***Handwriting detection***

## **Abstract**

This is an overview and an improvement for the most recent published approaches to solving the handwriting recognition problem. Due to the complex structure and handwritten deformation, the offline handwritten characters recognition has been one of the most challenging problems. This paper is aimed at clarifying the role of handwriting recognition in accordance with today’s technologies and algorithms. This paper will try to list and clarify the components that build handwritting recognition and related technologies such as OCR (Optical Character Recognition) and Signature Verification. The motivation of this topic is to recognize the handwriting of a doctor and also for sorting envelopes. The method to transform handwritten data into electronic format is „Optical Character Recognition”. It involves several steps including pre-processing, segmentation, feature extraction and post-processing. Many researchers have been used OCR for recognizing character. Levels of practicality of use of this algorithms and technology for a specific language is also discussed.

# **1. Introduction**

Nowadays demand increases to create a paperless environment [20]. Recognition of handwritten text is easy for a human but it is a complex task for computer systems. Many researchers have done work on this field but 100% accuracy is not achieved by the researchers [21]. Our eyes can figure out the handwritten character of different people but the computer cannot do this easily. ‘Optical Character Recognition’ is the solution to this problem. Optical Character Recognition (OCR) is one of the techniques that convert the scanned or printed image document into an editable text document.

Every individual has different handwriting as unique as the personality traits; even when a similar sentence is written twice by the same person the handwriting may not appear exactly the same [1]. Handwritten characters differ by 12 considerable characteristics: line quality, spacing (line or spaces between character and word), height, width and size of letters, pen lifts and separations, connection strokes, beginning and ending strokes, unusual letter formation, shading (pen pressure), slant, baseline habits, flourishment and embellishments and diacritic placement. External conditions also play a role in affecting the style of handwriting such as the types and colours of ink, pen tip type, smoothness of paper, table surface quality and material, personal emotions, age, gender and speed of the writing process.

Handwriting recognition has been studied for nearly forty years and there are great many proposed approaches. The problem is quite complex, and even now there is no single approach that solves it both efficiently and completely in all settings. In the handwriting recognition process (Fig. 1), an image containing text must be appropriately supplied and preprocessed. Next, the text must either undergo segmentation or feature extraction. Small processed pieces of the text will be the result, and these must undergo recognition by the system. Finally, contextual information should be applied to the recognized symbols to verify the result.

![Diagram

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDcRXhpZgAATU0AKgAAAAgABAE7AAIAAAAGAAAISodpAAQAAAABAAAIUJydAAEAAAAMAAAQyOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE1paGFpAAAFkAMAAgAAABQAABCekAQAAgAAABQAABCykpEAAgAAAAMxMQAAkpIAAgAAAAMxMQAA6hwABwAACAwAAAiSAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure 1. Steps involved in handwriting recognition. Source: [2]

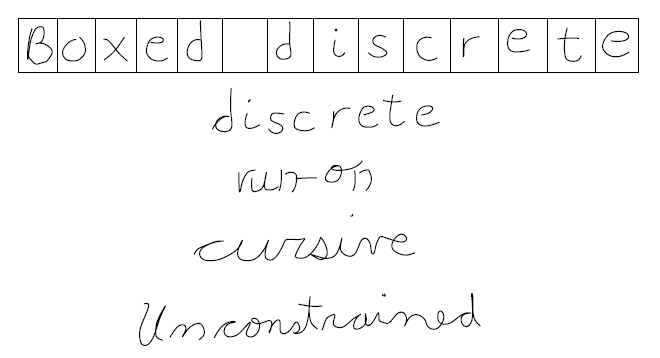
Handwriting recognition can be divided by its input method into two categories: off-line handwriting recognition and on-line handwriting recognition. For off-line recognition, the writing is usually captured optically by a scanner. For on-line recognition, a digitizer samples the handwriting to time-sequenced pixels as it is being written. Hence, the on-line handwriting signal contains.

