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Paper Currency Authenticity Recognition Model Using Machine Vision, Image Processing, Based on Fuzzy Interface System

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Abstract: This study presents the paper currency authenticity recognition model using machine vision and image processing and fuzzy interface system in the Framework of Industrial Information Integration and it is applied research category. Therefore, this is a new presentation of an industrial information integration engineering system to develop methods of recognition between original paper currency and fake paper currency. We used machine vision to improve human vision in paper money authenticity recognition. The growing production of fake paper currency in some countries explains the need to define the way authenticity paper money recognition. Paper money makers often define and implement unique features to further identify and secure paper currency and prevent counterfeit money printing. Most of these features are not easily recognizable to the human eye and require an auxiliary tool to identify their authenticity. So; this study aims to aggregate different tools identified by other researchers in the subject of paper currency authenticity recognition because current mechanical tools such as sensors have several problems such as calibration and accurate maintenance and repair and errors. The proposed model can recognize the difference between original paper currency and fake paper currency with machine vision and image processing; also in this research different comparative methods have been used.

Keywords: Industrial Information Integration, Paper Currency Authenticity Recognition, Machine Vision, Image Processing, Fake Currency Recognition System, Fuzzy Interface System

1. Introduction

Most banks and stores operate with large amounts of paper currency daily, and due to the increase in counterfeit paper currency, their validation is necessary. Researchers have come up with various methods to validate and verify the authenticity of paper currency. For example, based on optoelectronic sensors and classification by multilayer perceptions' whose operation is scheduled by an external controlling algorithm. [1], or based on characteristic vectors extracted on neural networks [2], or using characteristics extraction and negatively correlated neural network ensemble based on size, color, and texture, [3], or based on local binary pattern algorithm [4], or based on edge detection, image segmentation, feature extraction, [5], or based on extracting the textural and non-textural features [6], or based on classification using weighted Euclidean distance [7], or based on Features of currency note like serial number, security thread, Identification mark, Mahatma Gandhi portrait (Indian Rupee) [8], or using image processing [9, 10], and summarizing the main points of the literature review from 2009-2021 [11], So, Researchers have willingly or unwillingly used a part of the general of information integration model, although it is not mentioned. This research is in the framework of information integration by defining a library of features of each piece of paper currency used, and important and unique information of each paper currency is collected into the library, which is part of the novelty of this research. Also previously similar to this research to industrial parts change recognition model using machine vision and image processing in the framework of industrial information integration was done [12], that the issue of "change recognition" in solving the design of this model is also effective.

2. Materials and Method

2.1. Materials

In this study, 20$, 50$ & 100$ banknotes as data were used, which is tested on both sides, but the model applies to any other type of banknote.

Note: To reveal some of the important features of the dollars, shooting with a 24-megapixel camera was done using UV rays.

Figure 1. *On $20.*

Figure 2. *Back of $20.*

Figure 3. *On $50.*

Figure 4. *Back of $50.*

Figure 5. *On $100.*

Figure 6. *Back of $100.*

2.2. Method

The paper currency authenticity recognition model is as follows:

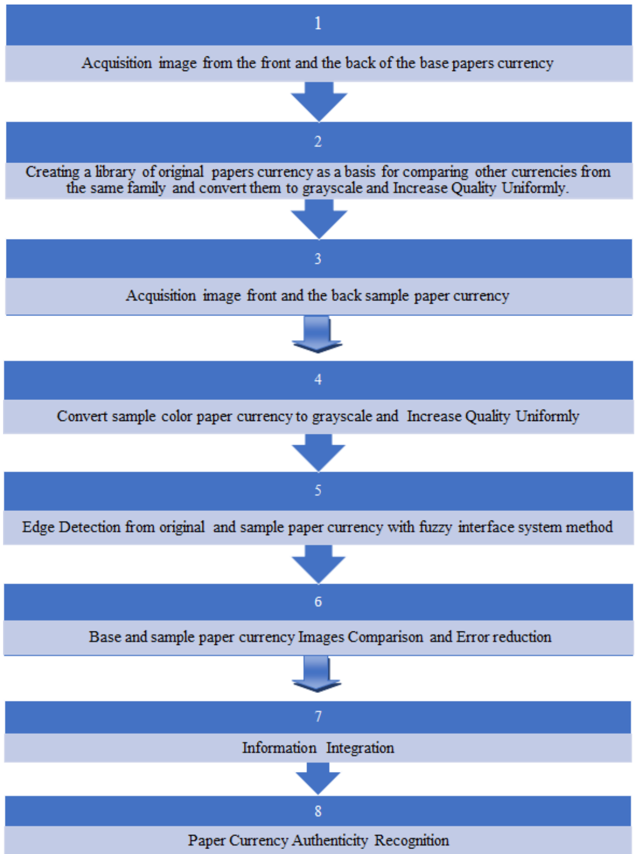

Figure 7. *Paper Currency Authenticity Recognition Model.*

Description of Model Components:

