

SVD Implementation on MNIST Image Classification Based on CNN

Satrya Budi Pratama
Institut Teknologi Bandung
Sekolah Teknik Elektro dan Informatika
Bandung, Indonesia
satrya@zeroinside.net

Abstract—In recent years, many development has been made in the field of image classification. Deep learning has proven to be powerful for classification, one of them is convolutional neural networks (CNN). In image classification one of the challenge is to recognized the handwritten digit. CNN architecture which has high precision for that problem is Lenet-5.

In this paper, we recognized the handwritten of MNIST dataset and implement SVD for feature extraction as preprocessing method. We build LeNet-5 model and evaluate the model.

Index Terms—CNN, LeNet-5, SVD, MNIST

I. INTRODUCTION

Handwriting recognition is the recognition of handwritten letters, numbers and symbols by computer systems [1]. The problem is every handwritten has different style. Every person has their style of writting a character, word and symbol. The computer try to assign the digitilzed character to its symbolic class. In the case of a print image, this is referred to as optical character recognition (OCR) meanwhile in the case of handprint, it is loosely referred to as intelligent character recognition (ICR) [2]. This has been a topic of research for decades. Some of the research areas include signature verification, bank check processing, postal address interpretation from envelopes, and get the digits on test letter for recurrence.

In recent years, the rise of artificial intelligent (AI) and big data especially in machine learning has brought a rapid development in the handwriting recognition application. Google has been developed Vision AI ¹ that can be used for reading printed and handwritten text. Some mobile application also has the OCR features such as Pen to Print ², Notes Plus ³, and Photomath ⁴. The web application such as i2OCR ⁵, OnlineOCR ⁶, and Convertio⁷. All of these technologies are use machine learning for the recognition or classification model.

Deep learning is one of the popular method on machine learning. It has been highly and widely implemented in various research fields especially in image recognition. The most important property of deep learning methods is that it can

automatically learn feature representations thus avoiding a lot of time-consuming engineering [3]. Betterchip processing abilities, considerable advances in the machine learning algorithms, and affordable cost of computing hardware are primarily crucial reasons for the booming of deep learning [4].

One of them is Convolutional Neural Network (CNN). CNN was firstly introduced by Kunihiko Fukushima [5]. It was later proposed by Yann LeCun. He combined CNN with back-propagation theory to recognize handwritten digits and document recognition [6], [7]. His system called LeNet-5, it was eventually used to read hand-written checks and zip codes. CNN is a powerful technique for image processing as well as natural language processing. The main advantage of CNN is the high accuracy in its results. However, it requires high computational cost. In addition, it needs a lot of data to be trained. The complexity of the CNN slows down the training process thus it is necessary to use a good GPU to overcome this problem [8]. Beside the hardware, another approach to reduce computational cost by eliminating the features as input to the model and use low-rank approximation. Liu et al. [9] claim that training classifiers using MNIST dataset without using feature extraction methods shows inferior performance. This motivates us to use SVD as feature extraction and compare the performance to its original features from MNIST dataset using LeNet-5 model.

II. DATASET AND SVD

A. MNIST Dataset

In this paper, we use Modified National Institute of Standards and Technology (MNIST) dataset. The MNIST is a dataset developed by LeCun, Cortes, and Burges for evaluating machine learning models on the handwritten digit classification problem [7]. It has been widely used in research and to design novel handwritten digit recognition systems. It contains 60,000 training cases and 10,000 test cases of handwritten digits (0 to 9). Each digit is normalized and centered in a grayscale (0 - 255) image with dimension 28×28 . Each image consists of 784 pixels that represent the features of the digits. An example of a digit can be shown in 1 and a example of dataset in 2.