Research on automated written language recognition dates back several decades. Today, cleanly machine-printed text documents with simple layouts can be recognized reliably by OCR software. There is also some success with handwriting recognition, particularly for isolated handprinted characters and words. For example, in the on-line case, the recently introduced personal digital assistants have practical value. Similarly, some online signature verification systems have been marketed over the last few years and instructional tools to help children learn to write are beginning to emerge. Most of the off-line successes have come in constrained domains, such as postal addresses [10], bank checks, and census forms. The analysis of documents with complex layouts, recognition of degraded printed text, and the recognition of running handwriting continue to remain largely in the research arena. Some of the major research challenges in on-line or off-line processing of handwriting are in word and line separation, segmentation of words into characters, recognition of words when lexicons are large, and the use of language models in aiding preprocessing and recognition. In most applications, the machine performances are far from being acceptable, although potential users often forget that human subjects generally make reading mistakes [9].

Another important technology which is going to be briefly touched here is signature verification [3]. Signature verification if done on-line, could use the same pen-computers as discussed earlier to do a much better analysis of the signature than any human specialist will ever be able to do. Computer driven signature verification systems have much more information available to them, such as the local velocity of the pen-tip at different portions of the signature.

## **2. Methodology (State of the art)**

Hand input is classified into five different types: boxed discrete, discrete, run-on, cursive and unconstrained.



In the case of boxed-discrete input, basically the writer is segmenting his writing into separate characters. This is probably the simplest form of writing to be recognized. In the second type, the writer once again aids the recognizer in segmenting the writing into individual characters. In this case, the problem of segmenting the data into separate characters is solved by finding those gaps between successive chunks of data in the horizontal direction which are greater than a predefined or statistically obtained threshold.

In run-on writing, the problem of segmenting the word into characters becomes nontrivial. In this case, the characters could even overlap such that gap information is no longer sufficient for character segmentation. The only restriction which is imposed on the method of writing run-on is that the pen should be lifted from the surface of the digitizer after each individual character is inputted. One solution to this problem is to treat each stroke of the writing as the smallest unit of the word and conduct a search through reasonable combinations of the stroke labels which could create legal words.

The next type of writing is pure cursive which has even less restrictions imposed on its methodology. For pure cursive, the only two restrictions which are imposed are that there is a pen lift at the end of each word and that all characters are connected to their adjacent character.

Most people, however, write in combination of cursive and run-on. This writing style has no limitations imposed other than in some cases there should be a pen-lift after each word. This is the ultimate challenge in handwriting recognition which has attracted lots of attention. For cursive and unconstrained writings, segments are often defined to be a subset of a character and they are generated based on some criteria set by the recognition algorithm.

In the case of our project as a state of the art, we turned to two implementation solutions. The first solution was based on Markov models and the second is based on the use of neural networks. After extensive research, we decided to focus more on artificial intelligence combined with OCR, because the Markov model involves difficult-to-apply mathematics.

OCR technology allows the conversion of a captured image into machine editable [12]. OCR technology do the work in three stages first is scanning of the document. Second is recognition of character and third is storing the text in the desired format. Optical character recognition is the electronic conversion of scanned image or printed text into machine editable text [13]. OCR with Keras and Tensorflow software is used for our work. Tesseract is considered as one of the most accurate opensource engines. The steps followed by Optical character recognition are shown in the algorithm as follows:

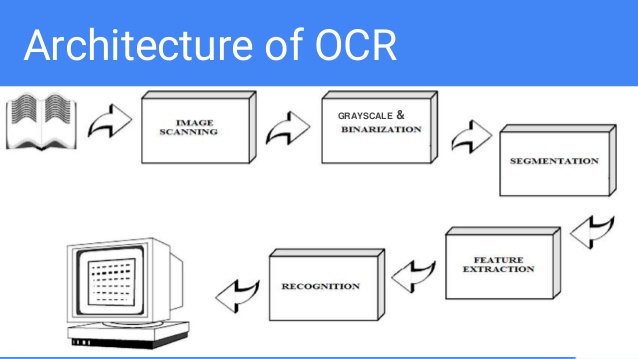


Figure 1 – OCR Algorithm.

*A. Image Acquisition*

The system uses OCR from Tensorflow. The camera from a phone helps to capture an image of handwritten documents. This is nothing but the scanning process. By scanning process, the original image can be made as a digital image. The original images are in the black colored text on a white colored background. This process makes the digital image as greyscale image [14].

*B. Preprocessing*

Preprocessing is one of the most important stages in character recognition. It helps to make grayscale images more readable for software. It filters out the impurities from the images. Preprocessing is important for handwritten images that are more sensitive to noise. Preprocessing has various task are such as greyscale conversion, binarization, thinning, skewing and normalization [15].

