Introduction

CHAPTER 1

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1.1 Background

One of the most impressive capabilities of human brain is the ability to recognize patterns in nature. Throughout the history of human search for knowledge, pattern recognition has been one of the main rationales behind the vast range of theories and concepts that we developed to understand natural world. The major goal of pattern recognition research is to make computers easier to communicate with people in a less constrained manner and thus to make its benefits available to the society. As a result machine simulation of human reading has been a subject of intensive pattern recognition research in the last three decades. In the infant stages of this research, investigations were limited by the memory and computational power available at that time. With the explosion of Information Technology, there has been a dramatic increase of research in this field since the beginning of 1980s.

Document Image Analysis refers to algorithms and techniques that are applied to images of printed or handwritten documents to obtain a computer readable description from it. Research in this field dates back to the earliest experiments in computer vision, and remains prominent by the close and productive ties between the academic and industrial communities. A well-known document image analysis product is the Optical Character
Recognition (OCR) system. This software converts the scanned images of printed text (numerals, letters or symbols), into computer processable format (such as ASCII). At present, reasonably good OCR packages are available for most of the languages. But these packages are able to recognize only high quality printed text documents. It is worth noticing that despite the emergence of some specific application specific OCR systems for printed documents, progress is still to be made in the case of handwriting processing. In this background an exhaustive research is needed in the area of Handwritten Character Recognition (HCR) to deal with unconstrained handwritten documents.

According to the way in which handwriting data is generated, two different approaches are present in HCR: on-line and off-line. In the former, the data are captured during the writing process by a special pen on an electronic surface. In the latter, the data are acquired by a scanner after the writing process is over. The recognition of off-line handwriting is more complex than the on-line case due to the presence of noise in the image acquisition process and the loss of temporal information such as the writing sequence and the velocity. Off-line and on-line recognition systems are also categorized according to the applications they are devoted to. The off-line recognition is dedicated to bank check processing, mail sorting, reading of commercial forms etc., while the online recognition is mainly dedicated to pen computing industry and security domains such as signature verification.
and author authentication. The present study, based on pattern recognition, is specifically interested in off-line recognition of isolated Malayalam handwritten characters.

1.2 Motivation

The motivation for the spurt of activities in the field of handwritten character recognition is the increasing need for common people to interact with the computing machines in their natural mode of communication. Another important motivation is to design and make intelligent machines. The interest devoted to this study is not only due to the exciting challenges involved but also by the expected huge benefits that a HCR system, designed in the context of a commercial application, could bring.

Our visual system is capable of recognizing image patterns in an impressively fast and accurate way. We recognize various patterns and objects in the daily environment without much effort. The task of handwritten character recognition, that is simple for human, is still a problem to a machine. It depends on various constraints and parameters and still without a definite solution. Even though tremendous advances have been made for the recognition of printed characters recently, the recognition of handwritten characters pose some difficult and interesting challenges.

The recognition of numerals, a sub field of character recognition, is subject of much attention since the beginning of research in the field of HCR
and has achieved almost saturation with more than 99% recognition accuracy. In the case of recognition of alphabetic characters, the problem becomes more complicated since the ambiguity is high and the number of classes to be distinguished is more.

Many promising research results are reported in the area of handwritten character recognition for languages like English, Chinese, Korean, Japanese and Arabic. In Indian languages studies are active in Devanagari and Bangla. Some promising research findings are also reported in South Indian (Dravidian) languages like Tamil, Telungu and Kannada, whereas HCR research in Malayalam is still in its infancy. So extensive research works are highly essential in Malayalam handwritten character recognition.

Selection of a feature extraction method is probably the single most important factor in achieving high recognition performance. At present there is no perfect mathematical model that can describe the extreme variations present in handwriting and hence it is impossible to find characteristic features that are invariant with different writing styles. It is also noted that the existing features like Fourier descriptors, Wavelet Transformation based parameters, Zernike moments, Invariant moments etc. are not easy to implement because of their computational complexity. So in the present study an investigation is carried out for designing a computationally simple
feature extraction method in order to extract parameters that are reasonably insensitive to variations caused by individual writing styles.