(i). Acquisition Image from the Front and the Back of the Base Papers Currency

Because there is the variable serial number on paper currency, we cannot use them in the comparison model, so the image should be taken by sampling from the screen so that there are no serial numbers in the images. The shooting method will be such that the image will be taken from the bottom, middle, and top of the page with a specific width that does not include the serial number. This imaging method will be fixed and unchanged in all cases. Images are captured using a scanner with at least 24 megapixels using UV rays. All basic images are stored in the library.

(ii). Creating a Library of Original Papers Currency as a Basis for Comparing Other Currencies from the Same

Family and Converting Them to Grayscale and Increasing Quality Uniformly

Providing a library of images of the desired currency provides the ability to update it and also increases the performance of the model quickly.

(iii). Acquisition Image Front and the Back Sample Paper Currency

This step is the same as step (i), except that the sample images are not saved and are only compared to the base sample from the library.

(iv). Convert Color Paper Currency to Grayscale and Increase Quality Uniformly

Converting images from color to grayscale is done using the MATLAB toolbox, and its advantage is to increase the clarity of the required data and eliminate unnecessary data to edge detection, which increases both the accuracy and speed of the model. To increase Images quality, we use the following command as an image processing toolbox to increase the resolution and quality of images: (I = imadjust (I)) Which maps the intensity values in the grayscale image I to new values such that 1% of data is saturated at low and high intensities of image [13].

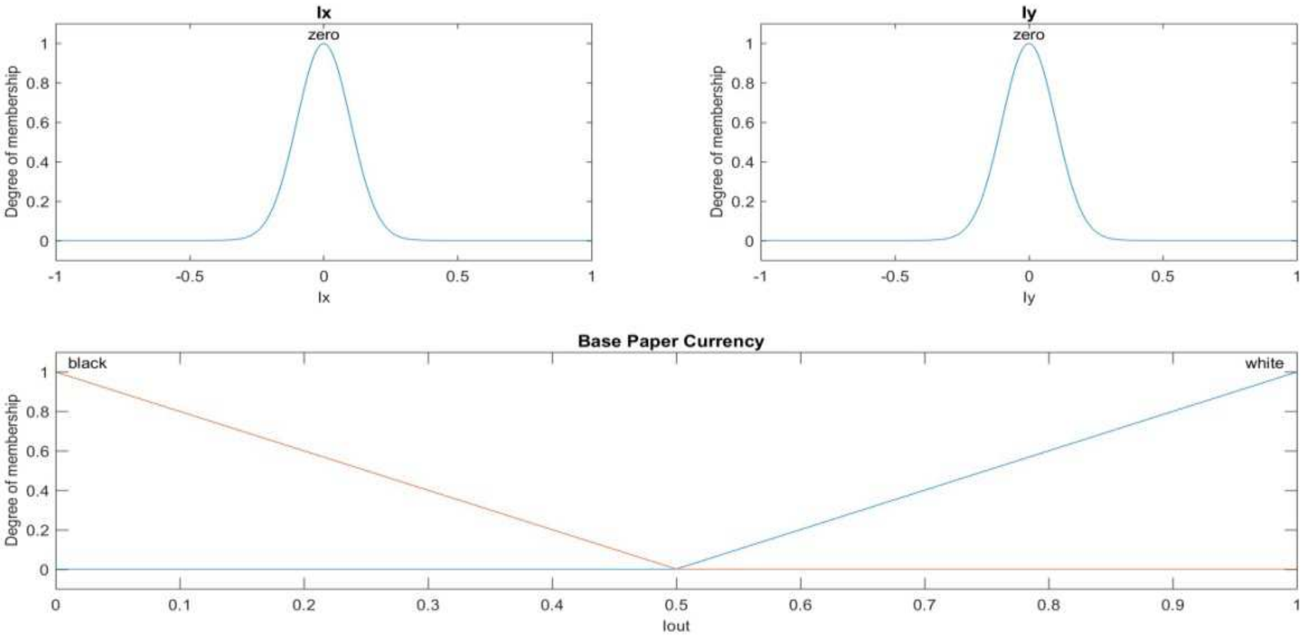

Figure 8. *Define a fuzzy inference system (FIS) for edge detection (base & sample paper currency).*

