Bulletin of Electrical Engineering and Informatics
Vol. 13, No. 5, October 2024, pp. 3380~3391
ISSN: 2302-9285, DOI: 10.11591/eei.v13i5.7222

Braille letter recognition in deep convolutional neural network with horizontal and vertical projection

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Article Info

Article history:

Received Jul 19, 2023
Revised Mar 7, 2024
Accepted Mar 20, 2024

Keywords:

Braille recognition
Deep convolutional neural network
Deep learning
Image processing
Visually impaired

ABSTRACT

Brail is a written mode of communication utilized by individuals with visual impairments to engage in interpersonal exchanges. The braille writing system consists of patterns printed on specialized paper that feature embossed dots. Braille documents enable the visually impaired to acquire knowledge and information exclusively through the application of their sense of contact. Comprehending braille is not a simple undertaking, particularly for the general populace. Because braille is not a required subject in Indonesian education, the majority of the population lacks proficiency in the language. This may therefore result in a minor communication barrier between visually impaired individuals and non-impaired individuals. In order to address this challenge, the present study employs digital image processing via the deep convolutional neural network (DCNN) technique to facilitate comprehension of braille document contents by non-braille speakers. This study employs a deep learning technique that is highly accurate, effective at image processing, and capable of recognizing complex patterns. This study employed the following image processing methods: grayscaling, filtering, contrast enhancement, thresholding, morphological operation, and resizing. Following testing in this investigation, it was determined that the proposed method accurately identifies embossed braille images with a precision of 99.63%.

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1. INTRODUCTION

Individuals with visual impairments are an integral part of society. Due to their limitation, it could cause a minor issue in communication between visually impaired persons to the ordinary ones. As times goes by, braille system is presented to help the visual impaired person to be used as written communication. Braille is a writing system that uses raised dots to write characters on paper. With the presence of the braille system can help visual impaired person to be able to obtain information only by utilizing their sense of touch, not vision [1]. Braille system was invented by a Frenchman, Louis Blair in the 1800s. The braille system was created to help people with visual impairments to be able to read and write. Since its discovery, the system has been used extensively throughout the world as a medium for exchanging information among blind people. The publication of braille documents also increased substantially. However, for most people, braille documents are not very useful because of their inexperience in braille, making them difficult to obtain information from the existing braille documents [2].

In the last two decades, developments in technology continuously increasing. Research on braille has become one of the hottest topics to be discussed. Various studies have been carried out in the area of braille recognition studies. Braille recognition does not only reduce the dyslexia of the blind but also overcomes the problems of people involved in the world of braille education, such as correcting school work, marking paper [3]. Through computer technology, difficulties in translating braille can be solved by a variety of methods. One of those is by using deep convolutional neural network (DCNN). DCNN shows an outstanding performance in the field of image recognition, especially on pattern recognition. DCNN has a performance that is capable of extracting high-level features. The advantage of the DCNN method is they don't require complex preprocessing and feature extraction stages [4].

Various studies on braille recognition have been carried out such as Smelyakov *et al.* [5] which in his research, he identified braille characters only for each cell. The accuracy he obtained was 97.1% for training and 95% for testing which is quite high. However, the data that was used in this research were only 33 images for training and 8 images for testing. The next research was conducted by Wong *et al.* [6] while this research utilizes the braille recognition to transcribe identified braille characters into computer files. The accuracy they obtained in their research was 99%. Next was Namba and Zhang [7] who conducted research using cellular neural network in braille image recognition. This research only processed numeral braille images as its input. This research utilizes cellular neural network as computer associative memory to store braille characters. The accuracy they obtained in their research was 87.9%.

Besides that, there was also another similar research, such as Kim and Xie [4] where this research identified Hangul based on handwriting. The method used in this research was the DCNN. The accuracy they obtained in their research was 95.96% for SERI95a and 92.92% for PE92. There was also another research conducted by Singh *et al.* [8] which identified Devanagari's character based on handwriting. This research proposed DCNN as its method. The accuracy they obtained in their research was 98.11%.