Another intention of this study is to identify features to represent Malayalam handwritten characters with reduced dimensions and design computationally simple algorithms to extract them. The curse of dimensionality phenomenon [Duda.R.O and Hart.P.E, 1973], [Jain.A.K and Chandrasekaran.B, 1982] cautions us that with a limited training set, the size of feature must be kept reasonably small to get a better recognition result. The problem with existing features (e.g., chain code histograms/directional chain codes, contour profiles, stroke based features etc.,) is that, in almost all the cases, size of the feature vector is very large. At present, the computational complexity of feature extraction technique and the large size of the feature vector both play major role in limiting the performance of the recognition systems. To develop a considerably small sized feature vector with an easy to implement feature extraction technique, gray-scale based state-space parameters and the perceptual fuzzy-zoned normalized vector distance parameters are presented. These features are computationally less complex and easy to implement on hardware.

In each and every phase of a pattern recognition system, uncertainty can arise either implicitly or explicitly. This is mainly due to the incomplete, imprecise or ambiguous input information and the ill defined and/or
overlapping boundaries among the classes of regions. At present there is no HCR system that has sufficient provision for representing and handling these uncertainties. The best solution for this problem is the fuzzy inference system. Its significance in the realm of pattern recognition is adequately justified in

- Representing linguistically phrased input features for processing
- Providing an estimate (representation) of missing information in terms of membership values.
- Representing multi-class membership of ambiguous patterns and in generating rules and inferences in linguistic form
- Extracting ill-defined image regions, primitives and properties and describing relations among them as fuzzy subsets.

This is the main motivation of the study towards the development of a HCR system with fuzzy inference based classifier architecture. The aim is to incorporate generic advantages of artificial neural networks (massive parallelism, robustness and learning) and fuzzy logic (handling of uncertainty and impreciseness) into the recognition system. As a result an integration of neural networks and fuzzy theory, commonly known as neuro-fuzzy computing has been adequately investigated in this study. Often the neuro-fuzzy models are found to perform better than either a neural network or a fuzzy system considered individually. In this perspective the present study
proposes a suitable pattern recognition scheme based on adaptive neuro-fuzzy inference model for the recognition of unconstrained isolated Malayalam handwritten characters.

1.3 Outline of the Work and Main Results

The intend of the chapter 2 is to establish the necessary background for the following chapters. The former part of the chapter presents a summary of the research findings reported in the pre-processing techniques with a review of reported methods and main investigations towards the feature extraction. The later part describes various successful recognition strategies adopted in handwriting recognition followed by a special review on handwritten character recognition research in Indian languages.

Chapter 3 deals with the data acquisition methods and creation of an image database for Malayalam handwritten character set including eighty one elements consisting of vowels, consonants, chillukal, special symbols and numerals. The character samples are digitized by scanning at 300 dpi and stored as 128x84 pixel size in the BMP file format. The database consists of a total of 57,996 samples of eighty one character elements collected from 716 writers. The whole set of available data is split up into two categories namely training set and test set in the ratio 1:1. The developed database has the potential to be used as a resource for the handwritten character recognition research and this work is the first of its kind in Malayalam.
Chapter 4 describes various pre-processing techniques that are necessary for character images including binarization (thresholding), size normalization and thinning (morphological skeletonization) with their application outcomes. The objective of binarization is to automatically choose a threshold that separates the foreground and background information. The character images are binarized, using Otsu's iterative global thresholding technique. The second pre-processing is the size normalization, which is highly essential because of the large size variations present in the handwritten character samples in the database. To this end all the character image samples are mapped into a standard window of 66x42 pixel size. For this mapping, Affine Transformation is performed with the Bilinear Interpolation algorithm. Thinning is applied on character images for obtaining a one pixel wide skeleton of the original pattern. To perform thinning, a rotation invariant rule based thinning algorithm proposed by Ahmed.M and Ward.R is applied on the size normalized binary character image sample. The character samples obtained after these pre-processing operations are then considered for feature extraction.