*C. Segmentation*

The segmentation is the most important process. Segmentation is done to make the separation between the individual characters. First handwritten text segmented into line, the line is segmented into a character and then is segmented into a word [16].

*D. Feature Extraction*

The feature extraction is the step in which OCR recognize alphabets based on different classes. Feature extraction is the transformation of the input data into the set of features. It extracts the features from the text image. Features are nothing but their characteristics. The alphabets are classified based on slant angle, height, curves etc. The selected text is matched with the MNIST and Kaggle database preloaded in the system and the dataset, the highest correlation is selected and declared as a character. Feature extraction is concerned with the representation of symbols [17]. Once the character is recognized based on classification it is converted into text. Feature detection gives information about the features of numbers or letters individually for the recognition of characters in the document [18].

## **3. Implementation**

This project has two different parts in order to succeed. The first step is to train an OCR model using deep learning in order to detect the letters from a known database. Those databases are MNIST 0-9 and Kaggle A-Z. This step is very important for the detection of real letters from pictures to work. The last step is to apply the OCR model to real pictures with human handwriting.

As a concept, we intend to:

Load both the datasets for MNIST 0-9 digits and Kaggle A-Z (Figure 2) letters from disk, combine these datasets together into a single, unified character dataset, we are then going to loop over each row of our CSV file and parse out the label and the associated image and casts it as a NumPy array of unsigned 8-bit integers, which correspond to the grayscale values for each pixel. We will have successfully train a Keras and TensorFlow model on the combined dataset using a custom implementation of the very popular and successful deep learning architecture, ResNet. The MNIST database of handwritten digits, has a training set of 60,000 examples, and a test set of 10,000 examples. It is a subset of a larger set available from NIST. The digits have been size-normalized and centered in a fixed-size image. The MNIST database was constructed from NIST's Special Database 3 and Special Database 1 which contain binary images of handwritten digits. NIST originally designated SD-3 as their training set and SD-1 as their test set. However, SD-3 is much cleaner and easier to recognize than SD-1. The reason for this can be found on the fact that SD-3 was collected among Census Bureau employees, while SD-1 was collected among high-school students. Drawing sensible conclusions from learning experiments requires that the result be independent of the choice of training set and test among the complete set of samples. Therefore, it was necessary to build a new database by mixing NIST's datasets.

SD-1 contains 58,527 digit images written by 500 different writers. In contrast to SD-3, where blocks of data from each writer appeared in sequence, the data in SD-1 is scrambled. Writer identities for SD-1 is available and we used this information to unscramble the writers. We then split SD-1 in two: characters written by the first 250 writers went into our new training set. The remaining 250 writers were placed in our test set. Thus, we had two sets with nearly 30,000 examples each. The new training set was completed with enough examples from SD-3, starting at pattern # 0, to make a full set of 60,000 training patterns. Similarly, the new test set was completed with SD-3 examples starting at pattern # 35,000 to make a full set with 60,000 test patterns. The full 60,000 sample training set is available [11].

![Shape, arrow

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDcRXhpZgAATU0AKgAAAAgABAE7AAIAAAAGAAAISodpAAQAAAABAAAIUJydAAEAAAAMAAAQyOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE1paGFpAAAFkAMAAgAAABQAABCekAQAAgAAABQAABCykpEAAgAAAAMzMAAAkpIAAgAAAAMzMAAA6hwABwAACAwAAAiSAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure 2 - On the left, we have the standard MNIST 0-9 dataset. On the right, we have the Kaggle A-Z dataset from Sachin Patel, which is based on the NIST Special Database 19. These two datasets are used for OCR training with Keras and Tensorflow.

The implementing methods and utilities will allow us to:

* Load both the datasets for MNIST 0-9 digits and Kaggle A-Z letters from disk;
* Combine these datasets together into a single, unified character dataset;
* Handle class label skew/imbalance from having a different number of samples per character;
* Successfully train a Keras and TensorFlow model on the combined dataset;
* Plot the results of the training and visualize the output of the validation data;

In order to train our custom Keras and TensorFlow OCR model, we first need to implement two helper utilities that will allow us to load both the Kaggle A-Z datasets and the MNIST 0-9 digits from disk. To train the model, the algorithm has two major functions in order to work.

