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An Efficient Kannada Handwritten Character Recognition Framework with Serial Dilated Cascade Network for Kannada Scripts

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Abstract

The most significant problem present in the digitized world is handwritten character recognition and identification because it is helpful in various applications. The manual work needed for changing the handwritten character document into machine-readable texts is highly reduced by using the automatic identification approaches. Due to the factors of high variance in the writing styles beyond the globe, handwritten text size and low quality of handwritten text rather than printed text make handwritten character recognition to be very complex. The Kannada language has originated over the past 1000 years, where the consonants and vowels are symmetric in nature and also curvy, therefore, the recognition of Kannada characters online is very difficult. Thus, it is essential to overcome the above-mentioned complications presented in the classical Kannada handwritten character recognition model. The recognition of characters from Kannada Scripts is also difficult. Hence, this work aims to design a new Kannada handwritten character recognition framework using deep learning techniques from Kannada scripts. There are two steps to be followed in the proposed model that is collection of images and classification of handwritten characters. At first, essential handwritten Kannada characters are collected from the benchmark resources. Next, the acquired handwritten Kannada images are offered to the handwritten Kannada character recognition phase. Here, Kannada character recognition is performed using Serial Dilated Cascade Network (SDCN), which utilized the Visual Geometry Group 16 (VGG16) and Deep Temporal Convolution Network (DTCN) technique for the observation. When compared to the baseline recognition works, the proposed handwritten Kannada character recognition model achieves a significantly higher performance rate.

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Keywords: Kannada handwritten character recognition, Serial dilated cascade network, Kannada scripts, Visual geometry group 16, Deep temporal convolution network

1. INTRODUCTION

Digitization techniques are applied to most of the historical manuscript documents by the manuscript preservation centers in India. The handwritten documents are degraded due to the factors like arbitrary geometric distortions such as wrapping and folding of manuscripts, and also ink bleed, maintenance and storage condition hence, it is essential to digitize the handwritten documents [1]. The recognition of ancient heritage evolution and its culture for future generations is essential. At first, the specialized scanner and camera are used for acquiring the images for digitization, and then these images are fed to further analysis that includes recognition and interpretation. The scripts are read and written in the Indian state of Karnataka, which is stated as Karnataka script. These scripts evolved in the regime of various dynasties like Devarajaswamy and Manjunath, namely, Shatavahana, Kadamba, Chalukya, Mysore Wodeyars, Rastrakuta, Hoysala, Ashoka, Ganga, and Vijayanagara. Based on the writing style, the evolution of Kannada scripts is categorized into Pre-old, old, middle and modern Kannada. The other name of this categorization is Poorva Halagannada (pre-old), Halagannada (old), Nadugannada (middle), and Aadhunika Kannada (modern Kannada).

Most of the handwritten document character recognition models [2, 3], relied only on the recent-age-type handwritten documents and hence the recognition of characters from old-type-age documents is important. The traditional approaches utilize image processing techniques to improve the quality of images, but there is a chance of missing some relevant information for recognizing characters. The text line identification methods are suggested for recognizing characters, but it needs more time for recognition. The Gabor-zonal and Local Binary Patterns (LBP) features-based approaches are adopted for the recognition of characters from Kannada handwritten documents [4]. But, the accuracy of these approaches is slightly low and hence several deep learning algorithms are recommended for recognizing the characters from the handwritten documents. Most of the deep learning approaches for recognizing characters suffered from insufficient samples. In addition, the recognition time and complexity of these approaches are high. Many deep learning-based handwritten character recognition approaches do not consider the consonants, vowels and numerals [5–8], for recognizing the characters. Therefore, a new Kannada handwritten character recognition model using a serial cascaded deep learning network from Kannada scripts is developed to solve the issues aroused during the recognition of characters from the degraded scripts.

The significant objectives of the proposed Kannada handwritten character recognition scheme are elucidated as follows.

- To design a new Kannada handwritten character recognition model using deep learning to identify the cursive nature of handwritten texts from scripts with higher accuracy.
- To implement a serial cascaded deep learning network for recognizing the handwritten characters very effectively by considering the numerals, vowels and consonants, where the VGG16 and DTCN structures are utilized.

- To ensure the recognition outcome of the developed Kannada handwritten recognition model in terms of distinct measures with respect to previously developed handwritten character recognition models.

SDCN is a type of neural network architecture designed for tasks such as image classification or segmentation. It incorporates dilated convolutions in a serial cascade structure. Dilated convolutions are a type of convolutional operation where the filter is applied over a larger area with gaps between the filter elements, allowing for an increased receptive field without increasing the number of parameters.

VGG16 is a specific convolutional neural network architecture developed by the Visual Geometry Group (VGG) at the University of Oxford. It is characterized by its deep architecture consisting of 16 layers, including convolutional layers with small 3x3 filters and max-pooling layers. VGG16 has been widely used for various computer vision tasks, including image classification and object detection.

DTCN is a type of neural network architecture designed specifically for modelling temporal data, such as time series or videos. It typically consists of convolutional layers followed by recurrent layers or temporal pooling layers to capture temporal dependencies in the data. DTCNs are commonly used in tasks such as action recognition, video classification, and speech recognition.

The remaining sections used to describe the proposed serial cascaded deep learning-based Kannada handwritten character recognition model are summarized as follows. The recently developed handwritten character recognition models are given in Part II. The architectural explanation of the proposed handwritten recognition model and the datasets used for identifying the characters are given in Part III. The proposed serial cascaded deep learning network with VGG16 and DTCN is briefly explained in Part IV. The comparative analysis of the presented scheme with traditional handwritten character recognition models is illustrated in Part V. The detailed summary of the proposed model is given in Part VI.

2. LITERATURE SURVEY

2.1 Related Works

In 2018, Rani *et al.* [9], have developed deformed character recognition approach using Convolutional Neural Network (CNN). The input images were collected from the ancient poetry documents under unconstrained environments. The characters from the degraded images were slightly blurry and it resulted in poor classification accuracy. The developed model considered the vowels, consonants, complex compound characters and simple compound characters for characterizing the documents using the CNN model. The final classification accuracy of the proposed CNN-based deformed character recognition approach was high rather than other models.

