Advances in Handwritten Gujarati Character Recognition: A Comprehensive Survey

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Abstract **-** Handwritten character recognition is indeed a significant problem in the field of pattern recognition. The task becomes particularly challenging when dealing with scripts of different languages, as each script has its own unique characteristics and complexities. In the case of the Gujarati script, which is the most popular script in the state of Gujarat, India, researchers have focused on developing methods and techniques to accurately recognize handwritten characters in this script. The objective of this paper is to present a review of existing research papers on handwritten character recognition in the Gujarati script. By analyzing these papers, the authors aimed to provide an overview of the methodologies employed and the outcomes obtained. This review provides as a helpful resource for researchers and practitioners who are interested in this particular field, as it strengthen the knowledge and findings from various studies.

Keyword **-** Handwritten Gujarati character, optical character recognition, Gujarati script, structure base features, texture based feature, pixel based features

I. INTRODUCTION

Handwritten character recognition (HCR) is a significant research area within the broader field of optical character recognition (OCR). The purpose of OCR systems is to automatically recognize text from images or scanned documents and convert them into editable electronic form. In the case of HCR, the focus is on recognizing handwritten characters rather than typewritten text. The goal is to develop algorithms and models that can accurately identify and classify handwritten characters without the need for manual intervention. This involves training a machine learning model or creating a pattern recognition system that takes an image of a handwritten character as input and predicts the corresponding class label or character. Indeed, there are several challenges encountered when attempting to solve the problem of handwritten character recognition. Some of these challenges include:

a) Variation in size, thickness, style, and orientation: Handwritten digits or characters can vary significantly in terms of their size, thickness, style, and orientation. The changeability of character makes it complicated to develop a consistent model that can precisely recognize characters with different visual characteristics.
b) Presence of noise and artifacts: Handwritten documents often contain various types of noise and artifacts, such as smudges, ink blots, or creases. These artifacts can introduce distortions in the character images, making it challenging for the recognition system to distinguish between meaningful information and noise.
c) Skew correction and slant detection: Handwritten characters may exhibit skew or slant, where the characters are tilted or inclined. Correcting the skew or detecting the slant is important for aligning the characters properly and improving the accuracy of recognition.
d) Skeletonization or thinning: Skeletonization or thinning is a process that aims to reduce the thickness of character strokes to their minimal representation. This step can help in extracting the essential structural features of the characters, making them more discriminative for recognition.
e) Size normalization: Handwritten characters may vary in size, and size normalization is often required to bring them to a consistent scale. Normalizing the size ensures that the recognition system can compare and match characters accurately based on their shape and structure.
f) Writing style variations: Different individuals have their own unique writing styles, which can significantly influence the formation and appearance of handwritten characters. These variations pose a challenge for HCR systems, as they need to handle diverse writing styles and capture the essential characteristics of each individual's handwriting.

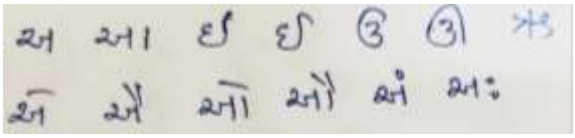
To tackle above challenges, we require the development of strong preprocessing techniques to handle variations in character size and style, orientation of character and noise. Additionally, advanced feature extraction methods and machine learning algorithms can be employed to capture the discriminative information from the preprocessed images. By carefully considering and mitigating these challenges, researchers can improve the accuracy and reliability of handwritten character recognition systems.

HCR possesses several real-life applications of handwritten character recognition and emphasizes the commercial significance of this technology. HCR finds use in reading bank cheques to extract the amount, sorting postal addresses, aiding the visually impaired, and extracting

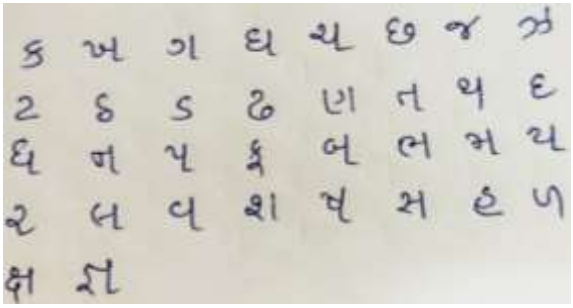
numeric data from forms, among other applications. Due to its practical importance, HCR is often used as a benchmark for comparing different classification methods.

