



IJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** X **Month of publication:** October 2023

DOI: <https://doi.org/10.22214/ijraset.2023.56079>

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Comparison of Various Algorithms for Handwritten Character Recognition of Indian Languages

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Abstract: In this paper, we present a comparison of various pre-processor, feature extraction methods and algorithms for handwritten character recognition of various Indian languages. Comparison of classifier, feature set and accuracy of offline handwritten character recognition of Gujarati, Devanagari, Gurmukhi, Kannada, Malayalam, Bangla and Hindi Indian languages. Comparison of classifier, feature set and accuracy of online handwritten character recognition of Assamese, Tamil, Devanagari, Malayalam, Gurmukhi, and Bangla Indian languages. Indian language wise best performance of each language is compared for both offline and online handwritten character recognition systems.

Keywords: HCR, OCR, SVM, ANN, CNN, HMM, Online Handwritten Character Recognition, Offline Handwritten Character Recognition

I. INTRODUCTION

Optical character recognition system can be used to identify the handwritten characters. Handwritten character recognition (HCR) can be classified into two types - offline and online.

Offline handwritten character recognition system recognizes character written on paper or other such material using a pen or any device. In offline handwritten character recognition system, a character written on paper is converted into an image using a scanner or other imaging devices. The scanned image is further processed using different algorithms to remove noise, size variation etc. Preprocessed image is used to extract meaningful information from the written character. Extracted features are provided to the classifier as an input.

Indian languages have large and complex character set compare to English and other Latin scripts. Indian scripts include constants, vowels and composite characters representing a combination of constants and vowels. There is a similarity between characters of different Indian languages, mainly based on a geographic location of languages used.

Many characters in different Indian languages requires multiple strokes to write. Such a complex character set makes traditional keyboard not practical for Indian languages. Most of the Indian languages have major differences among each other and due to that, there cannot be a single handwritten character recognition system for all the Indian languages. We need to develop separate systems for every Indian language.

II. LITERATURE REVIEW

The character recognition system has training data of all character classes of a particular language. Offline handwritten character recognition is more complex compared to printed character recognition due to variation in writing style. In this system, handwritten documents are scanned and converted into digital image.

The scanned image is further processed using pre-processing methods, segmentation methods, text extraction methods, feature extraction methods and classification methods.

The character recognition system can be categorized into Offline and Online. We have compiled and compared different work of researchers of major Indian languages.

The following tables 1 to 7 shows and compare classifier, feature set and accuracy of offline handwritten character recognition of Gujarati, Devanagari, Gurmukhi, Kannada, Malayalam, Bangla and Hindi Indian languages.

Table 1. Comparison of character recognition system for Gujarati

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|----------------------------------|--|----------|----------------------|
| 1 | Gujarati | SVM Polynomial Naïve based | Chain code Zoning Projection profile | 99.80% | A. Sharma [1] |
| 2 | Gujarati | DTW | grey level co-occurrence | 99.40% | S. B. Sunilkumar [2] |
| 3 | Gujarati | SVM Polynomial | Aspect ratio Extent Image sub division | 86.66% | A. A. Desai [3] |
| 4 | Gujarati | k-NN | Primary and Secondary | 63.10% | C. Patel [4] |
| 5 | Gujarati | SVM | PCA | 90.55% | Mamta [5] |

Table 2. Comparison of character recognition system for Devanagari

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|------------|---------------------|-------------------------------------|----------------------------|------------------|
| 1 | Devanagari | Multiclass SVM | Zernike and Legendre moment | 98.30% | K. V. Kale [6] |
| 2 | Devanagari | SVM | Gradient based directional features | 95.81% | M. Bhalariao [7] |
| 3 | Devanagari | ANN | Zoning | 93.40% | D. Khanduja [8] |
| 4 | Devanagari | Mapping | Line & Intersection features | 93.33% | R. Sharma [9] |
| 5 | Devanagari | SVM k-NN FFNN | Geometric Regional Gradient | 86.34% 79.10% 91.30% | S. Ansari [10] |

Table 3. Comparison of character recognition system for Gurmukhi

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|-----------------|----------------------------------|----------|---------------|
| 1 | Gurmukhi | Deep learning | Directional Regional | 99.30% | N. Kumar [11] |
| 2 | Gurmukhi | HMM Bayesian | Zoning Directional Zernike | 93.50% | M. Kumar [12] |

Table 4. Comparison of character recognition system for Kannada

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|---------------------------|-----------------------------------|----------|---------------------|
| 1 | Kannada | ANN | Structural Wavelet transform | 91% | S. Pasha [13] |
| 2 | Kannada | Distance measuring method | FLD | 68.00% | S. K. Niranjan [14] |
| 3 | Kannada | HMM | Gradient geometry Aspect ratio | 66% | G. S. Veena [15] |

Table 5. Comparison of character recognition system for Malayalam

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|-----------|--------------------------|--------------|----------|-----------------|
| 1 | Malayalam | Cross-sectional sequence | HLH patterns | 88% | A. Rahiman [16] |
| 2 | Malayalam | Two-layer FFNN | Chain code | 72.10% | J. John [17] |

