RESEARCH ARTICLE

SAMRIDDHI Volume 14, Special Issue 1, 2022 Print ISSN : 2229-7111 Online ISSN : 2454-5767

An Improved and Customized Hybrid of Deep and Machine Learning Technique Model for Handwritten Digit Recognition

A. K. Agrawal[1*], A. K. Shrivas[2], V. K. Awasthi[3]

[1*] Dr. C.V. Raman University, Bilaspur, C.G., India, e-mail: ayushagrawal369@gmail.com
[2] Guru Ghasidas Vishwavidyalaya, Bilaspur, C.G., India.
[3] Dr. C.V. Raman University, Bilaspur, C.G., India.

ABSTRACT

In modern research, pattern recognition is a vast field for the academicians and researchers to contribute their work. Various kinds of patterns like images, character, handwritten digit, etc can be recognized and classify with the help of the intelligent techniques. This research work is concentrated on the classification of handwritten digit recognition. In the world, peoples' handwriting is different from each other's and uses different languages, so it is necessary to develop a model that is able to recognize handwritten digits with high accuracy. Various deep and machine learning methods have been implemented by various authors and achieved satisfactory results. This research work has proposed a hybrid technique that combines deep learning and machine learning algorithms for classification of handwritten digit characters. The proposed model has two steps, first feature extraction, and second is classification of handwritten digits. The Convolutional neural network (CNN) has been used as feature extractor, and support vector machine (SVM), K-nearest neighbors (KNN), and Random Forest Classifier (RFC) algorithms have been used to recognize and classify handwritten digits. We have used very famous handwritten digit dataset as MNIST that contains 70000 samples of 0-9 digits, and EMNIST is an extended version of the MNIST dataset, that contains 280000 handwritten digit samples. The contribution of this research work is to enhance the recognition rate by our proposed hybrid models as CNN with SVM named as CNN-SVM, CNN with RFC named as CNN-RFC, and CNN with KNN named as CNN-KNN model, and achieved excellent recognition rate with both MNIST and EMNIST data samples. We have achieved the testing accuracy as 99.45% by CNN-RFC, 99.48% by CNN-KNN, and 99.55% by CNN-SVM with MNIST dataset while 99.54% by CNN-RFC, 99.46% by CNN-KNN, and 99.66% by CNN-SVM with EMNIST dataset. The testing accuracy achieved by our proposed model is tremendous and higher than previous research work.

***Keywords*:** Convolutional Neural Network (CNN),EMNIST Handwritten Digit Dataset, K-nearest neighbors (KNN), MNIST Handwritten Digit Dataset, Random Forest Classifier (RFC), Support Vector Machine (SVM).

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology, (2022); DOI : 10.18090/samriddhi.v14spli01.3

INTRODUCTION

Deep learning and machine learning play very important role in the field of pattern recognition, face recognition, image processing, and many more. Deep learning is a classifier and filter is used for more and more filtering the data and achieves better accuracy. The main motive and contribution of this research work is to develop the robust and efficient model that achieves better accuracy. The proposed model is developed using hybridization of deep learning and machine learning techniques classification of for handwritten digit patterns. We have used CNN to extract features of dataset and standard machine learning algorithms like SVM, KNN, and RFC for reorganization and classification of handwritten digits patterns. Here, the MNIST handwritten digit dataset is used to train

Corresponding Author : A. K. Agrawal, Dr. C.V. Raman University, Bilaspur, C.G., India,

e-mail: ayushagrawal369@gmail.com

How to cite this article : Agarwal, A.K., Shrivas, A.K., Awasthi, V.K. (2022). An Improved and Customized Hybrid of Deep and Machine Learning Technique Model for Handwritten Digit Recognition.

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology, Volume 14, Special Issue (1), 13-19.

Source of support : Nil

Conflict of interest : None

the classifier and calculate the accuracy. The MNIST dataset [1] is freely available. We have also used one more handwritten dataset such as EMNIST digit dataset for analysis of proposed model. The EMNIST digit dataset has been downloaded [2] which is also freely available.