In their investigation of braille recognition, Li *et al.* [9] introduced the stacked denoising auto encoder (SDAE) approach as a solution to the challenges associated with automated feature extraction and dimensional reduction in the field of braille recognition. They implemented three distinct forms of algorithms in their research: multilayer perceptron, radial basis function, and softmax. Those 3 methods are compared by using 2 types of feature extraction such as traditional feature extraction and SDAE. The accuracy obtained by utilizing the traditional feature extraction is 64%, 55%, and 65%. Meanwhile, the accuracy obtained by utilizing SDAE feature extraction is 86%, 80%, and 92%.

Smelyakov *et al*. [5] conducted research on braille character recognition by using Backpropagation algorithm. In this research, the training and testing data are only focused on braille image for each character. The accuracy obtained is 97.1% for training and 95% for testing. The accuracy is obtained by involving 33 training images and 8 testing images. In our research, we collected at least 100 images for each braille character so that we could obtain various conditions for every braille images. Our research also uses data testing, which is a braille image in the form of sentences or words which have a higher level of difficulty.

Wong *et al.* [6] conducted research on braille recognition which aims to transcript back those braille character into computer files. The algorithm used in this study is half character detection. Half character detection processes each line of the scanned image from a braille document, which will detect the possible dot position. Then, the half character recognition and probabilistic neural network are used for recognition from the previous half character detection results. After the half character results are recognized, the grid will be determined by the transcription of the text file to produce braille text in the form of computer file. This study obtained 99% of accuracy. The obtained accuracy is very high, but in this research, they only transcript the braille character to be used as a computer file, so this research is only useful for agencies or schools that publish braille books.

Several other researches of braille system conducted in several languanges, such as Sinhala [10], Hindi [11], [12], Bharti [13], Arabic [14] Kannada [15], Taiwan [16], Fillipino [17] and Indonesia [18]. Other researchs on braille also reach convertion area such as text to braille [19], text and voice to braille [20], dual text to braille and braille to text [21], and braille script to text [22]. From many previous studies above, there are research gaps that might be achieved. The use of the DCNN with horizontal and vertical projection to identify braille characters with embossed characters and taken directly from various braille books has never been done before, although many previous studies have shown good results, the research gap for this research is measurable. Meanwhile, the objective to be achieved is, a significant increase in accuracy for direct detection of embossed braille letters from images taken from braille books with quite a lot of data.

2. METHOD

The general architecture used to describe the stages carried out can be seen in Figure 1.