While HCR has been studied for several decades, with numerous techniques developed to achieve high classification accuracies, research in this field continues to pursue further improvements in recognition rates. India, being a multilingual country with multiple scripts, presents its own challenges and requirements for HCR. Gujarati, the national language of Gujarat state in India and one of the major scripts, has a significant number of native speakers and a wide presence in the Indian subcontinent.

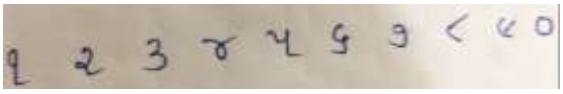
The literature survey mentioned in Liu et al. [1] indicates that previous HCR research has primarily focused on scripts such as Farsi and Roman. Several standard databases, such as NIST [2], CENPARMI [3], CEDAR [4], CENPARMI Arabic cheques [5], and UNIPEN [6], have been established for testing and benchmarking handwriting recognition techniques. However, there has been relatively less work reported specifically for character recognition in the Gujarati script. This could be attributed to the complexities and shape variations inherent in the Gujarati script compared to the Roman script. For convenience, a set of sample handwritten images of *Gujarati* script is also shown in Fig 1.



(a)



(b)



(c)

Fig. 1 Sample Handwritten characters written in Gujarati script: (a) Vowels (b) Consonants (c) Digits

Motivated by these factors, the authors of the paper conducted a comprehensive survey to analyze the feature extraction and classification techniques employed in the domain of Gujarati character recognition. The work in this area is grouped and different methods are compared to understand their effectiveness and performance. By reviewing and comparing these approaches, the paper aims to provide insights into the existing methodologies and identify potential avenues for future research in Gujarati character recognition.

This paper is organized as follows: Section 2 describes the state-of-the-art techniques for the recognition of characters written in *Gujarati* script whereas Section 3 compares the various handwritten Gujarati character recognition (HGCR) techniques. Section 4 highlights some of the open problems for Gujarati HCR. Finally, conclusions are provided.

II. FEATURE USED IN HGCR

To find the correct set of features is much more complicated task in handwritten *Gujarati* character recognition. Researchers are still analyzed in this regard from last few decades. As per the nature of features used, all ongoing works on Gujarati HCR can be broadly categorised into three approaches:

1. structure-based features
2. texture-based features
3. Pixel-based features.

The choice between structural-based, textural-based, or pixel-based features depends on the specific requirements of the handwritten character recognition task and the characteristics of the dataset. Each type of feature extraction method has its strengths and weaknesses, and the effectiveness of a particular method can vary depending on the nature of the handwritten characters and the variability within the dataset.

Here is a brief comparison of the three types of feature extraction methods:

- Structural-based features: These features capture the topological and geometric properties of the characters, such as the number of strokes, endpoints, loops, and curves. Structural features can be effective in capturing the overall shape and structure of the characters. They are often robust to variations in style and size. However, they may not capture fine texture details and may struggle with highly complex or distorted characters.
- Textural-based features: These features analyze the local pixel structures or statistics in the image to capture texture patterns, such as co-occurrence matrices, local binary patterns, or statistical measures. Textural features can be effective in capturing fine details and variations in the texture of characters. They are often robust to variations in size and style. However, they may struggle with characters that have very limited or uniform texture patterns.
- Pixel-based features: These features utilize the raw pixel values directly from the images as input information. Pixel-based features can capture fine details and subtle variations in character shapes, as they

leverage the full information present in the images. They can be effective for characters with intricate details or faint characteristics. However, they may be sensitive to noise and image artifacts, and their performance can be influenced by variations in size, style, and orientation.

A better feature extraction method depends on the specific characteristics of the handwritten characters, the variability within the dataset, and the goals of the recognition task. It is often beneficial to explore and compare multiple feature extraction methods, as their performance can vary across different datasets and recognition scenarios. Additionally, combining multiple types of features or using hybrid approaches can also improve recognition accuracy by leveraging the strengths of different methods.

A. Structured-based features

For any classification problem, structure is the most essential hint for human being for identification and recognition of unfamiliar patterns, including characters. Structure provides crucial cues for human beings to understand and recognize various shapes and forms, including simple geometrical elements like straight lines in different orientations.