The function *load\_az\_dataset* takes a single argument *datasetPath*, which is the location of the Kaggle A-Z CSV file. Then, we initialize our arrays to store the data and labels. Each row in Sachin Patel’s CSV file contains 785 columns, one column for the class label (i.e., “A-Z”) plus 784 columns corresponding to the 28 x 28 grayscale pixels. From the beginning of the algorithm, we are going to loop over each row of our CSV file and parse out the label and the associated image. We parse the label, which will be the integer label associated with a letter A-Z. For example, the letter “A” has a label corresponding to the integer “0” and the letter “Z” has an integer label value of “25”. Also, we parse our image and casts it as a NumPy array of unsigned 8-bit integers, which correspond to the grayscale values for each pixel from [0, 255]. We reshape our image from a flat 784-dimensional array to one that is 28 x 28, corresponding to the dimensions of each of our images. After these steps, we will then append each image and label to our data and label arrays respectively.

To finish up this function, we will convert the data and labels to NumPy arrays and return the image data and labels.

Our next I/O helper function, *load\_mnist\_dataset*, is considerably simpler. This function loads our MNIST 0-9 digit data using Keras’s helper function, *mnist.load\_data*. Notice that we do not have to specify a dataset path like we did for the Kaggle data because Keras, conveniently, has this dataset built in. Keras’s *mnist.load\_data* comes with a default split for training data, training labels, test data, and test labels. For now, the function just going to combine our training and test data for MNIST using *np.vstack* for our image data and *np.hstack* for our labels. Later, in *train\_ocr\_model.py*, we will be combining our MNIST 0-9 digit data with our Kaggle A-Z letters. At that point, we will create our own custom split of test and training data.

For handwriting recognition on real pictures, we have the following steps. The *load\_model* utility from Keras and TensorFlow makes it super simple to load our serialized handwriting recognition model. Recall that our OCR model uses the ResNet deep learning architecture to classify each character corresponding to a digit 0-9 or a letter A-Z.

After loading the image, we convert it to grayscale, and then apply Gaussian blurring to reduce noise. From there, we detect the edges of our *blurred* image using *cv2.Canny*. To locate the contours for each character we apply contour detection. To conveniently sort the contours from "*left-to-right*", we use my *sort\_contours* method. Next, the algorithm initializes the *chars* list, which will soon hold every character image and associated bounding box.

After these steps, the algorithm will involve a large contour processing loop in a series of four steps.

* Step 1: Algorithm selects appropriately-sized contours and extract them.
* Step 2: Algorithm cleans up the images using a thresholding algorithm, with a goal of having white characters on a black background.
* Step 3: Resize every character to a 32×32 pixel image with a border.
* Step 4: Prepare each padded ROI for classification as a character.

To perform handwriting recognition OCR on our set of pre-processed characters, we classify the entire batch with the *model.pred*ict method. This results in a list of predictions, *preds*.

![Text, whiteboard

Description automatically 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8A+Cyb/wCJo/4Vt44/6E7X/wDwWTf/ABNfftFAHwF/wrbxx/0J2v8A/gsm/wDiaP8AhW3jj/oTtf8A/BZN/wDE19+0UAfAX/CtvHH/AEJ2v/8Agsm/+Jo/4Vt44/6E7X//AAWTf/E19+0UAfAX/CtvHH/Qna//AOCyb/4mj/hW3jj/AKE7X/8AwWTf/E19+0UAfAX/AArbxx/0J2v/APgsm/8AiaP+FbeOP+hO1/8A8Fk3/wATX37RQB8Bf8K28cf9Cdr/AP4LJv8A4mj/AIVt44/6E7X/APwWTf8AxNfftFAHwF/wrbxx/wBCdr//AILJv/iaP+FbeOP+hO1//wAFk3/xNfftFAHwF/wrbxx/0J2v/wDgsm/+Jo/4Vt44/wChO1//AMFk3/xNfftFAHwF/wAK28cf9Cdr/wD4LJv/AImj/hW3jj/oTtf/APBZN/8AE19+0UAfAX/CtvHH/Qna/wD+Cyb/AOJo/wCFbeOP+hO1/wD8Fk3/AMTX37RQB8Bf8K28cf8AQna//wCCyb/4mj/hW3jj/oTtf/8ABZN/8TX37RQB8Bf8K28cf9Cdr/8A4LJv/iaP+FbeOP8AoTtf/wDBZN/8TX37RQB8Bf8ACtvHH/Qna/8A+Cyb/wCJo/4Vt44/6E7X/wDwWTf/ABNfftFAHwF/wrbxx/0J2v8A/gsm/wDiaP8AhW3jj/oTtf8A/BZN/wDE19+0UAfAX/CtvHH/AEJ2v/8Agsm/+Jo/4Vt44/6E7X//AAWTf/E19+0UAfMX7NXhLxHoHxG1C51zQNT02B9KkjWW7s5IlZvOiO0FgBnAJx7Gvp2iigD/2Q==)