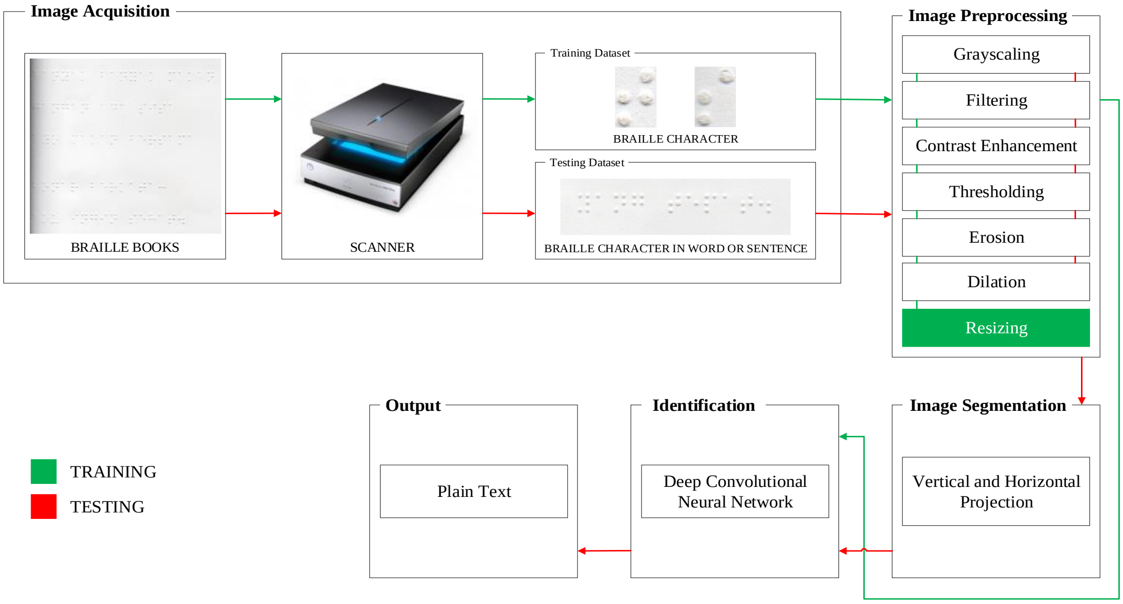


Figure 1. General architecture

2.1. Image acquisition

Image acquisition is the data collection stage that will be used in a study. In this study, the data used are braille images data obtained from 2 braille books entitled "Myself" and "My Environment" *("Diriku" dan "Lingkunganku")*. Both braille books were borrowed from karya murni SLB-A school, Medan. The collected braille images were divided into 2, such as training data and testing data. The first step in the process of image acquisition is scanning. Data is retrieved by using a scanner with a 300-dpi resolution. The result of scanned braille books can be seen in Figure 2. After the scanning process had been conducted, the next step is to crop. Cropping aims to obtain the region of interest from the image to be processed. In this study, training data and testing data were taken using different cropping techniques. The training data is cropped with a size of 53×81 pixels to obtain a braille image in one character or cell. Meanwhile, for testing data, the data was cropped in words or sentences. The amount of data used in this study is 3345 training images and 100 testing images. The examples of the images for training and testing images can be seen in Figures 3(a) and (b) respectively.

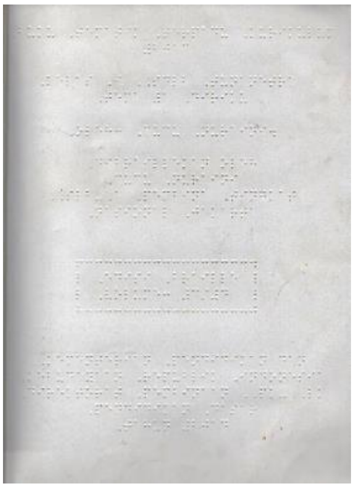
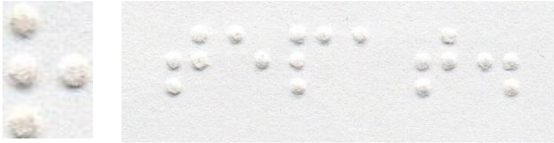


Figure 2. Scanned braille books



(a) (b)

Figures 3. The examples of; (a) training sample images from scanned brailled books and (b) testing sample images from scanned brailled books

2.2. Image preprocessing

Prior to identification processed, the step that must be done is to do image preprocessing. In this study, the stages carried out in preprocessing include grayscaling, filtering, contrast enhancement, thresholding, erosion, dilation, and resizing.

- Grayscaling

In this study, grayscaling aims to change the image that was originally an RGB image into grayscale. To apply the luminosity method to an image, it can be done using (1):

$$I = 0.299R + 0.587G + 0.144B \quad (1)$$

- Filtering

After the grayscaling processed had been conducted, the next step is filtering. Filtering is needed to eliminate noise in the form of paper fibers from the image. To eliminate the noise, this study applies gaussian blur. Gaussian blur works by blurring the image and eliminating the high frequencies that exist in the image so that the noise in the image becomes less clear [23]. To apply gaussian blur to an image, it can be done using (2):

$$G(x) = \frac{1}{2\pi\sigma^2} \exp\left(x^2 + y^2/2\sigma^2\right) \quad (2)$$

- Contrast enhancement

The next step is to do a contrast enhancement. Contrast enhancement is needed to increase the contrast value on an image to make it look clearer. To apply contrast enhancement, this study applies contrast limited adaptive histogram equalization (CLAHE). CLAHE has advantages compared to ordinary histogram equalization that this method works adaptively so this method can limit the increase of excessive contrast value so it can reduce the appearance of noise in the image [24]. To apply clahe to an image, it can be done by using (3):

$$\beta = \frac{M}{N}\left(1 + \frac{\alpha}{100}\left(S_{max} - 1\right)\right) \quad (3)$$