Table 6. Comparison of character recognition system for Bangla

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|---------------------|--------------------------|----------|---------------------|
| 1 | Bangla | Deep Belief Network | Pixel values | 91.30% | M. M. R. Sazal [18] |
| 2 | Bangla | MLP | Chain code histogram | 88.74% | R. Pramanik [19] |
| 3 | Bangla | MLP ANN | Zone density Directional | 88.64% | F. I. Alam [20] |

Table 7. Comparison of character recognition system for Hindi

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|------------------------------|---------------------|----------|---------------------|
| 1 | Hindi | Two-pass dynamic programming | Directional element | 91.23% | S. Ramachandra [21] |
| 2 | Hindi | CNN | Augmented | 94.19% | Ajay Indian [22] |

The following tables 8 to 14 shows and compare classifier, feature set and accuracy of online handwritten character recognition of Assamese, Tamil, Devanagari, Malayalam, Gurmukhi, and Bangla Indian languages.

Table 8. Comparison of character recognition system for Assamese

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|--------------------|--|------------------|-------------------|
| 1 | Assamese | SVM | Posterior feature | 99.52% | S. Mandal [23] |
| 2 | Assamese | Combined HMM & SVM | Coordinate sequence 1st & 2nd order derivative | 96.17% | H. Choudhury [24] |
| 3 | Assamese | HMM SVM | 1st & 2nd order derivative Baseline features | 95.10% | S. Mandal [25] |
| 4 | Assamese | HMM | Pixel coordinates | 93.35% | H. Choudhury [26] |
| 5 | Assamese | HMM SVM | Statistical Directional | 76.24% 76.56% | S. Mandal [27] |

Table 9. Comparison of character recognition system for Tamil

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|---------------------|-----------------------------------|----------|-------------------|
| 1 | Tamil | Naïve Bayes | Pixel coordinates | 91.81% | R. Kunwar [28] |
| 2 | Tamil | HMM BOS | Writing direction Curvature Slope | 91.80% | A. Bharath [29] |
| 3 | Tamil | Connected component | Blobs Stems features | 77.84% | K. H. Aparna [30] |

Table 10. Comparison of character recognition system for Devanagari

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|------------|-------------------|--|-----------------|------------------------|
| 1 | Devanagari | SVM HMM | Pixel coordinates | 97.27% | H. Swetha lakshmi [31] |
| 2 | Devanagari | HMM SVM | Zone wise slope of dominant points | 93.3% 97.11% | R. Ghosh [32] |
| 3 | Devanagari | Template matching | DTW | 97% | K. C. Santosh [33] |
| 4 | Devanagari | SVM | Structural Zone wise directional Zone wise slope | 90.63% | R. Ghosh [34] |
| 5 | Devanagari | HMM BOS | Writing direction Curvature Slope | 87.13% | A. Bharath [35] |

Table 11. Comparison of character recognition system for Malayalam

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|-----------|--------------------|---|----------------------------|-----------------------|
| 1 | Malayalam | k-NN | Pixel coordinates Direction Curvature Aspect ratio | 98.12% | M. Sreeraj [36] |
| 2 | Malayalam | HMM SVM | Pixel coordinates Direction Curvature Angular features | 97.97% | K.P. Prime kumar [37] |
| 3 | Malayalam | SVM DDAG | Pixel coordinates Direction Curvature Moments | 95.78% | A. Arora [38] |
| 4 | Malayalam | k-NN MLP SVM | Accurate dominant points Intersections | 90.39% 93.17% 95.12% | Baiju KB [39] |

Table 12. Comparison of character recognition system for Gurmukhi

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|--------------------|---------------------------------------|----------------------------|----------------|
| 1 | Gurmukhi | SVM | X & Y projection | 99.75% | H. Singh [40] |
| 2 | Gurmukhi | SVM HMM | RDP Chain code | 98.21% 98.27% | S. Singh [41] |
| 3 | Gurmukhi | K-means clustering | Direction Loops | 94.69% | A. Sharma [42] |
| 4 | Gurmukhi | k-NN MLP SVM | Spatial temporal Spectral features | 89.35% 89.89% 89.64% | R. Kaur [43] |
| 5 | Gurmukhi | HMM | Zoning features | 88.40% | K. Verma [44] |

Table 13. Comparison of character recognition system for Bangla

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|------------|---|----------|-------------|
| 1 | Bangla | CNN | Pooling | 99.40% | S. Sen [45] |
| 2 | Bangla | SMO | Mass distribution Chord length krill-herd | 98.57% | S. Sen [46] |
| 3 | Bangla | SVM | COG based global & local | 98.26% | S. Sen [47] |
| 4 | Bangla | MLP | Hausdorff Distance Directed HD | 95.57% | S. Sen [48] |
| 5 | Bangla | SVM | Transition counts, centre of gravity, & topological | 95.49% | S. Sen [49] |

Table 14. Comparison of character recognition system for Gujarati

| Sr. No. | Language | Classifier | Features | Accuracy | Author(s) |
|---------|----------|--------------------|--|----------------------------|-------------|
| 1 | Gujarati | SVM k-NN | derivative of pixel values, zoning, normalized chain code | 94.65% | Vishal [50] |
| 2 | Gujarati | SVM | zoning features dominant point-based normalized chain code | 94.13% | Vishal [51] |
| 3 | Gujarati | SVM MLP k-NN | Structural Statistical | 91.63% 86.72% 90.09% | Vishal [52] |
| 4 | Gujarati | SVM | zoning and chain code directional features | 95% | Vishal [53] |

III.RESULTS AND DISCUSSION

The comparison of various classifier, feature set and accuracy of offline and online handwritten character recognition for various Indian languages. For offline handwritten character recognition, following are the best result achieved by the researcher for various Indian languages.

