'KaVt16_KTa.jpg'	క్త	3	6	8	10	10	12	14	16	19	21	23	29	32	35	39	40
	'KaVt17_KTha.jpg'	క్థ	3	5	7	8	15	19	22	25	28	32	35	35	38	42	47	50
	'KaVt18_KDa.jpg'	క్ద	3	5	7	9	16	19	22	27	30	32	38	49	52	56	60	63
	'KaVt19_KDha.jpg'	క్ధ	3	6	8	9	16	18	22	25	28	30	34	35	38	41	45	48
	'KaVt20_KNa.jpg'	క్న	1	2	2	6	7	7	9	10	11	12	16	23	23	23	27	28
	'KaVt21_KPa.jpg'	క్ప	1	2	2	4	6	6	6	7	8	8	16	22	24	24	26	28
	'KaVt22_KPha.jpg'	క్ఫ	2	3	3	6	10	10	10	10	11	13	19	24	24	24	30	32
	'KaVt23_KBa.jpg'	క్బ	1	2	2	5	7	7	7	7	9	9	13	18	18	18	22	24
	'KaVt24_KBha.jpg'	క్భ	1	2	2	4	6	6	6	8	9	9	11	17	17	17	24	26
	'KaVt25_KMa.jpg'	క్మ	1	2	2	5	9	9	9	13	14	15	18	22	23	23	25	33
	'KaVt26_KYa.jpg'	క్య	2	5	8	10	11	13	14	18	20	22	24	28	31	33	38	41
	'KaVt27_KRa.jpg'	క్ర	0	0	1	2	3	5	7	10	10	13	21	22	26	29	32	35
	'KaVt28_KLa.jpg'	క్ల	2	5	7	9	9	10	12	16	19	23	28	37	38	41	43	46
	'KaVt29_KLla.jpg'	క్ళ	1	2	3	6	11	11	11	12	15	15	22	28	31	31	40	41
	'KaVt30_KVa.jpg'	క్వ	1	2	2	5	6	6	8	9	10	16	18	22	22	22	25	27
	'KaVt31_KSa.jpg'	క్స	1	2	6	9	11	11	11	14	16	17	20	25	33	33	37	38
	'KaVt32_KSha.jpg'	క్శ	1	3	5	6	6	6	8	9	11	14	21	25	25	28	31	33
	'KaVt33_KSsa.jpg'	క్ష	1	2	2	5	7	7	7	7	8	8	15	21	30	30	35	37
	'KaVt34_Kha.jpg'	క్హ	3	5	7	9	9	11	14	18	19	25	29	29	32	36	39	54
	KaVt35_KSRra.jpg'	క్ఱ	1	3	5	7	7	9	12	14	17	24	27	27	30	40	46	47

Figure A.3: Comparison report for printed and hand-written characters

(a) Connected Components Analysis & Closed Regions (Holes) Analysis

Feature Extraction values for the Telugu Characters

Telugu Character	Type of Character	No. of Connected Components	No. of Closed Regions (Holes)
న	Printed	1	0
	Hand-written	1	0
ప	Printed	2	1
	Hand-written	2	1
వ	Printed	1	1
	Hand-written	1	1
స	Printed	2	0
	Hand-written	2	0

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10-way Grid based Analysis

Feature Vector-1 values for the Telugu Characters

Telugu Character	Type of Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
న	Printed	1	3	4	7	10	13	15	18	21	23
న	Hand-written	1	3	4	7	10	12	13	16	19	21
ప	Printed	1	3	4	7	10	13	15	17	19	21
ప	Hand-written	1	3	4	7	10	13	16	18	20	22
వ	Printed	2	4	5	8	11	14	16	19	22	24
వ	Hand-written	1	4	5	8	12	15	18	21	22	24
స	Printed	1	1	2	5	8	11	13	15	17	19
స	Hand-written	1	2	3	6	9	12	14	16	18	20

Feature Vector-2 values for the Telugu Characters

Telugu Character	Type of Character	E-2	E-1	E	E+1	E+2	N-2	N-1	N	N+1	N+2
న	Printed	2	8	9	13	18	21	23	26	30	32
న	Hand-written	1	7	10	13	17	19	21	24	27	29
ప	Printed	2	5	7	12	17	20	22	25	27	32
ప	Hand-written	2	7	8	12	15	18	21	23	25	27
వ	Printed	3	9	11	15	21	26	29	33	36	38
వ	Hand-written	1	7	8	11	18	22	25	29	32	34
స	Printed	2	2	3	9	14	19	21	24	26	30
స	Hand-written	2	8	9	12	16	19	21	24	26	28

(c) Critical Points Analysis

16-way Radial based Analysis

Feature Vector-1 values for the Telugu Characters

Telugu Character	Type of Character	E	EN	N	NW	W	WS	S	SE	E-EN	EN-N	N-NW	NW-W	W-WS	WS-S	S-SE	SE-E
న	Printed	1	9	2	10	4	11	5	11	5	13	7	14	8	15	8	16
న	Hand-written	1	9	2	11	4	12	5	12	5	14	7	15	8	16	8	17
ప	Printed	1	6	2	6	3	7	3	10	3	14	3	16	4	17	5	18
ప	Hand-written	1	7	2	7	3	8	4	11	4	13	5	15	6	16	6	16
వ	Printed	1	9	2	10	4	12	5	12	5	14	7	16	8	17	8	18
వ	Hand-written	1	8	2	9	4	10	5	10	5	12	5	16	6	17	7	18
స	Printed	1	7	2	7	3	8	4	10	4	12	5	14	6	15	6	16
స	Hand-written	1	7	1	8	2	9	3	9	3	10	5	12	6	13	6	14

Feature Vector-2 values for the Telugu Characters

Telugu Character	Type of Character	E	EN	N	NW	W	WS	S	SE	E-EN	EN-N	N-NW	NW-W	W-WS	WS-S	S-SE	SE-E
న	Printed	1	9	2	10	4	17	5	17	5	23	7	24	8	25	8	28
న	Hand-written	0	10	1	14	3	16	4	16	4	20	5	21	7	23	8	24
ప	Printed	2	8	3	8	5	11	5	17	5	27	5	32	6	33	7	36
ప	Hand-written	1	7	2	7	3	9	4	15	4	18	5	21	6	23	6	23
వ	Printed	2	12	3	13	6	16	7	16	7	22	10	26	11	27	11	30
వ	Hand-written	1	12	2	13	5	14	9	14	9	17	9	25	10	26	11	27
స	Printed	1	9	2	9	3	11	4	13	4	20	5	24	7	25	7	28
స	Hand-written	1	9	1	10	2	11	3	11	3	17	5	19	7	22	7	23

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