In 2019, Karthik and Murthy [10], have proposed a Deep Belief Network (DBN)-based Kannada handwritten recognition approach using a distributed average of points. The printed patterns of the Indian language have been recognized through the proposed deep learning model. The accuracy of the proposed handwritten recognition model has been validated with the traditional algorithms in terms of various measures.

In 2023, Siddanna and Kiran [11], have proposed a handwritten character recognition model for the Kannada language with the support of CNN and transfer learning. The Kannada handwritten document has been initially subjected to preprocessing techniques like removing noise, cropping each character and image resizing. The enhanced pixel values have been achieved at output that has trained with CNN for classification respective to their classes. The vowels, numerals and consonants were separately considered and then classified with their respective classes. The new style of handwritten documents has been predicted via transfer learning.

In 2020, Rao *et al.* [12], have employed an exploring deep learning procedure for recognizing Kannada handwritten document. The quality of the image has been enhanced with the help of preprocessing algorithms and the deep learning algorithm was adopted for extraction of features. The experiments have been conducted for validating the performance of the proposed model by considering the Chars74K dataset. The error rate has been considered for measuring the performance and the developed model has proven its effectiveness when compared to other models.

In 2022, Rani *et al.* [13], have introduced a robust recognition approach for recognizing handwritten language via capsule networks. The layers presented in the capsule networks were the primary capsule layer, input layer, routing capsule layer, and two convolution layers followed by output and tri-level dense convolution layer. Experimental tests have been considered for validating the performance with respect to accuracy and the implementation outcome were revealed the efficiency of the proposed model.

2.2 Problem Statement

The automated learning of Kannada handwritten documents is crucial because of consonants, vowels and modifiers. The complexity of the traditional Kannada handwritten [14], recognition methods is affected by complexity issues and the processing time required for recognizing the handwritten documents is also high [15]. Therefore, deep structural learning-based handwritten character recognition for Kannada language is designed and the benefits as well as challenges are listed in Table 1. SLD [9], eliminates the unwanted words properly from the handwritten document. But, it pertains to the line and word characters very effectively. Yet, it does not consider the vowels and consonants from the document. Moreover, it can be hampered by the space resemblance among characters and words. In DBN [10], the isolated handwritten characters are recognized very efficiently. On the other hand, the accuracy of the proposed system is better when compared to other schemes. However, the numerals of the handwritten document are not effectively categorized [16–18]. CNN is highly suitable for a small number of handwritten samples. Furthermore, validation accuracy is also high in the proposed model [11, 19]. But, it requires more recognition time when compared to other methods. In CNN [12], the speed of the recognition process is high. In addition, it provides a bridging gap between machines and humans. Yet, it is not suitable for learning non-linear relationships, and hence the classification performance is poor. In the Capsule network [13], the tunable hyperparameters improve the recognition accuracy. Moreover, the F1-score value is also high by using the capsule networks. However, it is more tedious and it takes more training time during recognition. To address these challenges, the deep learning-based Kannada handwritten character recognition model is proposed with the usage of deep learning algorithm.

Table 1: Merits and Disadvantages of the traditional Deep Learning-based Kannada Handwritten Character Recognition Models

Author [citation]	Methodology	Features	Challenges
Rani *et al.* [9],	CNN	It provides higher classification accuracy over the degraded ancient documents during character recognition. It considers the vowels, consonant and compound characters for recognizing the documents.	The training speed of the proposed CNN-based handwritten character recognition model is low. It is affected with overfitting issues.
Karthik and Murthy [10],	DBN	The isolated handwritten characters are recognized very efficiently. The accuracy of the proposed system is better when compared to other schemes.	The numerals of the handwritten document are not effectively categorized.
Siddanna and Kiran [11],	CNN	It is highly suitable for a small number of handwritten samples. Validation accuracy is also high in the proposed model.	It requires more recognition time when compared to other methods.
Rao *et al.* [12],	CNN	The speed of the recognition process is high. It provides a bridging gap between machines and humans.	It is not suitable for learning non-linear relationships and hence the classification performance is poor.
Siddanna, and Kiran [13],	Capsule network	The tunable hyperparameters improve recognition accuracy. The F1-score value is also high by using the capsule networks.	It is more tedious and it takes more training time during recognition.

3. DEVELOPED KANNADA HANDWRITTEN CHARACTER RECOGNITION FRAMEWORK FOR KANNDA SCRIPTS WITH DESCRIPTION OF DATASETS

3.1 Primary Illustration of Implemented Scheme

Character recognition from Kannada scripts is challenging because a large number of letters are available in the Kannada language and hence it is an open problem for researchers. Moreover, the recognition of handwritten characters from Kannada scripts is crucial due to the variations in the handwriting styles and also the scanner quality. This recognition process needs network training and it increases the computation overload by processing with large volume of data. The recognition of characters with respect to vowels and consonants is quite challenging in Kannada scripts. In addition, the traditional handwritten character recognition approaches need high memory space to store large volumes of data. The speed of the recognition process is also low in the existing handwritten character recognition models. Therefore, a new Kannada handwritten character recognition model is developed using a serial cascaded deep learning network. The primary illustration of the proposed Kannada handwritten recognition model is depicted in FIGURE 1.