¹<https://developers.google.com/ml-kit/vision>

²<https://www.pen-to-print.com>

³<https://new.notesplusapp.com/>

⁴<https://photomath.net>

⁵<http://www.i2ocr.com/about>

⁶<https://www.onlineocr.net/>

⁷<https://convertio.co/ocr/>

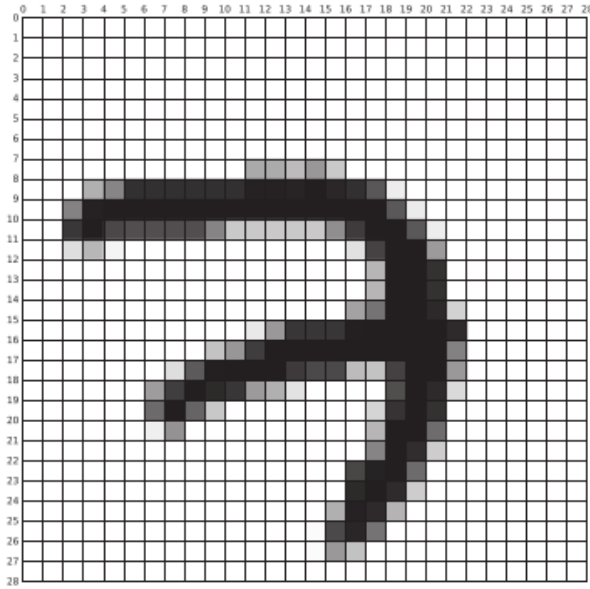


Fig. 1. MNIST sample belonging to the digit 7 adopted from [10]



Fig. 2. 100 digit example of a MNIST dataset adopted from [10]

B. SVD

Singular Value Decomposition or SVD intimately related to the familiar theory of diagonalizing a symmetric matrix [11]. SVD says that rectangular matrix A can be broken down into the product of three matrices : an orthogonal matrix U , a diagonal matrix Σ , and the transpose of an orthogonal matrix V as equation 1 below.

$$A_{m \times n} = U_{m \times m} \Sigma_{m \times n} V_{n \times n}^T \quad (1)$$

where :

$U^T U$: Identity Matrix (I)

$V^T V$: Identity Matrix (I)

U : orthonormal eigenvectors of AA^T

V : orthonormal eigenvectors of $A^T A$

Σ : diagonal matrix containing the square roots of eigen values from U or V in descending order.

SVD is a method for identifying and ordering the dimensions along which data points exhibit the most variation. This ties in to the third way of viewing SVD, which is that once we have identified where the most variation is, it's possible to find the best approximation of the original data points using fewer dimensions. Hence, SVD can be seen as a method for data reduction. Also the SVD applied on linear squares optimization and data compression with reduced rank approximation on [11].

To construct matrix with the low-rank approximation obtain from SVD, with the number of components as k in 2.

$$A_{m \times n} = U_{m \times k} \Sigma_{k \times k} V_{k \times n}^T \quad (2)$$

III. IMPLEMENTATION

We use LeNet-5 architecture to train model on MNIST dataset using TensorFlow. The architecture of the networks shown in 3. It has 7 layers exclude the input layer, it's

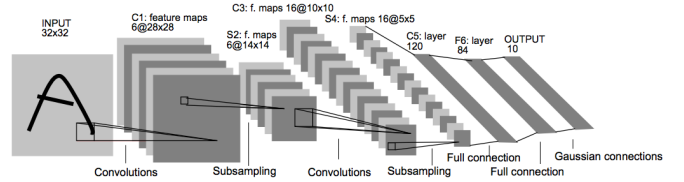


Fig. 3. LeNet-5 Architecture adopted from [7]

basically consist of convolutional layer, pooling layer, and fully connection layer.

1) Convolution

This layer has input dimension $32 \times 32 \times 1$ and the output is $28 \times 28 \times 6$. We will use ReLu activation function since it's better than sigmoid [12].

2) Subsampling or Pooling

This layer has input dimension $28 \times 28 \times 6$ and the output is $14 \times 14 \times 6$.

3) Convolution

This layer has input dimension $14 \times 14 \times 6$ and the output is $10 \times 10 \times 16$. Also has ReLu activation function.

4) Subsampling or Pooling

This layer has input dimension $10 \times 10 \times 16$ and the output is $5 \times 5 \times 16$.

5) Fully Connected

This layer has input dimension $5 \times 5 \times 16$ and the output is 120.