Many authors have calculated the recognition accuracy of various models with MNIST testing samples and achieved the satisfactory results. In case of MNIST dataset, some authors [3] proposed two-stage classification techniques for feature extraction and classification and achieved 99.03% of accuracy. The authors [4] proposed a DBN-based classification model based on two approaches like evolutionary algorithm and structure learning, and they achieved as 97.02% of recognition rate with testing samples. The Genetic algorithm-based techniques have been implemented by authors [5] for feature extraction of training and testing samples and used machine learning techniques for classification. The authors [6] proposed ANN, which is fast and efficient because they have used GPU for the calculation and experimental work and achieved 98% of recognition rate. The minimal CNN and extended minimal CNN based on layered approach has been proposed by the authors [7] for recognition of handwritten digits and achieved 97.30% accuracy with minimal CNN, and 98.50% accuracy with extended minimal CNN. Some authors [8][9][10][11][12][13][14] used different layered approach of CNN and achieved an excellent results as 98.80%, 98.32%, 99.20%, 99.10%, 98.40%, 98.00%, and 99.31% of accuracy respectively. Some authors proposed hybrid deep learning and machine learning model for handwritten digit recognition. Some authors [15] proposed hybrid CNN-SVM and achieved 94.40% of accuracy, [16] proposed hybrid CNN-SVM model and achieved 99.28% of recognition rate, which is better than previous results. The authors [17] studied the research on MNIST and EMNIST dataset with different techniques and author [18] used deep learning model for classification.

Some authors also contributed their research with EMNIST handwritten digit dataset. The authors [19] used a deep neural network technique with an encoder to validate testing samples and achieved 98.50% of recognition rate with testing image samples. The Deep-CNN technique has been implemented by the authors [20] and also compared the accuracy with much iteration. The Evolutionary-DNN methods proposed by the authors [21] for handwritten digit recognition and achieved 99.30% of accuracy with digits dataset and also calculated the performance of the model with various datasets. The authors [22] proposed the LeNet model for recognizing handwritten digits and achieved 99.50% balanced recognition accuracy with digits data.

This paper has enhanced the recognition and classification accuracy by our proposed hybrid model that is a combination of CNN and SVM named as CNN-SVM, CNN with RFC named as CNN-RFC, and CNN with K-NN named as CNN-KNN model. Here, CNN has been used for the feature extraction of dataset, and SVM, KNN, and RFC techniques have been used to classify data samples. The proposed hybrid models CNN-SVM, CNN-RFC, and CNN-KNN achieved an excellent recognition rate with both MNIST and EMNIST datasets.

PROPOSED ARCHITECTURE

This section has explored the flow of proposed architecture of the research work. The proposed hybrid technique for handwritten digit recognition consists of feature extraction using CNN, and reorganization and classification of digits using machine learning techniques. We have implemented proposed hybrid CNN-SVM, CNN-KNN, and CNN-RFC models with MNIST and EMNIST handwritten digit datasets. The main advantage of proposed system is to classify the handwritten digits with high accuracy. We have also represented flow diagram of proposed model.

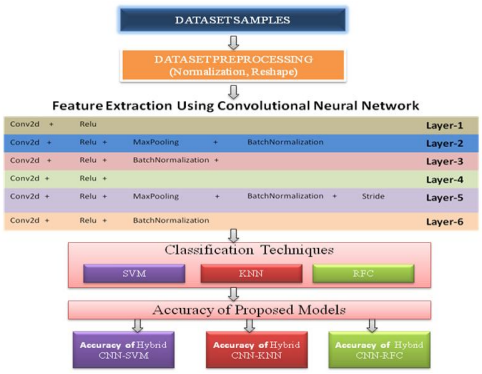
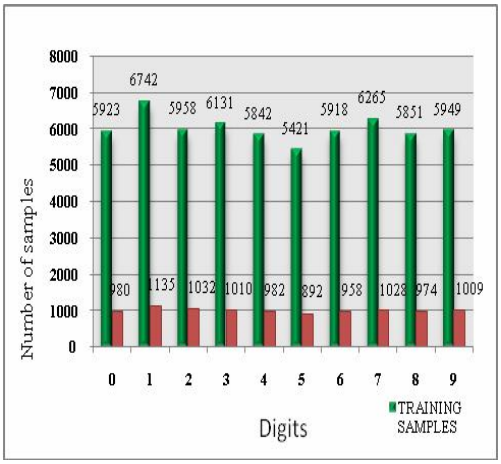