- Thresholding

Thresholding aims to separate the braille dots in the image with the background behind it. Thresholding will convert the image into 2 colors such as black and white. In this study, white color in the image represents braille dots and black color represents the background. This study applies an adaptive threshold as their thresholding method. To apply the adaptive threshold to the image, it can be done by using (4):

$$T = \frac{\sum_{(y,x)\in W} f(i,j)}{N_w} - C \quad (4)$$

- Erosion

After the thresholding processed had been conducted, the image still contains some little noise. To eliminate those existing noise, this study applies erosion. Erosion is a part of morphological operations used in binary image processing for several purposes, such as to elimate noise [25]. Erosion works by eroding white details in the image from the threshold image. By using erosion, the little noise in the image will erode until it disappears. To apply erosion to the image, it can be done by using (5):

$$E(A, B) = A \ominus B = \{x: B_x \subset X\} \quad (5)$$

- Dilation

After the erosion processed removed the noises from the image, the next step is to do dilation. Dilation is also a part of morphological operations used to regulate shapes [25]. Dilation aims to add more white detail to the image so that it can be clearer. With the dilation applied to the image, the details that are almost lost due to the previous erosion process will become clearer. To apply dilation to the image, it can be done by using (6):

$$D(A, B) = A \oplus B = \{x : B_x \cap A \neq \phi\} \quad (6)$$

- Resizing

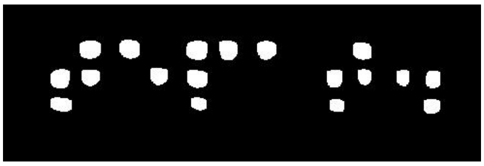
Once all aspects of the image appear distinct, the resizing process follows. To reduce the dimensions of the image from 53×81 pixels to 256×256 pixels, resizing is required. This phase is essential for meeting the system prerequisites, as the approach employed in this research necessitates a 256-by-256-pixel input image. To do resizing, this study applies the bilinear interpolation method. This method is often used in digital image processing because this method provides a compromise between computing and efficiency.

2.3. Image segmentation

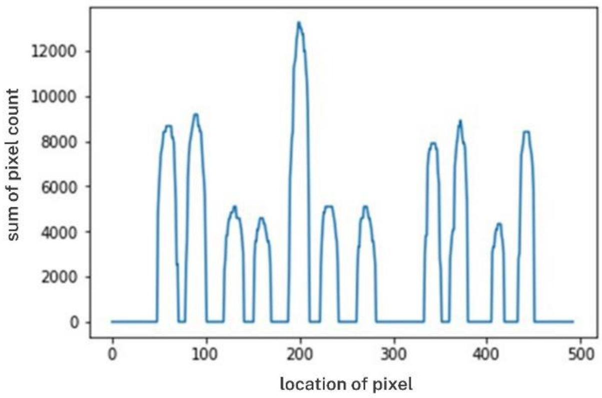
After the image preprocessing stage had been conducted, the next step is to do image segmentation. Image segmentation is needed to segment the testing image which was originally in the form of words or sentences into each character so the braille character can be identified. In this study, the stage carried out in image segmentation include vertical projection and horizontal projection.

- Vertical projection

Before segmentation, the first step is to do a vertical projection. Vertical projection is part of projection profiling. Projection profiling is a data structure used to store the number of pixels that are not the background of an image when it is projected on the normal x-axis and y-axis [26]. Vertical projection detects the presence of white pixels vertically from an image. The looks of vertical projection histogram can be seen in Figures 4(a) and (b). In this study, vertical projection is used to obtain the midpoint of the braille dots which will then be used to calculate the distance between each dot in the image. To segment the braille characters into each cell, several conditions need to be considered. Some of these conditions can be seen in Figure 5. These conditions are needed so that the system can do the segmentation automatically.