(v). Edge Detection from Original and Sample Paper Currency with Fuzzy Interface System Method

In a previous study, we found that the fuzzy inference system algorithm has higher edges detection and higher transparency in edges detection in the image than other operators like Prewitt, sobel, cany, Therefore, in this study, only the fuzzy inference system was used to find the edge [13]. To define Fuzzy Inference System[i] in MATLAB for Edge Detection, the following items need to be explained:

(a). Create mandani Fuzzy Inference System: With MATLAB functions, a=newfis ('newsys'); getfis (a)

(b). Advantages of mandani Fuzzy Inference System vs. Sugeno Fuzzy Inference System in our model:

Mamdani fuzzy inference was first introduced as a method to create a control system by synthesizing a set of linguistic control rules obtained from experienced human operators [15]. In a Mamdani system, the output of each rule is a fuzzy set. Since Mamdani systems have more intuitive and easier to understand rule bases, they are well-suited to expert system applications where the rules are created from human expert knowledge.

Table 1. *Comparison mandani Fuzzy Inference System vs. Sugeno Fuzzy Inference System [15, 16].*

Fuzzy Inference System	Advantages
Mamdani	1. Intuitive 2. Well-suited to human input 3. The more interpretable rule base 4. Have widespread acceptance
Sugeno	1. Computationally efficient 2. Work well with linear techniques, such as PID control 3. Work well with optimization and adaptive techniques 4. Guarantee output surface continuity 5. Well-suited to mathematical analysis

Here, because edge detection is a rule base of sharp change color at the border of the edges of the image and Mamdani fuzzy inference more interpretable rule base, we used Mamdani fuzzy inference system.

(b). 2-D convolution

Ix = conv2 (I1, Gx,'same');

Iy = conv2 (I1, Gy,'same');

The mask used for scanning the base & sample Paper Currency is shown in Figure 9.

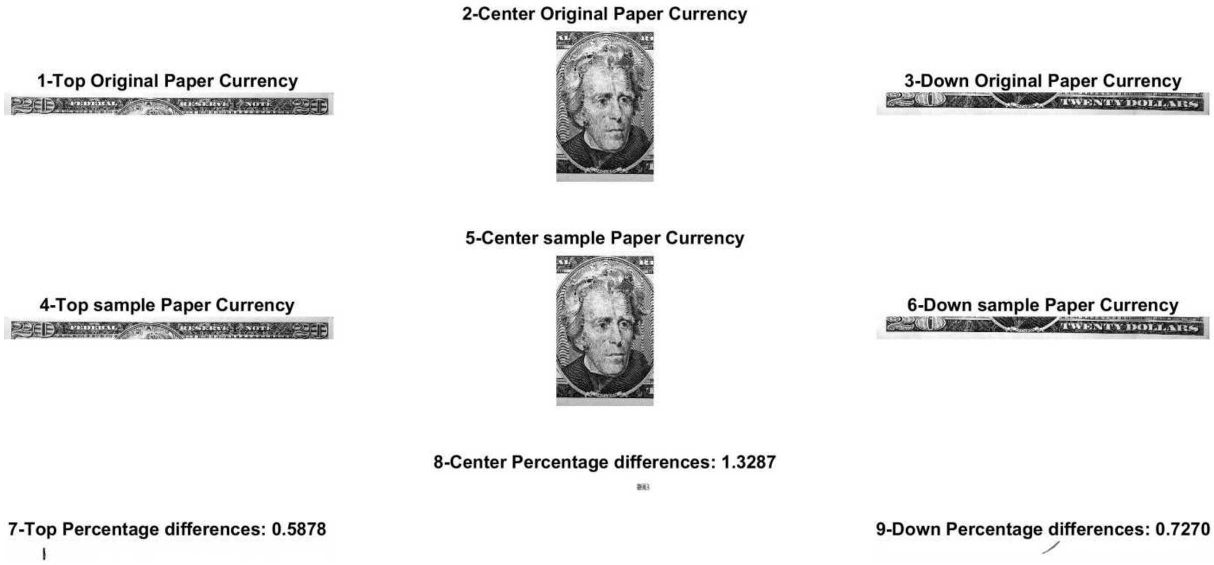

Figure 9. *Compare on $ 20 in a top, center, and bottom position, image 7, 8, and 9 show the difference between the sample and the base in three positions.*

Gx = [-1 1], Gy = Gx'
wa = 0.5; wb = 1; wc = 1;
ba = 0; bb = 0; bc =.5;

(c). Crisp inputs for fuzzified into various FS[ii]*, having conventional crisp membership functions i.e. Black & White. (Gaussian curve membership function).*

(d). Firing strength is calculated using fuzzy t-norms operators.