Figure 1: Flow diagram of proposed hybrid model

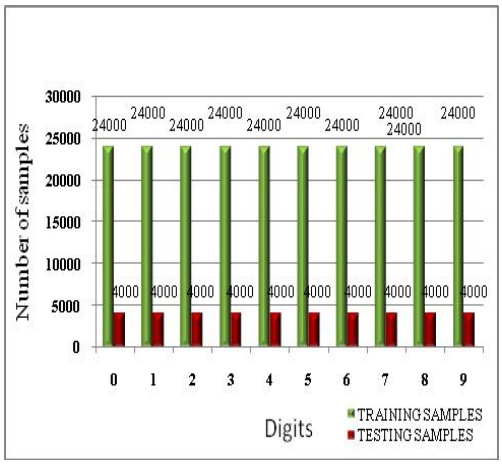
The architecture of the proposed model has represented in Figure 1. This is a flow diagram for developing the robust model to achieve better classification accuracy. The steps of creating the proposed model as given below:

Data Set

We have collected the MNIST dataset from the website [1] and EMNIST dataset from website [2] for handwritten digits recognition and classification. The MNIST dataset is a collection of 70000 samples that is divided into four files, 1st for 60000 image sample used as training images, 2nd for 60000 labels of training samples, 3rd for 10000 image sample used as testing images and 4th for 10000 labels of testing samples. Similarly, EMNIST dataset has 280000 images, and their labels samples, where we have used 240000 as training samples and 40000 as testing samples. The Figure 2 represent the total number of training and testing samples of each digits.



(A) MNIST samples



(B)EMNIST samples

Figure 2: Training and testing samples of each digit (0-9)

Data Preprocessing

The preprocessing of the data is a major task with the images because it is necessary to remove noises, irrelevant information and unstructured format of images. They consist of normalization, reshaping, image distortion, slant correction etc., and used normalization and reshaping for preprocessing of image samples.

Feature Extraction using CNN

The extraction of features by CNN combines various convolutional layers with various parameters. CNN is the part of deep learning, that extract the features from dataset and classify the handwritten digits. CNN [23][24] is one of the important deep learning approach for solving the complex problem. CNN handle complex data for image classification, pattern recognition and natural language processing. CNN has included multiple layers like input layer, convolutional layer, pooling layer, fully-connected layer and output layer as shown in Figure 3, and gives better performance in machine learning problem.

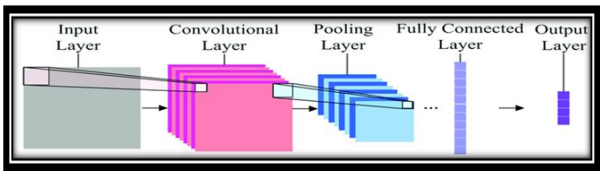


Figure 3: Simple architecture of CNN

Classification

Classification is the last step of our proposed model to classify the training images, and evaluate the performance of the models with testing samples. We have used SVM, KNN, and RFC as classifiers for classification of handwritten digits. It reduces the computation power to get efficient accuracy for any dataset and KNN classify the data based on similar classes into multiclass [25]. KNN solves the multiclass classification problem. The main task of KNN is find out value which have maximum distance from all available values using hamming distance or Euclidian, and that value known as k [8]. RFC [26] is a type of supervised machine learning algorithm that combined with multiple decision trees.RFC are useful for large size dataset and with has a large number of input features. A random forest use Gini index or entropy to handle the classification problem.

EXPERIMENTAL APPROCH

In this research work, we have used python 3.7 software available on anaconda navigator (anaconda3) with Tensorflow and Keras environment [27] for implementing the proposed hybrid models. We have

proposed hybrid CNN-SVM, CNN-RFC, and CNN-KNN models for the recognition and classification of MNIST and EMNIST handwritten digit datasets. The process of the experiment has been described in the following phase:

Dataset Preprocessing

In data preprocessing, we have normalized each image sample of training and testing data by dividing 255 and converting the pixel value between 0 to 1. Also, perform the reshaping of each image in 28*28*1 dimension. Some of the image samples of the digits dataset are represented in Figure 4.