In the context of character recognition, structure-based features play a significant role. These features involve extracting local information from the character images by dividing them into different zones or sub-images. By analyzing the local information, researchers can capture specific structural characteristics of the characters. Some studies have focused on extracting the exact outer shape of the character images as a way to calculate global information. By considering the overall structure of the characters, additional knowledge about their composition and arrangement can be obtained. A few of them had even applied it for extracting both the local and global information.

Structural features offer advantages in terms of their tolerance to distortions and variations in writing style. They capture topological and geometric properties of the characters, such as the number of horizontal or vertical lines, endpoints, cross points, loops, branch points, strokes and their directions, inflection points, and horizontal curves at the top or bottom. These structural features provide insights into the composition and organization of characters, allowing for robust recognition even in the presence of distortions, noise, or variations in writing style. They encode valuable information about the object's structure and the components that constitute it.

Thaker and Kumbharana [7] proposed feature extraction method that uses structural features to uniquely classify handwritten Gujarati character. They described eight structural features of characters like connected or disconnected component (Fig 2(a)), vertical line (Fig 2(b)), horizontal line (Fig 2(c)), diagonal line (Fig 2(d)), close region or loop (Fig 2(e)), end points (Fig 2(f)), cross point (Fig 2(g)) and type of curve (Fig 2(h)) present in Gujarati characters. The authors extracted 22 features of Gujarati characters and used decision tree classifier to recognize them. They achieved average accuracy rate about 88.78%.

Connected Component	
ક ખ ઘ ચ છ જ ઝ ટ ઠ ડ ઢ ત થ દ ધ ન પ ફ બ ભ મ ચ ર વ સ ષ હ ળ ક્ષ જ્ઞ	
Disconnected Component	
Two	Three
ગ લ શ	ણ

(a)

Vertical Line – Connected
ખ ઘ ચ ત થ ધ ન પ બ ભ મ ચ લ વ સ ષ ળ ક્ષ જ્ઞ
Vertical Line – Separated
ગ ણ શ

(b)

Horizontal Line
ત ન ભ મ લ સ

(c)

Negative slope
ષ
Positive Slope
ક જ ઝ ફ

(d)

Loop	
One	Two
ખ ચ છ ઠ ઢ થ ન બ ભ મ જ્ઞ	જ શ ક્ષ

(e)

No. of End Point	
One	Two
છ જ ઠ ઢ	ટ ડ થ દ ર ળ
Three	Four
ખ ઘ ચ ત ધ ન પ બ ભ મ ચ વ શ ષ હ ક્ષ જ્ઞ	ક ગ ઝ ફ સ
Five	Six
લ	ણ

(f)

No. of Cross Point	
One	Two
ક ઠ ઢ ત દ ૫ ૨ લ વ	ખ ઘ ચ છ જ ઝ ણ થ ધ ન ફ બ ભ મ શ ષ હ જ્ઞ
Three	
સ ક્ષ	

(g)

C – curve
છ ત દ ધ ઘ બ લ સ હ ક્ષ
D – curve
ગ ચ ઝ મ ૨ જ્ઞ
U – curve
ખ થ ૫ ચ વ

(h)

Fig 2 Structural features of Gujarati characters: (a) connected or disconnected (b) vertical lines (c) horizontal line (d) diagonal line (e) loop (f) end points (g) cross point (h) type of curve

Goswami and Mitra [8] proposed a feature extraction method named low-level stroke (LLS) which extract features of handwritten Gujarati numerals like endpoints, junction points, line segments, and curve segments, as shown in Fig 3, using template matching approach. They collected 14000 samples from 140 persons of different age groups and performed experiments on Gujarati and Devanagari databases using k-nearest neighbour (K-NN) classifier and further result would be improved by using support vector machine (SVM) classifier with radial basis function (RBF) kernel. They achieved average test accuracy on Gujarati and Devanagari database were 98.46% and 98.65%, respectively.

Patel and Desai [9] used combination of structural features and statistical features for classification and identification of handwritten Gujarati characters. The structural features such as number of objects in the character, number of object in upper half and lower half of a character and number of objects in right half and left half of a character etc are selected by studying the appearance of various handwritten characters. They combined moment based and centroid based features for character recognition of Gujarati script and achieved a success rate of 63% using proposed method.