A novel method for modeling Malayalam handwritten characters based on the state-space pixel distributions of their gray-scale images is described in chapter 5. In the proposed method the reconstructed state-space for each character pattern is modeled based on the information obtained from the pixel intensity distribution of both the foreground and the background of the
gray-scale image. The scatter plot of the row vector of the trajectory matrix of embedding dimension \(d=2\) named State-Space Map (SSM) is generated from the reconstructed state-space of character images. These SSMs are constructed by incorporating one, four and eight directional space variations, by considering one nearest neighbour, 4-neighbours and 8-neighbours of each pixel in the character image. The experimental results show that the SSMs constructed with eight directional space variations are well informed and hence it can be effectively used for modeling handwritten characters. The SSMs are also found to be similar for different samples of the same character and differs from character to character. In the next stage, the State-Space Point Distribution (SSPD) graph is plotted using the SSMs with eight directional space variations and consequently the SSPD parameters are extracted from it. The SSPD parameters are found to be promising and it is further used in recognition experiments.

In chapter 6, the shape analysis of Malayalam handwritten characters is carried out based on the existence ratio, aspect ratio and the centroid of each character pattern. From this study it is found that the region decomposition or zoning is the simplest and most suitable method to identify the information content regions of Malayalam characters. Two different perceptual zoning based features are specially designed for Malayalam characters. At first, the zoned vector distance (Z-VD) features are extracted from the pre-processed character images. These features are then modified by introducing fuzzy-zone
boarders and normalized vector distance measures to obtain fuzzy-zoned normalized feature vector (FZ-NVD) parameters. The recognition studies based on the above mentioned features using different pattern classifiers are performed in the succeeding chapters.

In Chapter 7, the cluster analysis and classification based on c-Means clustering algorithm is performed based on the extracted feature vectors. The well-known non-parametric statistical algorithm named $k$-Nearest Neighbour classifier is also employed for recognition purpose. Then the classification studies are performed by means of Class-modular Multilayer Feed-forward Neural Network with Error Back-propagation learning algorithm. The recognition accuracies obtained using FZ-NVD features are found to be more promising and it is used for developing a recognition scheme based on neuro-fuzzy networks to achieve better performance.

Chapter 8 describes the design and development of a handwritten character recognition system based on the adaptive network based fuzzy inference mechanism. For this purpose, a fuzzy if-then rule set is framed from the FZ-NVD features. This rule set is capable of handling the immense variations in distinct writing styles of individuals. This is achieved by the fuzzification of each attribute of the feature vector using the fuzzy sets SMALL, MEDIUM and LARGE defined by Gaussian membership functions. For recognition we used Adaptive Neuro-Fuzzy Inference System (ANFIS),
the inference part of, which is based on Sugeno fuzzy model. To perform parameter adjustments in learning, ANFIS needs partition of the input space according to the target pattern classes. For this purpose a pre-processing operation is performed on the entire rule set using ID3 decision tree induction procedure. The reduced set of ID3 driven optimum rules is given as input to the inference part of ANFIS. The network is then trained using a gradient based learning algorithm proposed by Jang.J.-S.R. Here we used a set of 15,752 samples of the forty four Malayalam handwritten characters for training and a disjoint sample dataset of same size for testing. The entire system is developed and implemented using MATLAB 7. The overall recognition accuracy obtained for forty four Malayalam handwritten characters using the proposed ANFIS approach based on FZ-NVD features is 82.35%. This result is as good as the highest recognition accuracy reported in various other Indian languages. Since the FZ-NVD feature vector size (Nine) is considerably small and the ill-defined inputs are efficiently treated using fuzzy inference part of ANFIS, this system can be easily implemented for high-speed recognition.

Finally, chapter 9 concludes this work and suggests a few directions for future research.