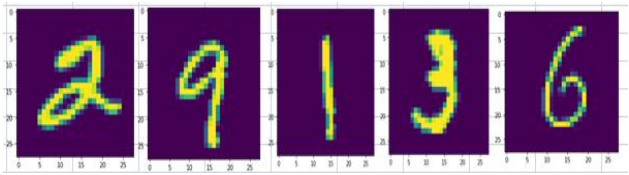


Figure 4: Some sample of handwritten digits

Feature Extraction using CNN

We perform the feature extraction with the preprocessed image samples. We have used the CNN method with different parameters and layers for feature extraction. The structure of CNN as follows:-

- Added first convolutional layer with 32 filters, (5,5) kernel size, and relu activation function.
- Added second convolutional layer with 32 filter, (5,5) kernel size, relu activation function and also added max-pooling of (2,2) size and batch normalization.
- Added third convolutional layer with 32 filter, (5,5) kernel size, relu activation function, and batch normalization.
- Added fourth convolutional layer with 64 filter, (3,3) kernel size, and relu activation function .
- Added fifth convolutional layer with 64 filters, (3,3) kernel size, relu activation function, and also added max-pooling of (2,2) size, stride, and batch normalization.
- Added sixth convolutional layer with 64 filter, (3,3) kernel size, relu activation function, and batch normalization.
- Added Flatten layer.

  After completing the feature extraction process, we have achieved the dimension of each image is 3136 for both training and testing data samples.

Classification of Handwritten Digits Data

Classification techniques play very important role to classify the handwritten digits patterns with high accuracy In this process, the extracted features of training and testing samples of MNIST and EMNIST datasets supplied to classification techniques. In this experiment, three machine learning techniques is used to recognize and classify both MNIST and EMNIST handwritten digits patterns. The classification of handwritten digits dataset is divided into two cases: Case1, proposed hybrid model is used to classify the MNIST handwritten digits patterns, while Case2 proposed hybrid model for classifying the EMNIST handwritten digits patterns.

➢ **Case – 1**

The experimental outcome of three proposed hybrid methods with the MNIST dataset is given in Table 1 that represents the training and testing accuracy of the proposed models with the MNIST dataset. We have used RFC classifier with optimized features of training and testing samples. The proposed CNN-RFC model achieved 100% of training accuracy. After training the CNN-RFC model, testing samples of the optimized MNIST dataset applied and achieved 99.45% of testing accuracy. We have used a standard KNN classifier with optimized features of training and testing samples. The proposed CNN-KNN model achieved 99.79% of training accuracy and 99.48% of testing accuracy. We have also used SVM classifier with optimized features of training and testing samples. The proposed CNN-SVM model achieved 100% of training accuracy and 99.55% of testing accuracy.

Table-1: Accuracy of Proposed Hybrid Models with Optimized MNIST Dataset

Model	Dataset	Accuracy
Hybrid CNN-RFC	Training samples	100%
	Testing samples	99.45%
Hybrid CNN-KNN	Training samples	99.80%
	Testing samples	99.48%
Hybrid CNN-SVM	Training samples	100%
	Testing samples	99.55%

From the above Table 1 show that the testing accuracy of CNN-SVM is higher than other proposed hybrid models. Figure 5 shows the (A) confusion matrix and (B) classification report of the hybrid CNN-

SVM model with testing samples of the MNIST dataset. In this figure, we have calculated the various performance measures as shown in Figure 5 in case of MNIST dataset.

```
Confusion Matrix:
[[ 977    0    0    0    0    0    0    2    1    0]
 [   0 1135    0    0    0    0    0    0    0    0]
 [   0    1 1029    0    0    0    0    2    0    0]
 [   0    0    0 1007    0    2    0    0    1    0]
 [   0    0    0    0  979    0    0    0    0    3]
 [   0    0    0    2    0  889    1    0    0    0]
 [   6    2    0    0    2    1  946    0    1    0]
 [   0    4    2    0    0    0    0 1022    0    0]
 [   1    0    2    0    0    1    0    0  970    0]
 [   0    0    0    0    5    2    0    1    0 1001]]
```

(A) Confusion matrix

```
Classification Report:
              precision    recall  f1-score   support

           0       0.99      1.00      0.99       980
           1       0.99      1.00      1.00      1135
           2       1.00      1.00      1.00      1032
           3       1.00      1.00      1.00      1010
           4       0.99      1.00      0.99       982
           5       0.99      1.00      0.99       892
           6       1.00      0.99      0.99       958
           7       1.00      0.99      0.99      1028
           8       1.00      1.00      1.00       974
           9       1.00      0.99      0.99      1009

    accuracy                           1.00     10000
   macro avg       1.00      1.00      1.00     10000
weighted avg       1.00      1.00      1.00     10000
```

(B) Classification report

Figure 5: Confusion and classification report of testing samples of MNIST by using hybrid CNN-SVM model

➢ Case – 2

Similarly, all three proposed hybrid models have implemented an optimized EMNIST digit dataset and achieved the satisfactory results represented in Table -2.