Desai [10] suggested a novel hybrid feature constituted by a structural approach and statistical approach for the handwritten Gujarati numerals. The image is divided into sub-image and then the pixel information is used as a structural approach whereas the aspect ratio of the number is considered as a statistical approach. The proposed model gives overall accuracy of 96.99% using KNN classifier.

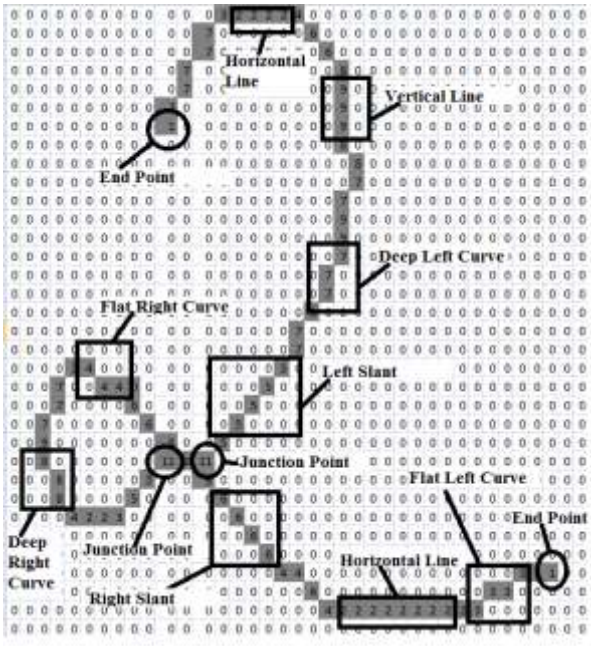


Fig 3 Gujarati handwritten digit with low-level stroke (LLS) features, like endpoints, junction points, line segments, and curve segments

Desai [11] proposed an optical character recognition (OCR) system which uses the features extracted from Gujarati digits by four different profiles for recognition of handwritten Gujarati numbers. The four different profiles such as horizontal, vertical, and two diagonals is suggested as shown in Fig 4 and the Fig 5 shows sample 3x3 pattern matrix. The overall performance of this proposed network achieved approximately 82%.

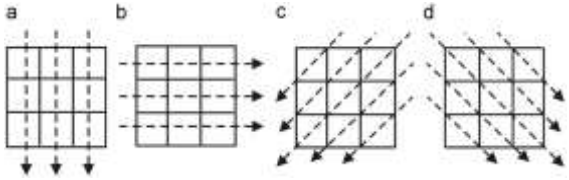


Fig 4: Pattern profile of 3x3 pattern matrix

Fig 5 3x3 pattern matrix

Sharma et. al [12] proposed a system which used chain code based method to recognize handwritten Gujarati numeral. Chain code method with horizontal scanning and chain code method with maximum distance from centroid method, as shown in Fig 6 and 7 respectively, are used for feature extraction from preprocessed numeral images. They achieved the accuracy of 96.37% for chain code method

with horizontal scanning and the accuracy of 95.62% for chain code method with maximum distance from centroid.

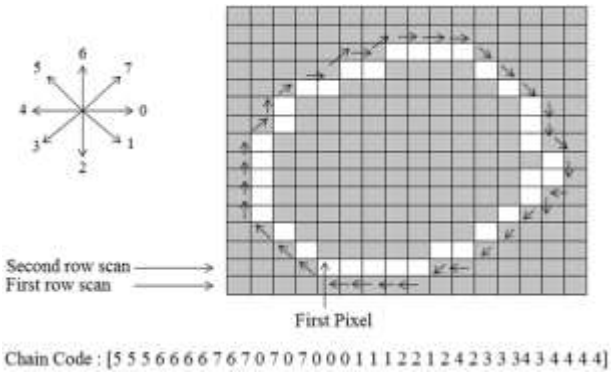
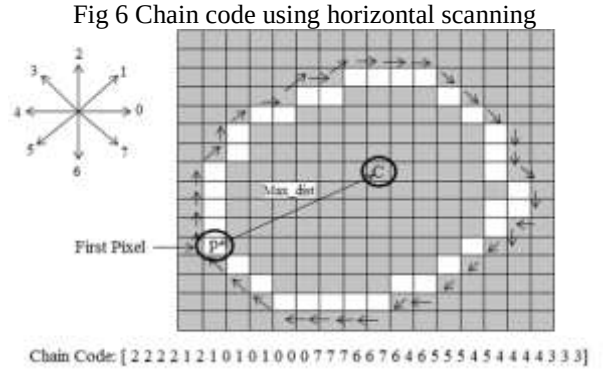