(e). Fuzzy rules are fired for each crisp input.

(f). Aggregate resultant output FS for all fired rules are achieved by using s-norm.

(g). De-fuzzification is performed using the centroid method, which shows the best performance.

Note: The output of each rule is a fuzzy set derived from the output membership function and the implication method of the FIS[iii]. These output fuzzy sets are combined into a single fuzzy set using the aggregation method of the FIS. Then, to compute a final crisp output value, the combined output fuzzy set is defuzzified using one of the methods described in De-fuzzification Methods.

(h). The crisp output is the pixel value of the output image i.e. one containing the edges, black and white regions.

(i). The first derivative is performed on the output from FIS after the application of the noise removal algorithm [13]. Briefly, we detected the edges in an image using a FIS, comparing the gradient of every pixel in the x and y directions. If the gradient for a pixel is not zero, then the pixel belongs to an edge (black). We defined the gradient as zero using Gaussian membership functions for your FIS inputs.

(vi). Base and Sample Paper Currency Images Comparison and Error Reduction

(a). The Structural Similarity Index (SSIM): [14].

The Structural Similarity (SSIM) Index quality assessment index is based on the computation of tree terms, namely the luminance term, the contrast term, and the structural term [14].

$$\mathrm{SSIM}(x, y) = [l(x,y)]^{\alpha} . [c(x,y)]^{\beta} . [s(x,y)]^{\gamma}$$

Where

$$l(x,y) = \frac{2\mu x\mu y + C1}{\mu 2x + \mu 2y + C1}$$

$$c(x,y) = \frac{2\sigma x\sigma y + C2}{\sigma 2x + \sigma 2y + C2}$$

$$s(x,y) = \frac{\sigma xy + C3}{\sigma x\sigma y + C3}$$

Where μ_x, μ_y, σ_x, σ_y, and σ_{xy} are the local means, standard deviations, and cross-covariance for images *x, y*. If $\alpha = \beta = \gamma = 1$ (the default for Exponents), and $C_3 = C_2/2$ (default selection of C_3) the index simplifies to: [16].

$$\mathrm{SSIM}(x,y) = \frac{(2\mu x\mu y + C1)(2\sigma xy + C2)}{(\mu 2x + \mu 2y + C1)(\sigma 2x + \sigma 2y + C2)}$$

(b). Error calculates and reduction:

For Error calculates and reduction, is enough to introduce two paper currencies, both family and base, to the system. If a difference is calculated between them, it is the amount of system error that must be deducted in the calculation and the total amount [13].

Error = {Original paper currency 1} - {Original paper currency 2}

Also, to reduce the model error, the following points are required:

It is necessary to calculate the error of the grinding machine mentioned earlier.

The use of UV rays at the same time as imaging is required to reveal the hidden features of banknotes.

To calculate the difference between a sample and the base paper currency, we can use the average of the differences obtained by subtracting the error of the device. Confirmation or rejection of the test depends on the threshold defined by the user.

(vii). Information Integration

In this part of the model the information collected is integrated. The collected information contains: base paper currency from library & sample paper currency, grayscale and increases quality base paper currency & sample paper currency, edge detection from them, system error calculation and reduction, base paper currency & sample paper currency comparison, which is integrated and prepared to authenticity recognition.

(viii). Paper Currency Authenticity Recognition

If the difference between the sample and base paper currency images was less than the threshold, the sample Paper Currency is accepted, otherwise, rejected. So, we use the following method to calculate the difference between the two main and desired images.

Percentage differences between base & sample paper currency = (1-SSIM[iv]) *100 - Error

3. Results

The output of the proposed model is shown as shown below, it is necessary to explain that, the proposed model can measure the difference between the two images with an accuracy of 0.1, and the result of the final difference can be obtained from the average of the measured values. Also, base on the model, all images are edge detected with a fuzzy inference system, and their details are revealed.