Table-2: Accuracy of Proposed Hybrid Models with Optimized EMNIST Dataset

Model	Dataset	Accuracy
Hybrid CNN-RFC	Training samples	100%
	Testing samples	99.54%
Hybrid CNN-KNN	Training samples	99.75%
	Testing samples	99.46%
Hybrid CNN-SVM	Training samples	99.99%
	Testing samples	99.66%

Table 2, shows that that the testing accuracy of CNN-SVM is higher than other proposed hybrid models. Fig 6 shows the confusion and classification report of hybrid CNN-SVM model's with testing samples of the EMNIST dataset.

In this figure, we have calculated the various performance measures as shown in Figure 6 in case of EMNIST dataset.

```
Confusion Matrix:
[[3990    1    1    0    0    1    3    1    2    1]
 [   0 3991    2    0    2    0    0    4    1    0]
 [   3    1 3984    5    1    0    0    5    0    1]
 [   0    0    4 3987    0    6    0    1    2    0]
 [   0    1    2    0 3981    0    2    2    1   11]
 [   3    1    0    6    0 3986    3    0    1    0]
 [   5    0    1    0    1    0 3992    0    1    0]
 [   0    2    5    0    2    0    0 3985    0    6]
 [   3    5    2    3    1    1    1    0 3982    2]
 [   0    0    0    0    8    0    0    3    2 3987]]
```

(A) Confusion matrix

```
Classification Report:
              precision    recall  f1-score   support

           0       1.00      1.00      1.00      4000
           1       1.00      1.00      1.00      4000
           2       1.00      1.00      1.00      4000
           3       1.00      1.00      1.00      4000
           4       1.00      1.00      1.00      4000
           5       1.00      1.00      1.00      4000
           6       1.00      1.00      1.00      4000
           7       1.00      1.00      1.00      4000
           8       1.00      1.00      1.00      4000
           9       0.99      1.00      1.00      4000

    accuracy                           1.00     40000
   macro avg       1.00      1.00      1.00     40000
weighted avg       1.00      1.00      1.00     40000
```

(B) Classification report

Figure 6: Confusion and classification report of testing samples of EMNIST by using hybrid CNN-SVM model

All three proposed hybrid models with MNIST and EMNIST digit dataset are implemented and found that the proposed hybrid CNN-SVM model gives a better recognition and classification rate with both MNIST and EMNIST testing data samples.

RESULT ANALYSIS

This section compares the accuracy of proposed model with existing models in case of both MNIST and EMNIST datasets.

Comparison of proposed hybrid model with previous research work with MNIST dataset

In handwritten digit recognition, various authors contributed their research experience using the CNN technique and hybrid techniques of machine learning and deep learning. This paper has also proposed a hybrid model based on deep learning and machine learning and achieved excellent results. The comparative analysis of various CNN frameworks with our proposed hybrid model represents in Table 3, where our proposed hybrid CNN-SVM gives better accuracy compared to others. The proposed hybrid model CNN-SVM gives the highest 99.55% of accuracy compared to other hybrid and existing models in case of MNIST dataset.

Table-3: Comparative Analysis of Proposed and Existing Models

Year	Reference	Name of the Model	Validation Accuracy
2010	[3]	Two-Stage Classification	99.03%
2011	[4]	DBN based Approach	97.02%
2014	[6]	Fast Efficient ANN	98.00%
2017	[7]	Minimum CNN	97.30%
2017	[7]	Extended Minimum CNN	98.50%
2017	[8]	CNN(Keras Based)	98.80%
2018	[9]	DenseNet	99.37%
2018	[10]	DeepLearning –CNN	99.20%
2017	[11]	CNN	99.10%
2019	[12]	CNN	98.40%
2011	[15]	Hybrid CNN-SVM	94.40%
2019	[28]	CNN+DL4J	99.21%
2020	[16]	Hybrid CNN-SVM	99.28%
2020	[16]	SVM	98.35%
2020	[14]	CNN	99.31%
2019	[13]	CNN	98.00%
2021	[29]	CNN	98.80%
Proposed Model		Hybrid CNN-RFC	99.45%
		Hybrid CNN-KNN	99.48%
		Hybrid CNN-SVM	99.55%