Fig 6 Chain code using horizontal scanning



(b)

Fig 7 Chain code using maximum distance from centroid

B. Texture based features

Texture-based feature are valuable for characterizing a wide range of images, including handwritten characters. Texture is known to play a significant role in human visual perception, as our visual system utilizes texture for classification and analysis purposes. Texture-based features are typically computed from a group of pixels. There are two broad categories of texture feature extraction methods: spatial and spectral.

1) *Spatial Texture Features:* In this approach, texture features are extracted by computing pixel statistics or analyzing local pixel structures in the original image. Various statistical measures can be computed, such as mean, variance, co-occurrence matrices, and local binary patterns (LBPs). These measures capture the patterns and variations in pixel intensities within the image, providing information about the texture characteristics. The spatial texture feature extraction approach, in particular, has been widely employed in Gujarati character recognition research to capture the distinct texture patterns and aid in accurate recognition of Gujarati characters.

2) *Spectral Texture Features:* In this approach, the image is transformed into the frequency domain, often using techniques like Fourier Transform or Wavelet Transform. Once the image is in the frequency domain, texture features can be computed from the transformed image. These features capture the distribution and characteristics of frequency components within the image.

Paneri et. al. [13] proposed an offline handwritten Gujarati word recognition system using Histogram of Oriented Gradients (HoG) features. This feature extraction technique uses the distribution of directions of gradients as features. The HoG technique counts occurrences of gradient orientation in localized portions of an image and hence describes local shape of an object. The experiment is performed on a small handwritten Gujarati city name database and achieved accuracy of 85.87% using HoG feature.

Dholakia et. al [14] presented paper on wavelet feature based confusion character sets for Gujarati script. They used feature vector which is made up of Daubechies D4 Wavelet coefficients. The performance of the proposed model is measured by applying on two different classifiers namely General Regression Neural Network (GRNN) and Nearest Neighbor and achieved over all accuracy more than 96% for a larger set of symbols.

C. Pixel-based features

Pixel-based methods utilize the pixel values directly from the images as input information, without the need for a separate feature extraction procedure. These methods bypass the feature calculation step and work directly with the raw pixel values for recognition purposes. One advantage of pixel-based methods is that they can potentially avoid errors caused by inaccurate feature calculations, particularly for faint or complex images. By utilizing the pixel values directly, these methods can capture fine details and nuances that might be missed or distorted during feature extraction.

In certain cases, pixel-based methods can offer higher performance compared to traditional feature-based HCR methods, especially when dealing with challenging images that have faint or complex characteristics. By working directly with the pixel values, these methods can leverage the full information present in the images and potentially achieve better recognition results. However, it is true that pixel-based methods have not received as much attention or interest from researchers compared to feature-based approaches.

The concept of pixel-based features in handwritten HCR is implemented in Prasad et al. [15], where individual image pixels were considered as features. They first create a sub-image or template of size 8 x 8 and a window of size 8 x 8. The center of this window is moved over the candidate image and calculated Cross Correlation. Following that, a

series of statistical tests are used to calculate the matched location and validate it.

III. COMPARATIVE ANALYSIS

Various features have been used by different researchers for the recognition of handwritten *Gujarati* characters which are also listed in Table 1. Again, it becomes crucial to examine the distinguished power of each *Gujarati* HCR feature proposed in the literature before one may employ it for their work. In view of this, a comparative analysis between different methods and features is desirable. Some of the significant work done on HCR by different researchers is shown in Table 1.