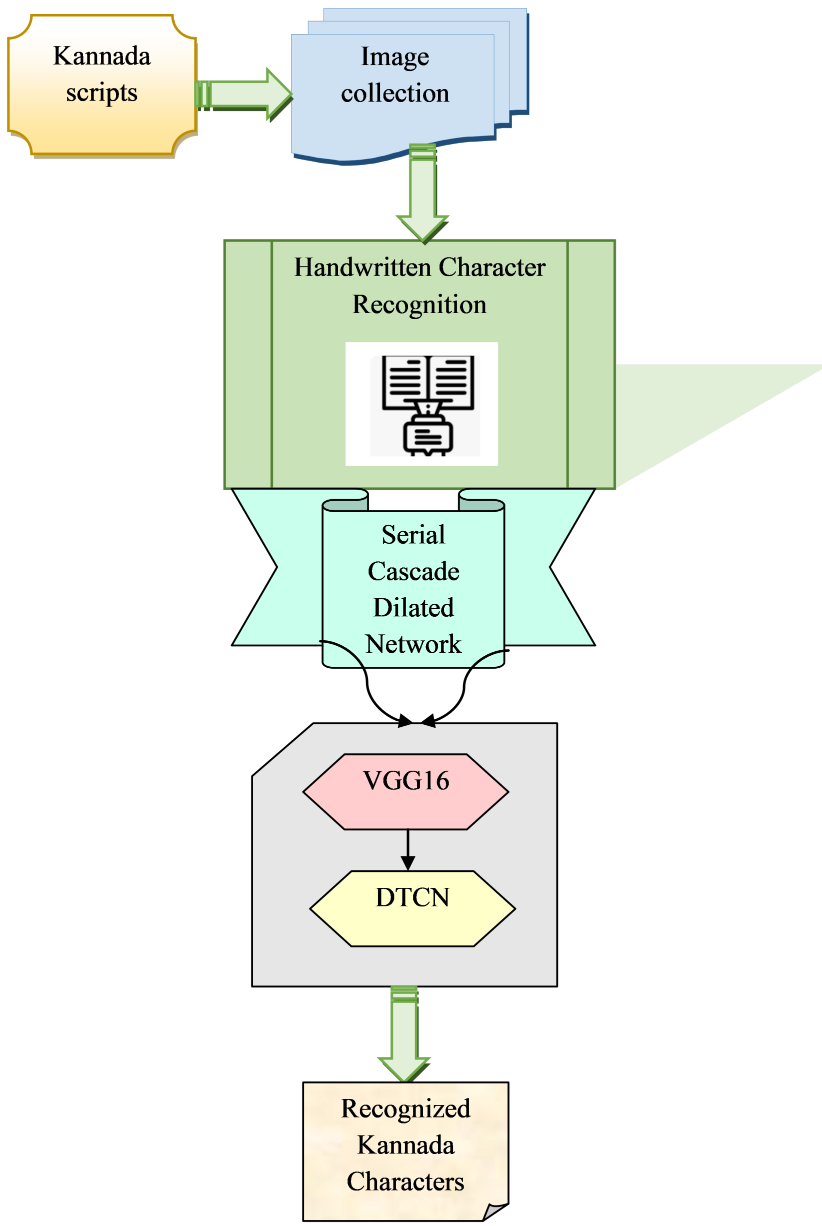


Figure 1: Schematic representation of proposed deep learning-based Kannada handwritten recognition scheme

A new Kannada handwritten character recognition system is designed to recognize the handwritten characters from damaged Kannada scripts with higher recondition efficacy. The data needed for recognizing the written characters are garnered through the online database. The collected images are given to the recognition process, where the proposed Serial Dilated Cascaded Network is used for the recognition of the characters. Here, the VGG16 and DTCN networks are serially connected to provide efficient character recognition outcomes. The results attained from the serial cascaded deep learning network are constricted with the previously used recognition models in terms of several measures to prove its effectiveness.

3.2 Dataset Collection

The required data is collected from the database of "Kannada Handwritten Characters", which is taken from [20]. The total images presented in this database are 16,425 images in the Kannada language. Generally, it is a classification dataset and it is utilized mainly for computer vision applications. Totally, 657 classes with 25 images are presented in this dataset. The file size of the dataset is 375.09 kB. The presented version is Version 2 with 171.73 MB. The sample images collected from the Kannada scripts are given in FIGURE 2.

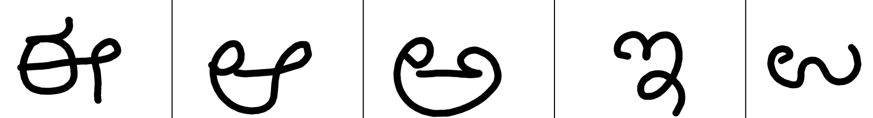
	1	2	3	4	5
Images					

Figure 2: Sample images collected from Kannada scripts

The collected Kannada language images are considered as H_y^{Kan}, where y indicates the total count of the sample images.

4. RECOGNITION OF HANDWRITTEN CHARECTERS FROM KANNADA SCRIPTS USING SERIAL CASCADED DEEP NETWORK

4.1 Basic VGG16

It is adopted in the developed Kannada handwritten character recognition framework to learn the more robust features from the input data.

VGG16 [21]: The VGG architecture is categorized on the basis of the number of layers present in the network architecture. It is simple in structure and it takes the baseline features from the input images that are useful for training the network. The VGG16 architecture includes 5, maximum pooling layers, 13 convolutional layers and 3 dense layers. Various features from the given input images are extracted using the convolutional layer. Pooling layer is used for decreasing the computations and training features. The classification is done in the fully connected layer. The conv1 has 3×3 with 64 filters, and conv2 has 3×3 with 128 filters, conv3 has 3×3 with 256 filters, conv4 and conv5 has 3×3 with 512 filters. The maximum pooling has the kernel size of 2×2. Between each convolutional layer and two dense layers, the ReLu activation function is inserted. For prediction, the softmax activation function is utilized at the final dense output layer. The learning rate and weights of the network plays the significant role during training the network. The usage of high learning rate reduces the error rate in the network. The VGG16 architecture is shown in FIGURE 3.