6) Fully Connected

This layer has input dimension 120 and the output is 84.

7) Output

This layer has input dimension 84 and the output is 10.

As suggestion by Wang et al [12], to improve the LeNet-5 model on MNIST dataset is to use 0.0002 learning rate and add drop out layer before output layer. So we use Adam as optimizer with 0.0002 learning rate, and add 0.2 dropout layer before output layer.

First step was downloaded the MNIST dataset ⁸. There are 4 main file for training data and testing data. The training data contains 60,000 examples, and the testing data 10,000 examples. However, the LeNet-5 architecture only accepts $32 \times 32 \times C$ images, where C is the number of color channels. In order to reformat the MNIST data into a shape that LeNet-5 will accept, we pad the data with n rows of zeros on the top and bottom, and n columns of zeros on the left and right. The number of n is a half of subtraction between 32 and feature extraction dimension. The original MNIST has 28×28 so we pad 2 rows at top and bottom, then 2 columns on left and right.

Before train the model, we did several preprocessing method. We shuffled the dataset and splitted training data into 2 sets: 20% train (48,000 images) and 80% validation (12,000 images). We applied SVD as feature extraction to all data, with the k number of components. We will choose k in range 2, 4, 6, ..., 30 based on the highest accuracy of evaluate model.

We trained the model with 12 epoch with SVD and without SVD using training data and validation data. We tested the model using testing data and evaluate both model then compared the performance between two method.

IV. RESULT AND ANALYSIS

A. Preprocessing with SVD

We compared the sample images from MNIST and the result of the preprocessing data. The result between the original features of the images can be shown in 5, and the reconstructed image with 2 number of components can be shown in 4. It

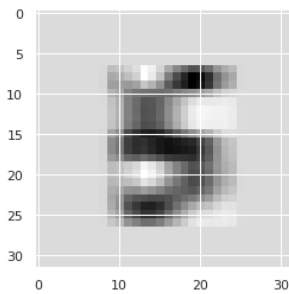


Fig. 4. Reconstructed Sample Image

gives the blurry images with lower number of components, and more detail with higher number of components. It's just has reduced rank of the matrix, so the value of the pixels is lower than before. The image dimension also not reduced, it stays with 32×32 since we don't use principal components analysis (PCA) approach but low-rank approximation.

⁸<http://yann.lecun.com/exdb/mnist/>

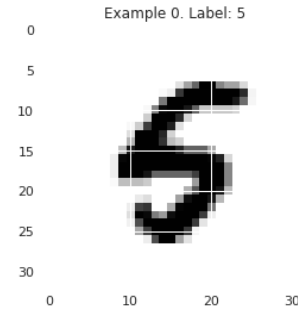


Fig. 5. Original MNIST Sample Image

B. Training Model

We trained the model with original data and SVD data. As we used the validation data, we can test the trained model on every epoch and give the performance. The accuracy without SVD can be shown in 6 and the accuracy with SVD can be shown in 7

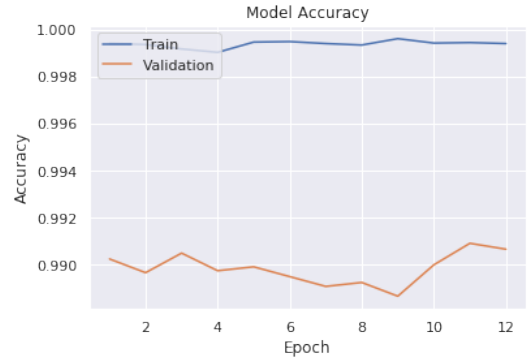


Fig. 6. Accuracy of Trained Model without SVD



Fig. 7. Accuracy of Trained Model with SVD

We focused on validation data not on the training data itself, since training data had been seen by our model. The highest validation accuracy is 99.09% until 11 epoch on model without SVD, and 99.17% until 12 epoch on model with SVD. So, we can choose the best model according to the epoch. From the result, we can conclude that SVD model gives higher accuracy.

C. Testing Model

We tested the model with data testing without SVD and with SVD.

ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page. [12]

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