Comparison of proposed hybrid model with previous research work with EMNIST dataset

In the EMNIST dataset, compared the performance of proposed hybrid techniques with the previous research performance of digit recognition. The comparative analysis of various CNN and hybrid models' frameworks is represented in Table 4, where our proposed hybrid CNN-SVM gives better accuracy compared to others. The proposed hybrid model CNN-SVM gives the highest 99.66% of accuracy compared to other hybrid and existing models in case of EMNIST dataset.

Table-4: Comparative analysis of proposed model with existing models

Year	Reference	Name of the Model	Validation Accuracy
2018	[19]	DNN	98.50%
2017	[20]	DCNN	99.62%
2017	[21]	EDEN	99.30%
2020	[22]	LeNet model	99.50%
Proposed Model		Hybrid CNN-RFC	99.54%
		Hybrid CNN-KNN	99.46%
		Hybrid CNN-SVM	99.66%

CONCLUSION

In the area of pattern recognition and classification, the domain of handwritten recognition has been adopted by various authors. This paper has proposed CNN-SVM, CNN-KNN, and CNN-RFC-based hybrid models to recognize MNIST and EMNIST handwritten digit datasets. CNN is the part of the deep learning that extract the features from dataset and machine learning technique is used for classification of handwritten digit samples. The proposed hybrid model CNN-SVM is achieved 99.55% of testing accuracy with MNIST dataset and achieved 99.66% testing accuracy with EMNIST dataset which represents the excellent performance. Finally, we have concluded that our proposed hybrid CNN-SVM model achieved higher accuracy than the previously developed models by different researchers.

REFERENCES

[1] Website: http://yann.lecun.com/exdb/mnist/ (Accessed date: August , 2020)

[2] Website: https://www.itl.nist.gov/iaui/vip/cs_links/EMNIST/gzip.zip (Accessed date: August , 2020)

[3] G. Vamvakas, B. Gatos, and S. J. Perantonis, "Handwritten character recognition through two-stage foreground sub-sampling," Pattern Recognition, vol. 43, pp. 2807-2816, 2010.

[4] O. Pauplin, and J. Jiang, "DBN-based structural learning and optimization for automated handwritten character recognition," Pattern Recognition Letters , vol. 33, pp. 685-692, 2012.

[5] C. D. Stefano, F. Fontanella, C. Marrocco, and A. S. D. Freca, "A GA-based feature selection approach with an application to handwritten character recognition," Pattern Recognition Letters, vol. 35, pp. 130-141,2013.

[6] V. N. Jagtap., and S. K. Mishra, "Fast Efficient Artificial Neural Network for Handwritten Digit Recognition," International Journal of Computer Science and Information Technologies, vol. 5, pp. 2302-2306, 2014.

[7] M. Y. W. Teow, "Understanding Convolutional Neural Networks Using A Minimal Model for Handwritten Digit Recognition," IEEE 2nd International Conference on Automatic Control and Intelligent Systems (I2CACIS), pp. 167-172, 2017.

[8] A. Dutt, and A. Dutt , "Handwritten Digit Recognition Using Deep Learning," International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), vol. 6, pp. 990-997, 2017.

[9] F. Chen, N. Chen, H. Mao, and H. Hu, "Assessing Four Neural Networks on Handwritten Digit Recognition Dataset (MNIST)," Chuangxinban Journal Of Computing, pp. 1-4, 2018.

[10] S. Mishra, D. Malathi,and K. Senthilkumar, "Digit Recognition Using Deep Learning," International Journal of Pure and Applied Mathematics, vol. 118, pp. 295-302, 2018.

[11] N. Jain, K. Rahul, I. Khamaru, A. K. Jha, and A. Ghosh, "Hand Written Digit Recognition using Convolutional Neural Network (CNN)," International Journal of Innovations & Advancement in Computer Science IJIACS, vol. 6, pp. 260-266, 2017.

[12] M. Zohra, and D. R. Rao, "A Comprehensive Data Analysis on Handwritten Digit Recognition using Machine Learning Approach," International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol. 8, pp. 1449-1453, 2019.