(a)



(b)

Figure 4. Image of: (a) target image for vertical projection and (b) vertical projection histogram from Figure 4(a)

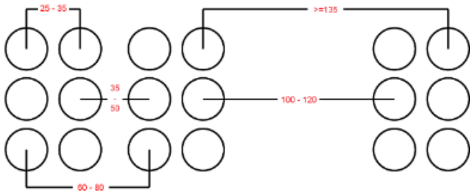
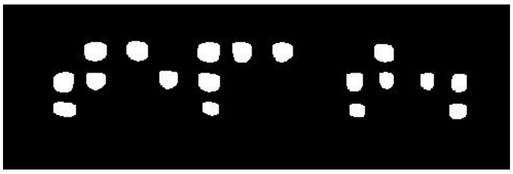


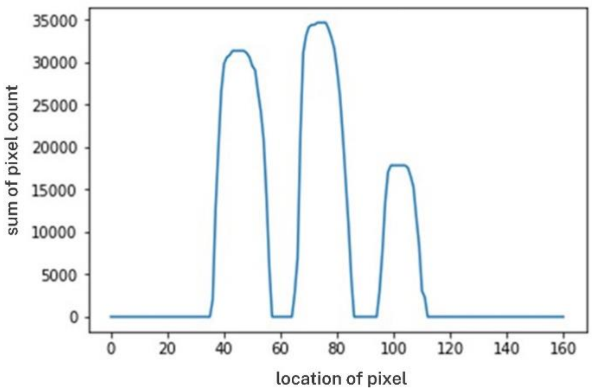
Figure 5. Condition of braille dots

- Horizontal projection

After the segmentation process using the vertical projection had been conducted, the next step is to do horizontal projection. Horizontal projection is the same as vertical projection, but what distinguishes them is horizontal projection the number of pixels of an image horizontally [26]. The histogram of horizontal projection can be seen in Figures 6(a) and (b). In this study, horizontal projection is used in two conditions such as for the image that had not been segmented using vertical projection and for the image that had been segmented using vertical projection. The use of horizontal projection in these two conditions is due to conditions where the braille dots in the image are not aligned. To deal with the image that is not aligned, the horizontal projection of an image that has not been segmented in vertical projection will be used as a reference for image that had been segmented in vertical projection. The histogram of the horizontal projection of the image that had been segmented using vertical projection can be seen in Figures 7(a) and (b).



(a)

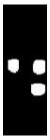


(b)

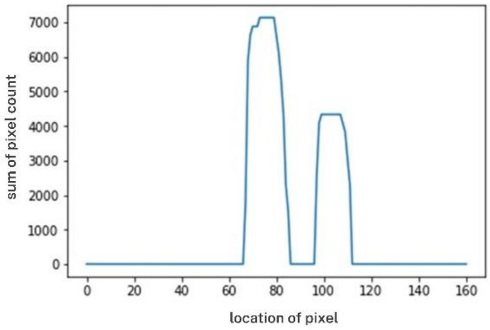
Figure 6. Image of: (a) target image for horizontal projection and (b) horizontal projection histogram from Figure 6(a)

2.4. Identification

In this study, identification is done by using neural network. The neural network method used in this study is DCNN. DCNN are best used in various fields of study such as object recognition [27], object tracking [28], facial emotion recognition [29], text detection and recognition [30], visual saliency detection [31], action recognition [32], scene labelling [33], texture recognition [34], and coastal forest satellite images change detection [35]. In order for this method to be applied in a system, it is necessary to make a model. A number of decisions must be made during the model construction process, including the hidden layer, number of neurons, activation function, optimizer, batch size, and epoch.



(a)



(b)

Figure 7. Image of: (a) target image for horizontal projection and (b) horizontal projection histogram from Figure 7(a)

- DCNN architecture

The input image in the DCNN method in this study is a braille image measuring 256×256×1 pixels. The input image is an image generated in the previous preprocessing stage. The input image is then inserted into the convolutional layer with 32 filters with 3×3 dimensions. After the image has been processed at the convolutional layer, the image will be inserted into the max pooling layer with 2×2 filter dimensions in order to compress the image size. This study applies 5 convolutional layers and 5 max pooling layers by utilizing the ReLU activation function. After the convolutional layer and max pooling layer has been passed, the next step is to flatten the data so that the data can be processed at the fully connected layer. The fully connected layer which is applied in this study consists of 3 dense layers. The first layer is the layer that processes the results of the previous flattening process. The first layer consists of 900 neurons using the ReLU activation function. Whereas the second layer dense receives input from the previous dense layer. This second layer consists of 90 neurons using the ReLU activation function. After the second dense layer has been processed, the last dense layer which consist of 32 neurons or equal to the number of braille characters trained will produce the probability of each prediction of braille characters in the input image. At the last layer dense utilizes the softmax activation function.