TABLE I. COMPARATIVE ANALYSIS OF SOME STATE-OF-THE-ART WORKS FOR GUJARATI HCR

Researchers	Feature set	Classification algorithm	Recognition accuracy
Thaker and Kumbharana [7]	structural features such as connected or disconnected components; vertical, horizontal and diagonal line; loop; cross point and type of curves	Decision tree	88.78%
Goswami and Mitra [8]	Low-level stroke (LLS) features like endpoints, junction points, line segments and curve segments	K-NN SVM	98.46% 98.65%
Patel and Desai [9]	Moment based and centroid based	K-NN	63%
Desai [11]	Horizontal, vertical and two diagonals profiles features	Neural network	81.66%
Sharma et. al [12]	Chain code method with horizontal scanning and chain code method with maximum distance from centroid	Feed forward back propagation neural network	96.37% 95.62%
Paneri et. al. [13]	Histogram of Oriented Gradients (HoG) features	K-NN SVM	76.78% 85.87%
Dholakia et. al [14]	Daubechies D4 Wavelet coefficients	GRNN NN	97.59% 96.71
Prasad et al. [15]	Individual image pixels, template of 8x8 pixels	Neural network	90-95

IV. FUTURE SCOPE AND CONCLUSIONS

A. *Better pre-processing*

Correct preprocessing is indeed crucial for achieving better results in Gujarati Handwritten character Recognition. Gujarati HCR preprocessing step encompasses some commonly employed preprocessing steps like:

a) Binarization : Convert the grayscale or color image into a binary image by thresholding, where the foreground (characters) is separated from the background.
b) Noise Removal: Apply filters or techniques to remove foreground and background noise, such as speckle noise or random pixel variations, to enhance the clarity of the characters.
c) Size Normalization: Resize the digit images to a consistent size to ensure uniformity and facilitate feature extraction. This step helps in reducing variations caused by different writing styles and sizes.
d) Skew and Slant Correction: Detect and correct any skew or slant in the character images caused by handwriting variations. These corrections align the characters horizontally or vertically for accurate feature extraction.
e) Segmentation: In some cases, segment the connected digits or characters from each other in case of multi-digit numbers or word. This step is necessary when the digits or characters are overlapping or touching each other.
f) Thinning: Perform skeletonization or thinning techniques to reduce the character stroke thickness while preserving the essential structural information. Thinning can help in capturing the key features and patterns of the characters.

By implementing these preprocessing steps effectively, the quality of the input data can be improved, which in turn aids in better feature extraction and subsequent recognition accuracy.

B. *Extraction of skillful features*

The extraction of proficient features is a critical step in Gujarati Handwritten Character Recognition (HCR) that contributes to accurate classification. In the context of the survey, researchers have primarily utilized general, shape-based, texture-based and pixel-based features. The majority of the researchers have been employed shaped based features whereas few of them Paneri et. al. [13] and Dholakia et. al [14] have applied texture based feature for better classification. In addition, the method based on pixel-

based features is in the infant stage and therefore, still left to be explored.

The researchers can also prefer a two-stage approach in which the first stage involves the general feature extraction procedure which will then be followed by applying some meta-heuristic optimization algorithms like GA, harmony search, ant colony optimization, particle swarm optimization for selecting the optimal feature subset from the original feature set in the second stage.

C. Grouping of different classifiers

Combining different classifiers is indeed a promising approach for improving the recognition accuracy in Gujarati Handwritten Character Recognition (HCR) systems. The use of ensemble methods or combining the outputs of multiple classifiers can help address the limitations of individual classifiers and enhance the overall performance. Goswami and Mitra [8] improved the recognition rate on Gujarati and Devanagari handwritten numeral by using the statistically advanced SVM classifier with RBF kernel. Patel and Desai [9] suggested a hybrid approach using binary tree and k-NN classifiers for Gujarati handwritten characters.

D. Necessity of Benchmark databases

The availability of benchmark databases is indeed crucial for the development and evaluation of Handwritten Character Recognition (HCR) systems, including those for Gujarati script. No any standard databases are freely available for Gujarati HCR. Here are some key points regarding the requirement of standard databases:

Creation of typical HCR test database is critical for Gujarati as well as other Indic scripts. Earlier researches on Gujarati HCR were reported on the basis of databases collected in the laboratory. In order to assemble a realistic system, researchers require real-life digit samples from a variety of writers belonging to dissimilar surroundings, educational levels, sex and age groups.

This analysis indicates how the research trend has evolved over the years, summarizes the various techniques being applied for classification, and highlights the shortcomings of the existing Gujarati HCR systems.

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