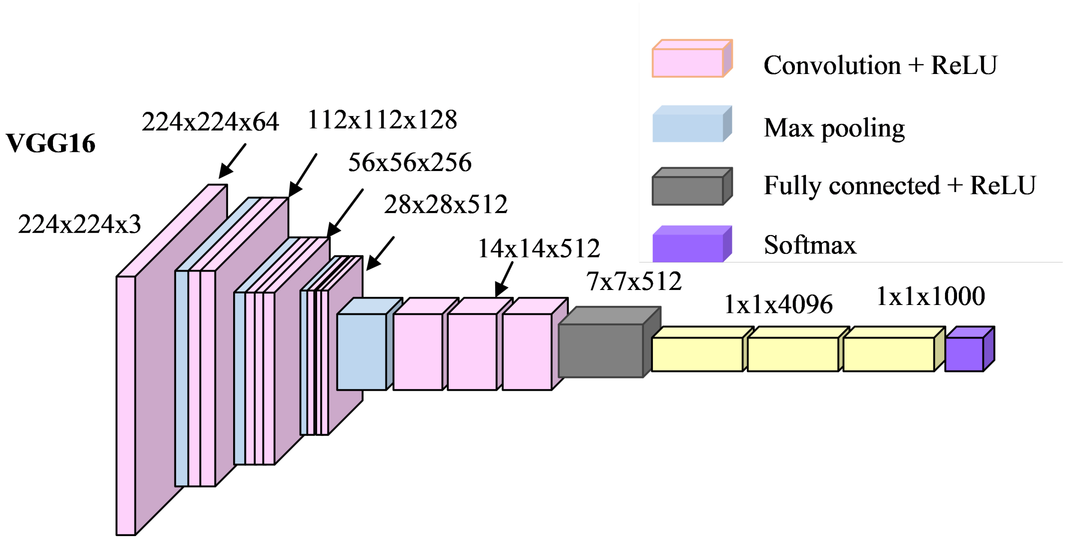


Figure 3: Architecture of VGG16

4.2 Basic DTCN

The DTCN model is used in the proposed approach to recognize the handwritten characters from the Kannada scripts. The description of the DTCN model is given as below.

DTCN [22]: The TCN structure decreases the number of parameters used for recognizing the handwritten characters. The output size mainly depends on the size of the input and hence this network is constructed in regard to some parameter settings like padding, kernel size and stride. The size of the interval among two consecutive convolution centers is defined as stride. In padding, the boundary of the input is added and the dimensionality is represented with respect to a number of kernels. The long-term correlations are displayed by the sequential data by using the 1Dconvolutional network. It performs sliding dot product operation among the kernel as well as the input vector. From the input series data $d_1, d_2, ..., d_P$, the predicted outputs $\hat{d}_1, \hat{d}_2, ..., \hat{d}_P$ are created. The output d_p is convoluted with the input from the previous layer. The future patterns are used for predicting the past patterns and hence it is not appropriate. Therefore, casual convolutions are adopted to solve this issue. Here, the output is convoluted with the input only, which is attained from the previous layer. Zero padding is applied to the beginning of the input series with a length of (kernel size - 1). Due to this factor, the shifting of output toward a number of the time step is happened.

In the residual connections, the skip layer is used to avoid processing all layers in the network. The shortcut connections are directly connected to the later layer. This process is otherwise called as identity mapping. The residual block output is given in Eq. (1).

$$f\,(G\,(p)+p) \tag{1}$$

The input applied to the residual block is indicated by p and the activation function is represented by f.

The previous layer activation function is reused until the weight is learned by the adjacent layer and hence the vanishing gradients problems are eliminated. The DTCN model is illustrated in FIGURE 4.

