The main focus of this research all along has been to simulate the manner in which human beings interact with a computer through handwritten means of communication. The research is an attempt to enhance the ways in which computers recognize handwritten characters and hence utilize artificial intelligence techniques to achieve this end. The research work has focused especially on the means to suggest new feature extraction methods for Odia characters. The literature resources available gave an insight into the steps required to achieve the aim of recognition of handwritten characters and an idea of what the upcoming research entailed. It was decided that the work would begin with the collection of samples, followed by work on the collected samples i.e., pre-processing and dimensionality reduction, and finally completed with character recognition algorithms.
6.1 SUMMARY OF THE WORK

In order to achieve the objectives, the research work is accomplished by starting with the collection of samples from wide diasporas of people and then progressed into preprocessing and finally ending with dimensionality reduction. The initial step of data collection was carried out by collecting handwritten characters from various Odia speaking people having different academic backgrounds. The characters thus obtained were of different sizes as was expected from the different penmanship of the persons. The differences in the collected handwritten characters with regards to size and resolution etc., are eliminated with the use of preprocessing steps. This data along with the data received from ISI, Kolkata are used in this research at various stages. After the collection of data sets, the proposed feature extraction methods are applied to verify their usability. Finally, the research ends with the implementation of four classification techniques.

This research proposes two new feature extraction methods for handwritten Odia characters. The first method is based on the mathematical concepts (linear algebra). Here, the feature vectors have been extracted using $LU$ factorization considering both the binary and gray scale forms of the images as a set of linear equations. The mathematical derivations, existence and uniqueness of this method have been discussed. The second method is based on linear transformation using binary image. Here, the feature vectors have been extracted through a three step linear transformation of the original image. Both the methods have been discussed with mathematical and logical evidences. Theoretical analyses prove the scientific existence of both the methods. However, wide application and universal acceptance of these methods need more research and confirmation in this area.

Implementation of four different classifiers have been analyzed and explained. The main objectives of these implementations are to test the applicability and suitability of the proposed methods of feature extraction in recognizing handwritten Odia characters.

The first experiment (conducted last), which is the implementation of recurrent neural network demonstrates the proposed method-II of feature
extraction i.e. the row-wise decimal conversion of the binary form of the character image. Theoretically this method looks very sound and has many advantages over other existing methods. The same has been proved in practical implementation also. An accuracy of 94.21% produced by the network is quite promising. This recognition accuracy of 94.21% is an implication that the proposed method has the potential to be in competition with the existing methods.

The second and third experiments have been intended to study and analyze the effectiveness of the proposed feature extraction method-I (using LU factorization) using naive Bayes classifier and ANN with back-propagation learning. In both the cases, LU factorization has been used as the method of feature extraction. Naive Bayes classifier has been implemented with five different cases of LU factorization. These are LU 4800 (both L and U factors have been included in feature vector and total input patterns are 4800), L 2400 (Only L factors have been included in feature vector and total input patterns are 2400), U 2400 (only U factors have been included in feature vector and total input patterns are 2400), L 1200 (only L factors have been included in feature vector and total input patterns are 1200) and U 1200 (only U factors have been included in feature vector and total input patterns are 1200). The recognition accuracy reported by the naive Bayes classifier is 80.56%, 86.66%, 87.87%, 90.75% and 92.75% respectively. This indicates that the U factor with less number of input patterns is a better choice for handwritten Odia numeral recognition with naive Bayes as the classifier. In the third experiment, comparatively lower recognition accuracy (85.30%) is reported when the LU factorization is tested on an ANN network with back-propagation learning. Here, a total of 2200 input patterns (consisting both L and U factors) have been tested. When this is compared with LU 4800, the results are impressive, but knowing the efficiency of ANN back-propagation network, better results are expected. This could be improved by implementing some hybrid model like ANN and Genetic Algorithm (GA).

The last experiment explained in this thesis (implementation of HNN) is the first experiment of this research. Here the elements in the feature vector are the elements of the bipolar form of the original image. Two different data sets
have been used to test the HNN model for handwritten Odia numerals. The results are outstanding when the HNN is tested with computer generated inputs. The same is true also in case of data set-2 where the input patterns are collected from different people. The recognition accuracy of 95.4% proves the effectiveness of Hopfield network in recognizing handwritten Odia numerals.

At the end, it is concluded that all experiments described here are performed under a controlled environment and in restricted conditions. The main objective of these experiments (experiment 5.3 to 5.5) is to analyze the effectiveness of the proposed feature extraction methods. It is found that the proposed methods have potential to be considered as methods for feature extraction. However, it is too early to say that these methods could be very useful for all scripts and data sets.

6.2 MAJOR FINDINGS AND ACHIEVEMENT OF THE OBJECTIVES

The research concludes with the following findings.

Finding-1: Proposition of two new feature extraction methods for handwritten Odia characters based on:

(i) \(LU\) factorization of the character image.
(ii) Linear transformation using binary image.

The proposition of the above two feature extraction methods confirm the achievement of the first objective undertaken in this research.

Finding-2: Verification of the proposed methods by implementing:

(i) Naive Bayes classifier and ANN with back-propagation algorithm on handwritten Odia numerals. (method-1)
(ii) Recurrent Neural Network (RNN) on handwritten Odia numerals and alphabet. (method-2)
Here, the proposed methods have been verified in two ways. The first approach is based on theoretical and scientific evidences which have been discussed already in chapter-IV earlier in this thesis. The second approach is the practical implementations of the methods. Again, the detailed implementation strategy and results have already been explained in chapter-V. These implementations confirm the achievement of the second objective.

**Finding-3:** Implementation of Hopfield Neural Network (HNN) for recognition of handwritten Odia numerals.

HNN is an associative memory which bears the capability of retrieving a pattern stored in memory, when an incomplete or noisy version of that pattern is presented. This is why HNN is very powerful in the area of character recognition. This research implements Hopfield network for recognizing handwritten Odia numerals and hence achieves its third objective.

**Finding-4:** This research uses Odia characters (numerals and alphabet) as input to the systems collected from various sources. Finally, a data set consisting of 9920 numbers of handwritten Odia characters has been generated. This fulfills the achievement of the fourth objective. This data set will be made available online for researchers with appropriate permission from the competent authorities.

### 6.3 LIMITATIONS & FUTURE SCOPE

Every research opens a door for another. This research also provides a platform for other researchers to carry this research to another extent. Though, this research primarily focuses on handwritten Odia characters, yet it has the potential to be used for printed characters. The proposed feature extraction methods here in this research could also be extended to understand, or rather, identification of handwritten characters of other languages. Research could also be initiated to find suitable values of vector ‘B’ in $AX=B$ (in case of $LU$ factorization method) so that the proposed method will perform more effectively and efficiently.
6.4 CONCLUSIONS

The nature of handwritten characters is very complex. The complexity increases when an attempt is made to develop a recognition system for handwritten characters. This research makes a humble attempt to propose two new improved feature extraction methods for handwritten Odia characters. The $LU$ factorization has been proved as a strong mathematical tool to solve the set of linear equations especially finding the inverse of a matrix. This research proposes to use this $LU$ factorization to find the feature vectors. This research has successfully demonstrated the $LU$ factorization method in the process of image understanding specifically for handwritten Odia characters. Thus concluding a significant methodology that can be adopted in the process of handwritten character recognition. Though, all efforts have been made to produce some effective outcomes, still it is too early to claim the universal acceptance of the proposed methods for all languages. However, such possibilities cannot be ignored. Researchers are welcome to explore more on this so that this research could reach another height.