Artificial Intelligence (AI) is the field that combines computer science, data science, and powerful computers to enable learning and problem-solving. Within the field of AI, machine learning is a powerful tool that utilizes large datasets and statistical algorithms to imitate human learning and perform pattern recognition [x]. One of the common areas of interest in machine learning is the problem of handwritten character recognition or natural language processing. Human beings can identify handwritten characters of a massive variety of handwriting styles. The ability for machines to be able to recognize handwritten characters, similarly to humans, can be an extremely powerful tool, allowing machines to solve many types of problems that would take humans a much longer amount of time. Through the implementation of machine learning algorithms, machines can process and detect the characters associated with a variety of languages.

A variety of machine learning algorithms have been implemented to perform hand-written character recognition. In the paper written by Naik,A and Desai, V, k-Nearest Neighbor and Support Vector Machine were utilized to classify Gujarati characters. k-Nearest Neighbor is a distance-based recognition method that computes the Euclidean distance between all samples within a training dataset. The k nearest neighbors to a data point are used to classify that data point such that the majority class of the neighbors determine that point’s class. The authors achieved an accuracy of 90% using 7-Nearest neighbors. Support Vector Machine transforms data into higher dimensions and will separate the classes using a decision hyperplane that maximizes the margin between the hyperplane and the datapoints to promote generalization. The SVM utilized by the authors of the paper achieved an accuracy of 92% using a radial kernel [x]. In Herman, et al. the Gaussian Naïve Bayes algorithm was utilized for number recognition. Gaussian Naïve Bayes is a classifier that utilizes the Bayes rule to calculate the conditional probability a datapoint belongs to a certain class. The Gaussian Naïve Bayes algorithm resulted in only 28.33% accuracy [x]. These machine learning algorithms should be improved upon as the accuracy of classification would ideally be 100%.

The most common machine learning technique utilized for hand-written character recognition is neural networks. A neural network consists of input nodes, hidden nodes, and output nodes. In the input layer no computation is performed, and the data is passed to the neural network. Hidden nodes perform computations and transfer information to following hidden layers. The output layer performs calculations resulting in an output. An example single layer neural network is shown in Figure 1 [x]. Pal, A and Singh, D utilized a multi-layer perceptron neural network to perform English character recognition. Using, one hidden layer and a backpropagation algorithm the authors were able to achieve 94% recognition accuracy [x]. Convolutional Neural Networks (CNNs) are artificial neural networks that are primarily utilized to process images. CNNs typically consist of three layers that include convolution, pooling, and activation. Convolutional layers consist of N convolutional kernels that scan the image looking for different patterns. These convolutional layers differ from traditional neural network hidden layers in that convolutional layers are not fully connected. Pooling layers decrease the number of pixels in an image through averaging. The activation layer consists of an activation function that will transform the feature matrix to some output. Al-Mahmud, Tanvin, A and Rahman, A implemented a convolutional neural network. Their implementation included an 28x28 image input layer, a first convolutional layer of 32 filters with 5x5 kernels, a max-pooling layer of 2x2 to reduce the image volume, another convolutional layer of 64 filters with 7x7 kernels, then a second max-pooling layer of 2x2 to create 64 4x4 feature maps. These 64 4x4 feature maps were flattened an input to a perceptron with one hidden layer and one output layer. This method achieved 99.47% accuracy for the MNIST dataset [x].

Diagram

Description automatically generated

For handwritten character recognition, pre-processing of input data is a vital aspect to achieving a highly accurate model. Dhande, P and Kharat, R implemented and detailed a variety of pre-processing techniques for images of handwritten characters. In pre-processing the noise reduction techniques can be divided into filtering for smoothing and sharpening of the image, morphological operations for character thinning and boundary extraction, and noise modeling. The most common preprocessing technique is morphological operations. The benefit of morphological operations in image preprocessing is that these operations can remove image imperfections and emphasize the structure and features of these images. The two main types of morphological operations include dilation which adds pixels to boundaries and erosion which removes pixels from boundaries [5]. An example of dilation and erosion can be seen in Figure 2, below.

A picture containing diagram

Description automatically generated

A picture containing diagram

Description automatically generated

In our research we tested a few machine learning algorithms for written character recognition before settling on utilization of a convolutional neural network. The models in this experiment utilized a labeled training dataset of 6720 300x300 images of hand-written characters a-h, #, and $. Uniform preprocessing was performed, and the different machine learning algorithms were implanted on the processed data. The final model presented utilized a convolutional neural network, and an accuracy of greater than 95% was achieved for classifying the training data. This result indicates that convolutional neural networks offer a framework for creating robust image recognition algorithms.

[What is Artificial Intelligence (AI)? | IBM](https://www.ibm.com/cloud/learn/what-is-artificial-intelligence)

[What is Machine Learning? | IBM](https://www.ibm.com/cloud/learn/machine-learning)

[Introduction to Neural Network (norwegiancreations.com)](https://www.norwegiancreations.com/2019/04/introduction-to-neural-network/)

[download (psu.edu)](https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1069.7445&rep=rep1&type=pdf)

[IEEE Xplore Full-Text PDF:](https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9641160)

[IEEE Xplore Full-Text PDF:](https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8300915)

[IEEE Xplore Full-Text PDF:](https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9234211)

[IEEE Xplore Full-Text PDF:](https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8953140)

[Morphological Operations in Image Processing | by Nickson Joram | Medium](https://himnickson.medium.com/morphological-operations-in-image-processing-cb8045b98fcc)

[Understanding Morphological Image Processing and Its Operations | by Prateek Chhikara | Mar, 2022 | Towards Data Science](https://towardsdatascience.com/understanding-morphological-image-processing-and-its-operations-7bcf1ed11756)

[IEEE Xplore Full-Text PDF:](https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8203926)