[13] N Sagar., Rajalekshmi J., U. Nikhil. S. , L . Dhrithi .,and R. Tushar .B., "Comparison of Machine Learning Techniques for Hand-Written Digit Recognition," International Research Journal of Engineering and Technology (IRJET) , vol. 06, No. 05, pp. 4972-4977, 2019.

[14] R. Dixit, R. Kushwah, and S. Pashine (2020), "Handwritten Digit Recognition using Machine and Deep Learning Algorithms," International Journal of Computer Applications vol. 176 , No. 42, pp. 27-33, 2020.

[15] N. Xiao-Xiao,and Y. S. Ching, "A novel hybrid CNN–SVM Classifier for Recognizing handwritten Digits," Pattern Recognition 45 , pp. 1318–1325, 2012.

[16] S. Ahlawat, and A. Choudhary, "Hybrid CNN-SVM Classifier for Handwritten Digit Recognition," International Conference on Computational Intelligence and Data Science (ICCIDS 2019) , Procedia Computer Science 167, 2554–2560, 2019.

[17] Shopon Md,and Mohammed Nabeel, Abedin Md Anowarul (2017), "Image Augmentation by Blocky Artifact in Deep Convolutional Neural Network for Handwritten Digit Recognition," IEEE International Conference on Imaging, Vision & Pattern Recognition (icIVPR), ISBN: 978-1-5090-6004-7 .

[18] P. Verma**,** V. K. Awasthi**,** S. K. Sahu ," A Novel Design of Classification of Coronary Artery Disease Using Deep Learning and Data Mining Algorithms," IIETA, vol. 35(3), pp. 209-215,2021

[19] T. S. Gunawan, A. F. Razi, M. Noor, and M. Kartiwi "Development of English Handwritten Recognition Using Deep Neural Network," Indonesian Journal of Electrical Engineering and Computer Science, vol. 10, No. 2, pp. 562-568, 2018.

[20] S. Singh, A. Paul, and M. Arun, "Parallelization Of Digit Recognition System Using Deep Convolutional Neural Network On CUDA," 2017 IEEE 3rd International Conference on Sensing, Signal Processing and Security (ICSSS), 978-1-5090-4929-5©2017 IEEE, pp.379-383.

[21] E. Dufourq, and B. A. Bassett, " EDEN: Evolutionary Deep Networks for Efficient Machine Learning," arXiv:1709.09161v1 [stat.ML] , 2017.

[22] W. Jiang, "MNIST-MIX: A Multi-Language Handwritten Digit Recognition Dataset," IOP SciNotes, vol. 1, 2020.

[23] A. Indoliaa, A. K. Goswamib, S. P. Mishrab and P. Asopa, "Conceptual Understanding of Convolutional Neural Network- A Deep Learning Approach," Procedia Computer Science, vol. 132, pp. 679–688, 2018.

[24] S. Albawi, T. A. Mohammed & S. Al-Zawi, "Understanding of a Convolutional Neural Network," 2017 International Conference on Engineering and Technology (ICET). doi:10.1109/icengtechnol. 2017. 8308186, 2017.

[25] Website: https://towardsdatascience.com/ (Last accessed date: Sep. 2020).

[26] A. Aulia, D. Jeong, I. M. Saaid, D. Kania, M. T. Shuker, and N. A. El-Khatib, "A Random Forests-based sensitivity analysis framework for assisted history matching," J. Pet. Sci. Eng., vol. 181, pp. 1-14, 2019, doi: 10.1016/j.petrol. 2019.106237.

[27] Website https://docs.anaconda.com/anaconda/install/hashes/win-3-64/ (Accessed date: July , 2020)

[28] A. Saqib, S. Zeeshan, A. Muhammad , S. Zareen , M. Tariq, and U. R. Khalil, "An efficient and improved scheme for handwritten digit recognition based on convolutional neural network," Springer Nature Switzerland AG, 2019.

[29] A.K. Agrawal, A.K. Shrivas and V.K.Awasthi," A Robust Model for Handwritten Digit Recognition using Machine and Deep Learning Technique," 2021 2nd International Conference for Emerging Technology (INCET) Belgaum India, IEEE,Doi. No. 10.1109/INCET51464. 2021.9456118,May 2021.