- Hyperparameter setup

The determination of the optimal number of concealed layers in this study is accomplished through a process of trial and error. A total of two concealed layers are implemented. Regarding the determination of the quantity of neurons to be utilized in the concealed layer, no precise calculation is performed. 1022 neurons are utilized in the entirely connected layer for this investigation. the relationship between input, weight, and bias will be computed utilizing the activation function's equation. Its objective is to obtain the result produced by every stratum. This study employs two distinct activation functions: the softmax activation function is utilized in the output layer and the ReLU activation function is utilized in the convolutional layer. To get the calculation of the ReLU activation function can be obtained using (7) while the softmax activation function can be obtained using (8).

$$\sigma(z) = max(z) \tag{7}$$

$$\sigma(z) = \frac{e^{z}}{\sum_{k=1}^{k} e^{2}k} \tag{8}$$

For determining the optimal weight, the rmsprop optimizer was utilized in this investigation. The batch size specifies the number of observations that must be completed prior to modifying the weight that is determined by the computer's specifications. The default collection size of 32 was utilized in this investigation. The quantity of literacy instruction conducted during the training procedure is named "epoch." The level of training results is influenced by the epoch, with a higher epoch resulting in improved training outcomes. A total of 100 epochs were utilized in this investigation.

3. RESULTS AND DISCUSSION

3.1. Implementation, training, and testing

The programming language used in core process of the system is python programming language then also several web-based languages such as involves HTML, CSS, jQuery and JavaScript. The hardware and software specifications used to build this braille letter identification system are as follows: i) the laptop device used is Asus X455LJ, ii) processor intel (R) core (TM) i5-5200U CPU @ 2.20GHz (4 CPUs), ~2.2GHz, iii) RAM capacity of 12GB, iv) hard disk capacity of 500GB, v) windows 10 Pro 64-bit, vi) python 3.7.1 and anaconda 4.6.14, and vii) tensorflow backend via keras and openCV 4.0.1. Testing was carried out using the DCNN method involving 3345 training data images divided into 90% for the training process and 10% for the validation process, while for the test data there were 100 images. In the training process, the accuracy obtained reaches 100% after going through the training process with an average time of 175 seconds/epoch, so it takes 4 hours 52 minutes to train 3010 images of 100 epochs. The training process also produces a model that is used in the testing process. The accuracy obtained in the testing process also gets satisfactory results which in 1342 images, 1337 images were correctly identified. The accuracy in this testing processed reaches 99.63%. The accuracy is obtained by using (9):

$$\begin{aligned} Accuracy &= \frac{correctly\ identified\ character}{total\ of\ characters} \times 100\% \qquad (9) \\ &= \frac{1337}{1342} \times 100\% = 99.63\% \end{aligned}$$

From the calculation above, the level of accuracy obtained is quite high but not perfect. Several factors cause imperfections in the system, for example, can be seen in Figure 8, there is a noise in the form of shadows in the image while scanning process so that when doing contrast enhancement, the colors on the dots and the paper become similar. So, when the image passed into the thresholding process, the braille dots in the image cannot be detected. The next factor can be seen in Figure 9, the braille dots in the image are not very clear so while the erosion process, the dots become disappear. There are also other factors as can be seen in Figure 10, the image is misidentified by the DCNN method. This method considers that the dots at the bottom of the image more as a noise rather than dots so that the image is identified as “h” not “r”.