- 1) *Gujarati*: The classification was performed using a Support Vector Machine and naïve based classifiers. The feature set included chain code, zoning, and projection profile-based features and their possible combinations as a fusion feature set. The result showed the highest accuracy of 99.80% using SVM with the polynomial kernel classifier and chain code & zone-based features. [1]
- 2) *Devanagari*: In the pre-processing stage, smoothing, enhancing, and filtering methods were used. In the pre-classification stage, local and global features were used. The features were extracted using Zernike and Legendre moment. Classification was performed using multiclass SVM. The result showed a maximum accuracy of 98.30% for a handwritten character. [6]
- 3) *Gurmukhi*: The feature set had 117 feature values which included the local binary pattern with directional and regional features. Classification was performed using deep learning classifier. The result showed an accuracy of 99.3%. [11]
- 4) *Kannada*: In pre-processing skew detection and correction, binarization, noise removal, normalization, and thinning methods were used. The features set had 149 feature values which included structural and wavelet transform features. Classification was performed using the Artificial Neural Network classifier. The result showed an accuracy of 91%. [13]
- 5) *Malayalam*: Characters were separated based on foreground and background colours. The HLH patterns featured with horizontal, vertical and cross-sectional sequence check was used to identify a character. The authors obtained an accuracy of 88%. [16]
- 6) *Bangla*: Deep Belief Network (DBN) was used for classification. DBN learning process has two steps, unsupervised feature learning and supervised parameter tuning. The result showed an accuracy of 91.30%. [18]
- 7) *Hindi*: They used augmented data set with CNN. The proposed method achieved accuracy of 94.19% with average training time/epoch 8.43s. [22]

For online handwritten character recognition, following are the best result achieved by the researcher for various Indian languages.

- a) *Assamese*: The Support Vector Machine was used for classification. The feature set included class-conditional probabilities features derived from a Gaussian mixture model. The result showed an accuracy of 97.67% for upper letters & processing time of 162.34 milliseconds, and 96.05% for lower letters & processing time of 335.56 milliseconds. The extended work of English word recognition showed an accuracy of 94.66%. [23]
- b) *Tamil*: The proposed algorithm was a semi-supervised method which learns from labeled and unlabeled samples. The classification was performed using the naïve Bayes classifiers and the expectation-maximization algorithm. The result showed an accuracy of 91.81%. [28]
- c) *Devanagari*: Normalization and smoothing pre-processing methods were used here. Single Engine Approach using SVM, Multiple SVM Engines and HMM were used for classification. The feature set included curve and coordinate points features. The result showed an accuracy of 97.27% using SVM and 83.08% using HMM. [31]
- d) *Malayalam*: They used dot detection, dehooking, smoothing, thinning, loop detection, normalization, orientation normalization and equidistant resampling for pre-processing. They used normalized x-y co-ordinates, pen up/down, aspect ratio, curvature and writing direction for feature extraction. They used k-NN for classification. They achieved an accuracy of 98.12%. [36]
- e) *Gurmukhi*: The Support Vector Machine with the RBF kernel was used for classification. The zone identification was performed using the x & y projection method. The feature set included x & y points, discrete Fourier transform features, and directional features. The result showed an accuracy of 94.8% for character and 99.75% for zone identification. [40]
- f) *Bangla*: Classification with different strategies. Comparison between max pooling and average pooling schemes was done. The softmax and sigmoid activation functions were also compared. The result showed an accuracy of 99.40% using max pooling and softmax function. [45]
- g) *Gujarati*: Classification with multi-layer classification using SVM at first layer and k-NN at second layer. The feature set is consist of derivative of pixel values, zoning and normalized chain code. The result showed an accuracy of 94.65%. [50]

IV. CONCLUSIONS

Comparison of classifier, feature set and accuracy of offline handwritten character recognition of Gujarati, Devanagari, Gurmukhi, Kannada, Malayalam, Bangla and Hindi Indian languages and online handwritten character recognition of Assamese, Tamil, Devanagari, Malayalam, Gurmukhi, and Bangla Indian languages. For offline handwritten character recognition, Gujarati, Devanagari, Gurmukhi and Hindi language performed best among all Indian languages with SVM and deep learning algorithms. For online handwritten character recognition, Assamese, Devanagari, Gurmukhi, Bangla and Gujarati language performed best among all Indian languages with SVM and CNN learning algorithms.

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