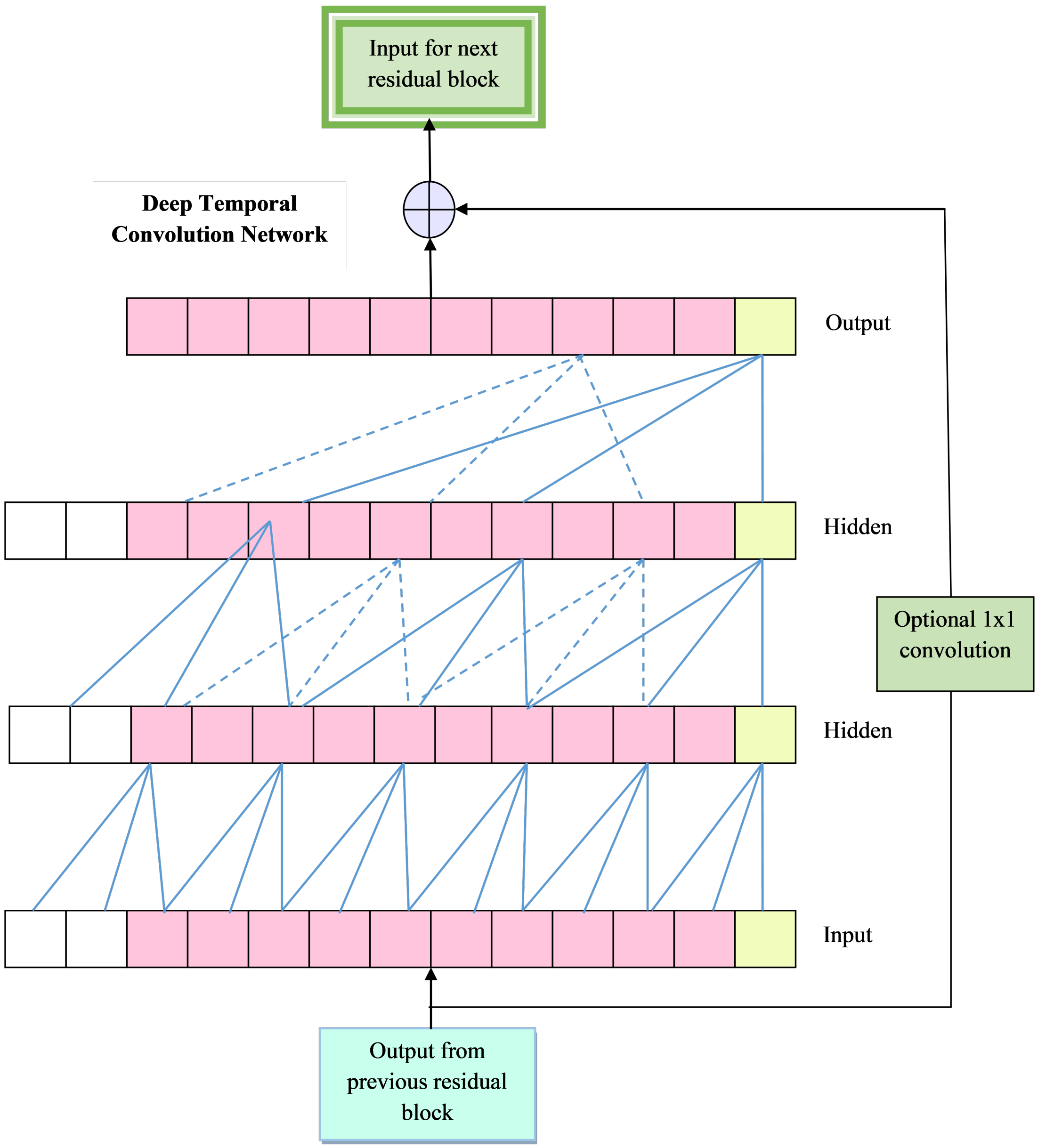


Figure 4: Basic structure of DTCN

4.3 Proposed SCDN-based Character Recognition

The SCDN model is developed to recognize the Handwritten Kannada characters from scripts with higher recognition accuracy. The collected Kannada language images H_y^{Kan} are given to SCDN to get the recognized characters. In the implemented SCDN, the VGG16 and DTCN models are integrated and the dilated convolution is added to improve the recognition performance. The vowels, consonants from the Kannada language are taken into consideration during the recognition of handwritten characters.

Dilated convolution: The long-term autoregressive dependencies are solved via the dilated convolutions. The casual convolutions have a larger receptive field, which problem to be solved via the usage of dilated convolution. Therefore, the number of large filters used is decreased. The dilated convolution is given in Eq. (2).

$$G(q) = (d *_r g)(q) = \sum_{j=0}^{l-1} g(j) \cdot d_{q-r\times j} \tag{2}$$

The 1D input is indicated by d that lies in $d \in \Re^P$ and $g : \{0, 1, ..., l-1\} \rightarrow$ N, where the filter size is indicated by l. The dilation rate is specified by the term r. We will refer to *r as a dilated convolution or an r-dilated convolution. The familiar discrete convolution * is simply the r-dilated convolution. It does not follow the simple sequential manner for convoluting the output with the input in the dilated convolutional layer. But, it skips the constant number of inputs in between them. Based on the layer depth, the dilation rate multiplicatively increased. Then, the receptive field is increased exponentially and hence the 2^{m-1} affect of the m^{th} hidden layer. The detailed description of the developed SCDN-based handwritten character recognition model for Kannada scripts is depicted in FIGURE 5.

5. RESULTS AND DISCUSSION

5.1 Experimental Setup

The proposed SCDN-based Kannada handwritten character recognition framework from Kannada scripts has been designed using Python software. The empirical experimental results have been compared to the previously suggested deep learning-based handwritten character recognition models to verify the recognition performance in accordance with several observation measures. The previously used handwritten character recognition models like LSTM [23, 24], ResNet [25], VGG16 [21], and DTCN [22], are considered to validate the effectiveness of the proposed SCDN-based handwritten character recognition framework.