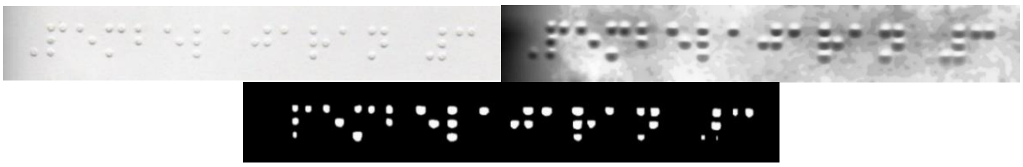


Figure 8. Failed processed images because of shadows

Figure 9. Failed processed image because of the dots not so clear

Figure 10. Image that failed to identify by DCNN

3.2. Comparison to previous research

Various studies related to the braille recognition will be compared to the process and its accuracy such as, Li *et al.* [9] that on their research they emphasized the use of the stacked denoising autoencoder (SDAE) feature extraction which was applied to 3 different methods such as multi layer perceptron, radial basis function, and softmax. In their research, they were not focused on using the appropriate preprocessing stages. Therefore, the accuracy they obtained were not too high. The accuracy they obtained before and after applying the SDAE feature extraction is 64%, 55%, 65% and 86%, 80%, 92%. Unlike their research, we focus on using one method, which is DCNN and pay attention to the use of more precise preprocessing stages so that the accuracy obtained can be higher, which is 99.63%.

Smelyakov *et al.* [5] also conducted research related to braille recognition. In their research, they only identified one character or one braille cell images. this will certainly difficult to use by ordinary people who have no experience in braille at all. Unlike their research, our research accepts the input image in the form of words or sentence so that it can be easier to be used. Smelyakov [5] applied the Backpropagation method on his research. The accuracy they obtained was 97.1% for training and 95% for testing. The accuracy was obtained by involving 33 training images and 8 testing images. Unlike their research, the data we used for the training process was 3345 images and 100 images in the form of words or sentence used for the testing process. With the amount of data that is more and varied, it certainly will affect the accuracy of the system made.

Wong *et al.* [6] also conducted research related to braille recognition. In his research, he identified Braille letters and then transcribed them back into computer files. Unlike their research, the output of our identification result is a translation of the processed braille image. In his research, he applied the use of half character detection, half character recognition, and probabilistic neural network. The accuracy obtained in his research was 99%.

Namba and Zhang [7] also conducted research on braille recognition. In their research, they only identified braille number character. Unlike their research, our research can identify letters, numbers, and 4 punctuation marks (dots, comma, question marks, and exclamation marks) characters. In their study, they apply the use of the method which is used as an associative memory. This method is also compared with multi layer perceptron which proves that the cellular neural network method is superior compared to multi layer perceptron. The accuracy they obtained reached 87.9% for cellular neural network and 62% for multi layer perceptron.

In our research, there are differences in the identification process that was carried out. This research identifies braille images in the form of words and sentences so that it makes it easier for users to do identification. The data used in our research was taken using a scanner with a 300-dpi resolution. The data collected totaled 3345 images for the training and 100 images for the testing. The level of accuracy achieved in this study was 99.63% which consisted of 1337 characters that were correctly identified from a total of 1342 characters.

For comparison of the accuracy of the methods used are implemented in our dataset and train like in the previous research, the results can be seen in Table 1 where it can be concluded that the accuracy obtained by using the DCNN method by involving 3345 training images and 100 testing images taken by using a scanner with a 300-dpi resolution is superior than other studies. The accuracy obtained is 99.63%. It proves that the DCNN method with the following types of data is quite effective for use in the identification of braille letters.

Table 1. Accuracy comparisons

Methods	Accuracy (%)
Radial basis function	60
Multi layer perceptron	67-69
Softmax	70
Multi layer perceptron + SDAE	91
Radial basis function + SDAE	91
Cellular neural network	91.9
Softmax + SDAE	92
Backpropagation	93
Proposed method (DCNN with horizontal and vertical projection)	99.63

4. CONCLUSION

In this study, it can be concluded that the DCNN method is able to identify braille letters with very good predicate. The accuracy obtained in this study reached 99.63%. But there are some things that need to be considered. One of them is that the scanning process by using a scanner is very influential in the identification process and the method used for contrast enhancement is still not optimal to solve problems in images that have dark shadows.

ACKNOWLEDGEMENTS

Author thanks to Universitas Sumatera Utara for their research grant and financial support with grant number 289/UN5.2.3.1/PPM/SPP-TALENTA USU/2021.

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