Figure 3 - Sample results of our OCR handwriting pre-processing pipeline, implemented with OpenCV and Python. We have our original color image (upper-left), our grayscale image (upper-right), our blurred image with reduced noise (lower-left), and our edge-detection map (lower-right).

Finally, we will plot the results of the training that used ResNet and visualize the output of the validation data by saving the model to disk, plot the results of the training history, and save the training history. The training was made with Google Colab and the time was short (almost 10 minutes on an epoch) (Figure 4).

Text, table

Description automatically generated

Figure 4 – Training the OCR using Google Colab services.

## **4. Results**

The results for these tests are pointed out in the figures below. The Keras/TensorFlow OCR model is obtaining ~96% accuracy on the testing set.

Chart, line chart

Description automatically generated

Figure 5 – Training Loss and Accuracy graph for the OCR model.

As evidenced by the plot, there are few signs of overfitting, implying that our Keras and TensorFlow model is performing well at our basic OCR task.

In the following example, we are attempting to OCR the handwritten text “Hello World”. Our handwriting recognition model performed well here but made two mistakes. First, it confused the letter “O” with the digit “0” (zero). Second, and a bit more concerning, the handwriting recognition model confused the “O” in “World” with a “2”.

Text, letter, whiteboard

Description automatically generated

Figure 6 – Result of the first real test with “Hello World”.

In the next example, our handwriting recognition algorithm performed almost perfectly here. We are able to correctly OCR every handwritten character in the “UMBC”; however, the ZIP code is incorrectly OCR’d, our model confuses the “1” digit with a “7”. If we were to apply de-skewing to our character data, we might be able to improve our results.

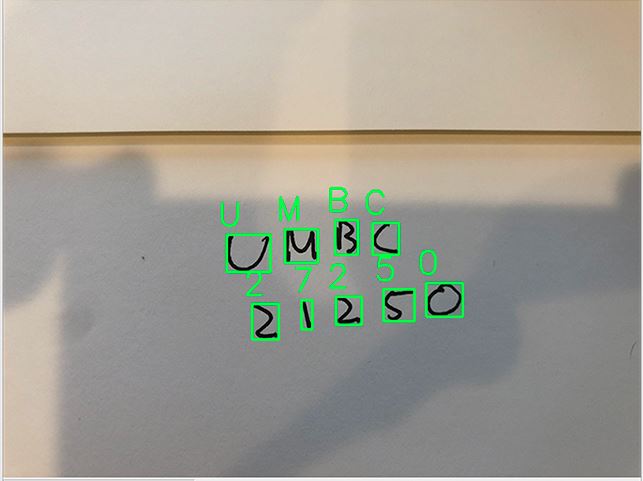


Figure 7 – Result of the second real test.

While our handwriting recognition model obtained 96% accuracy on our testing set, our handwriting recognition accuracy on our own custom images is slightly less than that. One of the biggest issues is that we used variants of the MNIST (digits) and NIST (alphabet characters) datasets to train our handwriting recognition model. These datasets, while interesting to study, do not necessarily translate to real-world projects because the images have already been pre-processed and cleaned for us (real-world characters aren’t that “clean”). Additionally, our handwriting recognition method requires characters to be individually segmented.

That may be possible for some characters, but many of us (especially cursive writers) connect characters when writing quickly. This confuses our model into thinking a group of characters is actually a single character, which ultimately leads to the incorrect results.

While our handwriting recognition model performed well on the training and testing set, the architecture, combined with the training dataset itself is not robust enough to generalize as an “off-the-shelf” handwriting recognition model.

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