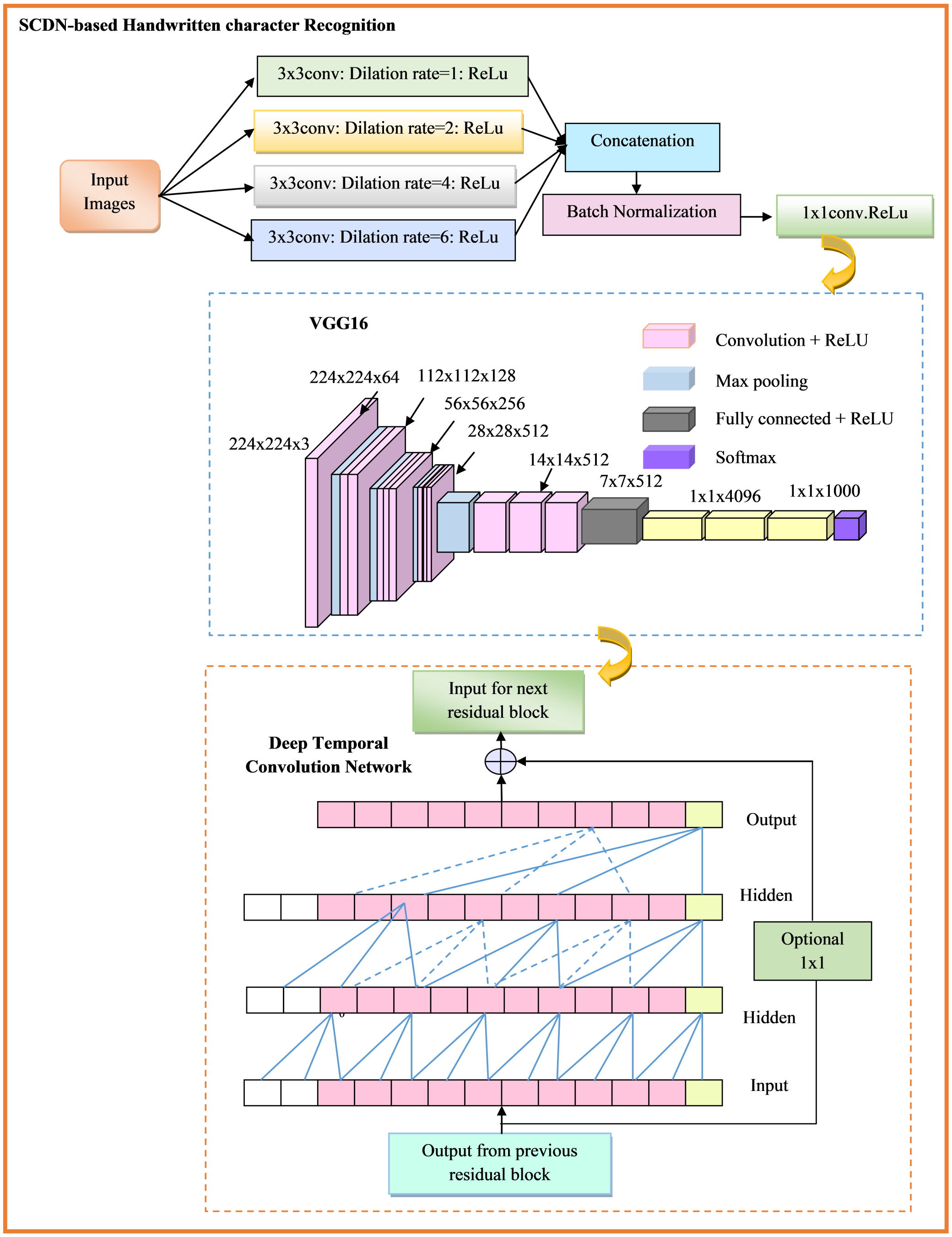


Figure 5: Recognition of Kannada Handwritten Characters using SCDN

5.2 Analysis Metrics

Several performance analysis metrics are utilized in the proposed Kannada handwritten character recognition model to ensure the effectiveness that is expressed as follows.

$$Fscore = 2 \times \frac{\Pr ecision \times Recall}{\Pr ecision + Recall} \tag{3}$$

$$NPV = \frac{T_{re}V_{gt}}{\left(T_{re}V_{gt} + F_{ls}V_{gt}\right)} \tag{4}$$

$$Sensitivity = \frac{T_{re}E_{ps}}{\left(T_{re}E_{ps} + F_{ls}V_{gt}\right)} \tag{5}$$

$$Specificity = \frac{T_{re}V_{gt}}{\left(T_{re}V_{gt} + F_{ls}E_{ps}\right)} \tag{6}$$

$$Ar = \frac{T_{re}E_{ps} + T_{re}V_{gt}}{T_{re}E_{ps} + T_{re}V_{gt} + F_{ls}E_{ps} + F_{ls}V_{gt}} \tag{7}$$

$$FPR = \frac{F_{ls}E_{ps}}{\left(T_{re}V_{gt} + F_{ls}E_{ps}\right)} \tag{8}$$

$$MCC = \frac{T_{re}E_{ps} + T_{re}V_{gt} - F_{ls}E_{ps} + F_{ls}V_{gt}}{\sqrt{\begin{array}{c}\left(T_{re}E_{ps} + F_{ls}E_{ps}\right)\left(T_{re}E_{ps} + F_{ls}V_{gt}\right)\\ \left(T_{re}V_{gt} + F_{ls}E_{ps}\right)\left(T_{re}V_{gt} + F_{ls}V_{gt}\right)\end{array}}} \tag{9}$$

$$Pn = \frac{T_{re}E_{ps}}{T_{re}E_{ps} + F_{l}V_{gt}} \tag{10}$$

5.3 Analysis of the ROC Curve

The ROC curve validation of the developed SCDN-based Kannada handwritten character recognition model among various baseline schemes is represented in below FIGURE 6. We have set the threshold value as None, hence all data points will be classified as positive. This will result in a ROC curve that is a straight line from the origin to the upper left corner. The true positive observation metric, as well as the false positive observation metric is varied here for validating the effectiveness of the developed handwritten character recognition framework. The ROC analysis outcomes show that the Roc curve of the presented SCDN-based Kannada handwritten character recognition framework is improved by 5.06% rather than LSTM, 3.75% rather than ResNet, 2.46% rather than VGG16, and 1.21% rather than DTCN while taking the false positive rate of 0.4. In between the false positives of 0.2 and 0.6, the developed Kannada handwritten character recognition scheme obtained with better performance in accordance with ROC when analyzed over the previous recognition models.

5.4 Analysis With Various Performance Measures

The performance of the proposed SCDN-based Kannada handwritten character recognition model among divergent baseline frameworks is considered for validating the effectiveness of the proposed

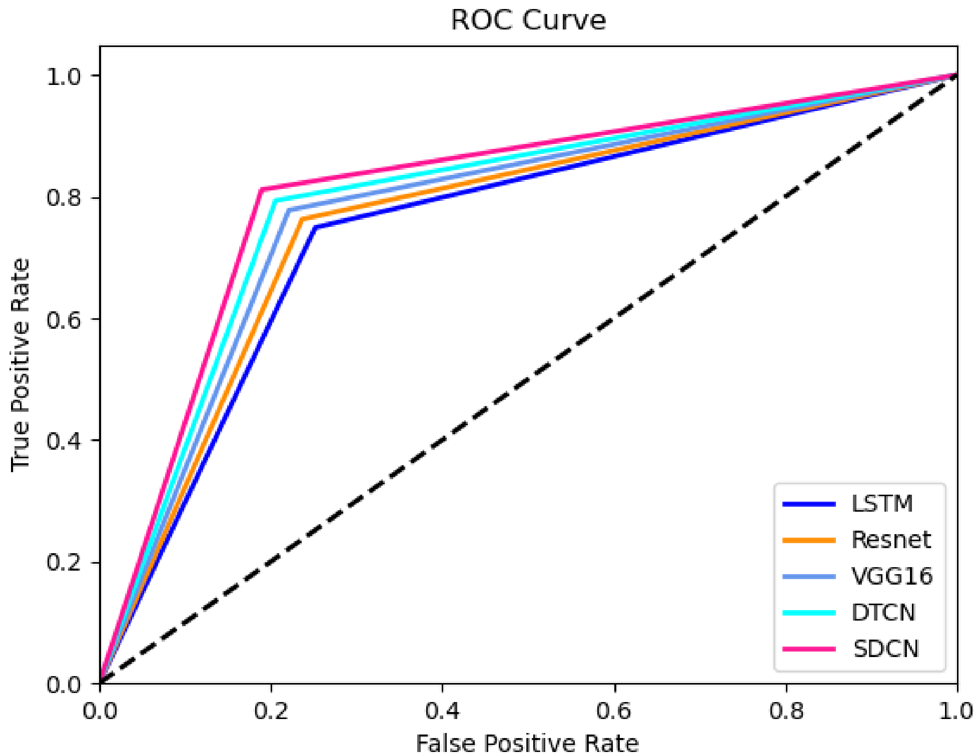


Figure 6: Performance computation of the developed SCDN-based Kannada handwritten character recognition framework among various baseline recognition models in terms of ROC curve

scheme concerning various evaluation measures. The analysis outcome among the classifiers is demonstrated in FIGURE 7. The epoch value is varied for conducting experiments over the traditional methods. The proposed model F1-score is improved by 35.48%, accuracy is progressed with 2.12%, FNR is enhanced with 15.21%, FDR is enhanced by 1.04%, MCC is improved by 15.96%, FPR is progressed with 20.87%, precision is progressed with 46.10%, NPV is enhanced with 2.12%, specificity is improved with 4.34%, and sensitivity is progressed with 3.26% than DTCN for the epoch value of 30. Furthermore, the F1-score, precision and MCC values are achieved more extensive performance than the traditional algorithms. Moreover, the negative measures are also performed well than the traditional handwritten character recognition models.

5.5 Efficiencyvalidation of the Proposed Model With Previous Models

The developed Kannada handwritten character recognition model is validated through conducting experiments over the traditional approaches in terms of several metrics like NPV, FNR, precision, FPR, F1-score, accuracy, FDR, MCC and FPR, which is given in Table 2. The F1-score value of the proposed SCDN-based Kannada handwritten character recognition model is gained with 57.63%, 50.28%, 66.68%, and 33.02% than the LSTM, ResNet, VGG16, and DTCN classifiers

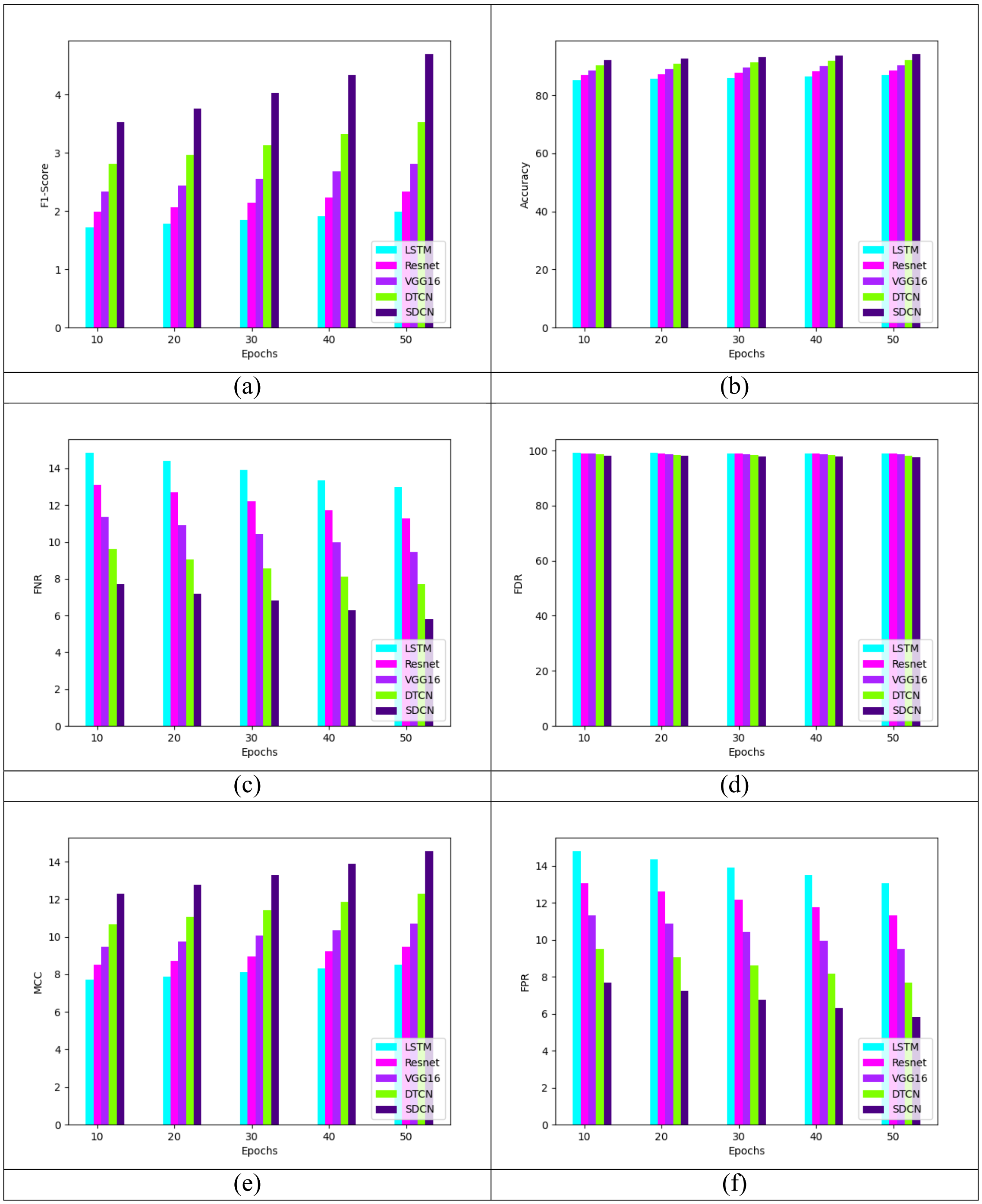


Figure 7: Performance computation of the developed SCDN-based Kannada handwritten character recognition framework among various baseline recognition models in terms of "(a) F1-score, (b) Accuracy, (c) FNR, (d) FDR, (e) MCC, (f) FPR, (g) Precision, (h) NPV, (i) Specificity and (j) Sensitivity"

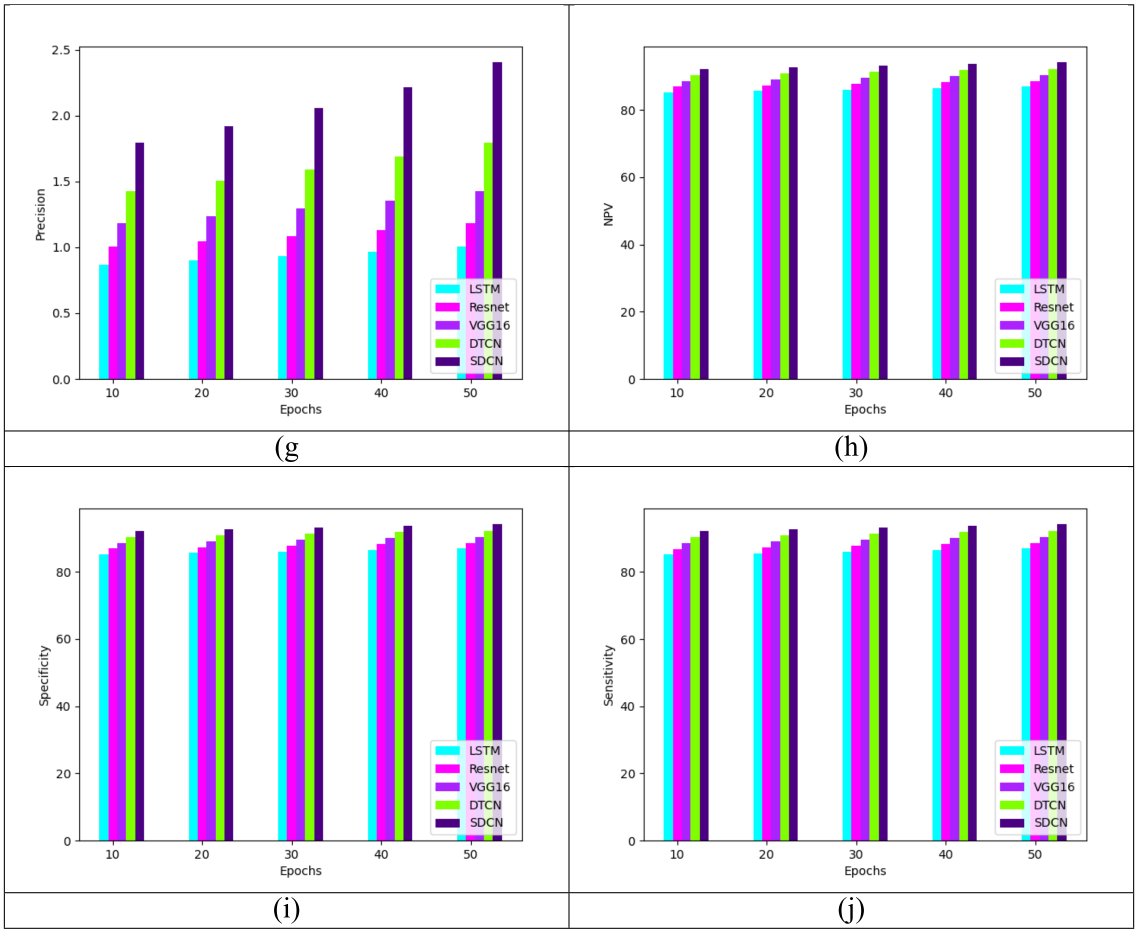


Figure 7: Continued.

from Table 2 analysis. The developed scheme has given extensive efficiency during the recognition of handwritten characters from Kannada scripts.

6. CONCLUSION

A new handwritten character recognition framework has been implemented to recognize the characters from the ancient Kannada scripts. The characters were effectively recognized from the degraded Kannada scripts with higher efficiency. Initially, the required images were taken from traditional online databases and then processed in the recognition process. The obtained images were given to the SCDN for recognizing the documents, where the VGG16 and DTCN have been utilized for recognition purposes. The requirement of a large receptive field has been eliminated with the help of integrating dilated convolution in the proposed scheme. The serially cascaded VGG16, and DTCN has provided higher recognition outcome from the Kannada scripts. The implementation results have been contrasted with the previously implemented deep learning-based Kannada handwritten recognition models while concerning with various evaluation metrics. The

Table 2: Performance computation of the developed SCDN-based Kannada handwritten character recognition framework among various baseline recognition schemes

Metrics	LSTM [24]	Resnet [25]	VGG16 [21]	DTCN [22]	SDCN
NPV	86.93736	88.69007	90.48302	92.31446	94.17413
FPR	13.06264	11.30993	9.516984	7.685544	5.825871
Specificity	86.93736	88.69007	90.48302	92.31446	94.17413
Accuracy	86.93747	88.69013	90.48309	92.31442	94.17416
FDR	98.99484	98.81827	98.57061	98.20234	97.59452
FNR	12.99239	11.27549	9.467275	7.707763	5.802131
MCC	8.523047	9.485931	10.70098	12.28893	14.55154
Sensitivity	87.00761	88.72451	90.53272	92.29224	94.19787
F1-Score	1.98736	2.332389	2.81434	3.526636	4.691164
Precision	1.00516	1.181727	1.429387	1.797664	2.40548

analysis outcome revealed that the accuracy of the proposed gained with 8.32%, 6.18%, 4.07%, and 2.07% than the LSTM, ResNet, VGG16, and DTCN classifiers from Table 2 analysis. Finally, the proposed SCDN-based Kannada handwritten character recognition model outperformed well than the traditional handwritten character recognition approaches. The accuracy of the proposed model was also greater while analyzing the experimental outcome.

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