Example 1: 20$ Comparison

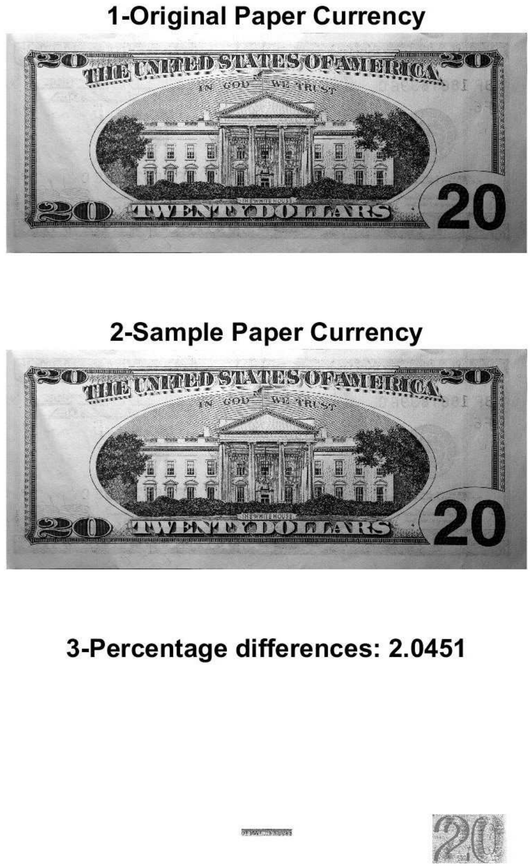

Figure 10. *Compare back of $ 20, image 3 shows the difference between the sample and the base.*

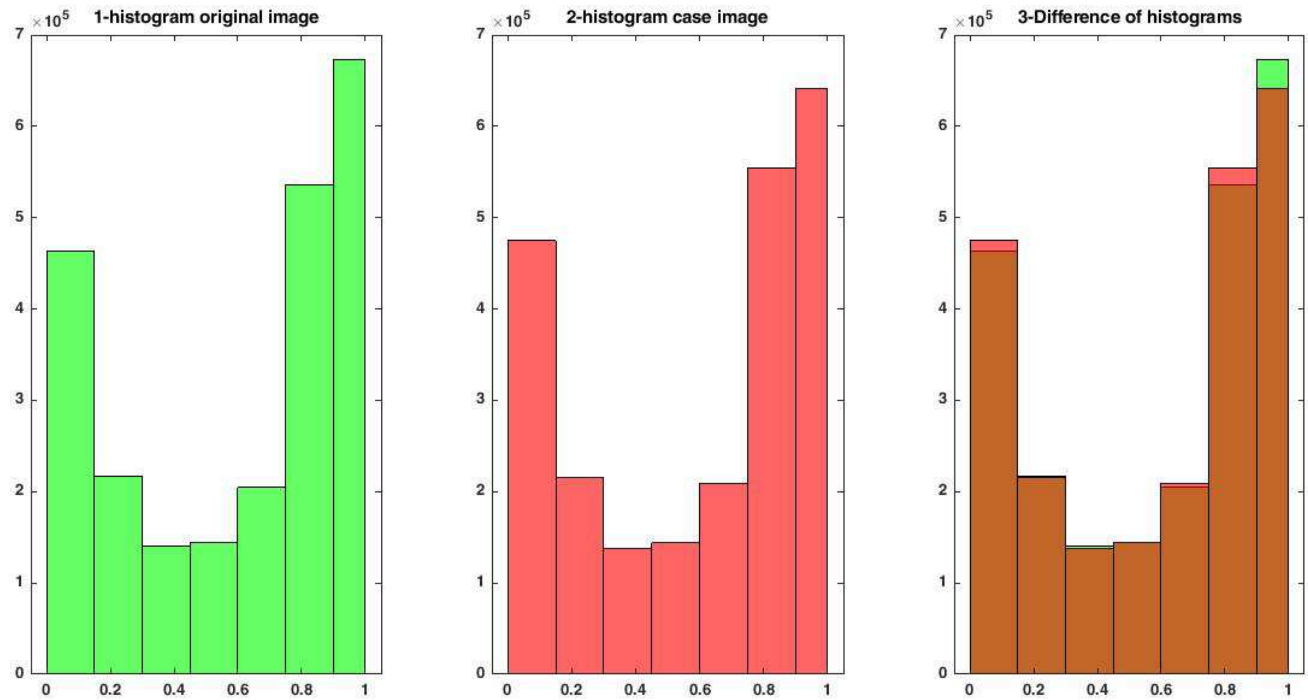

Figure 11. *Histogram comparison sample and base on 20$ and show difference.*

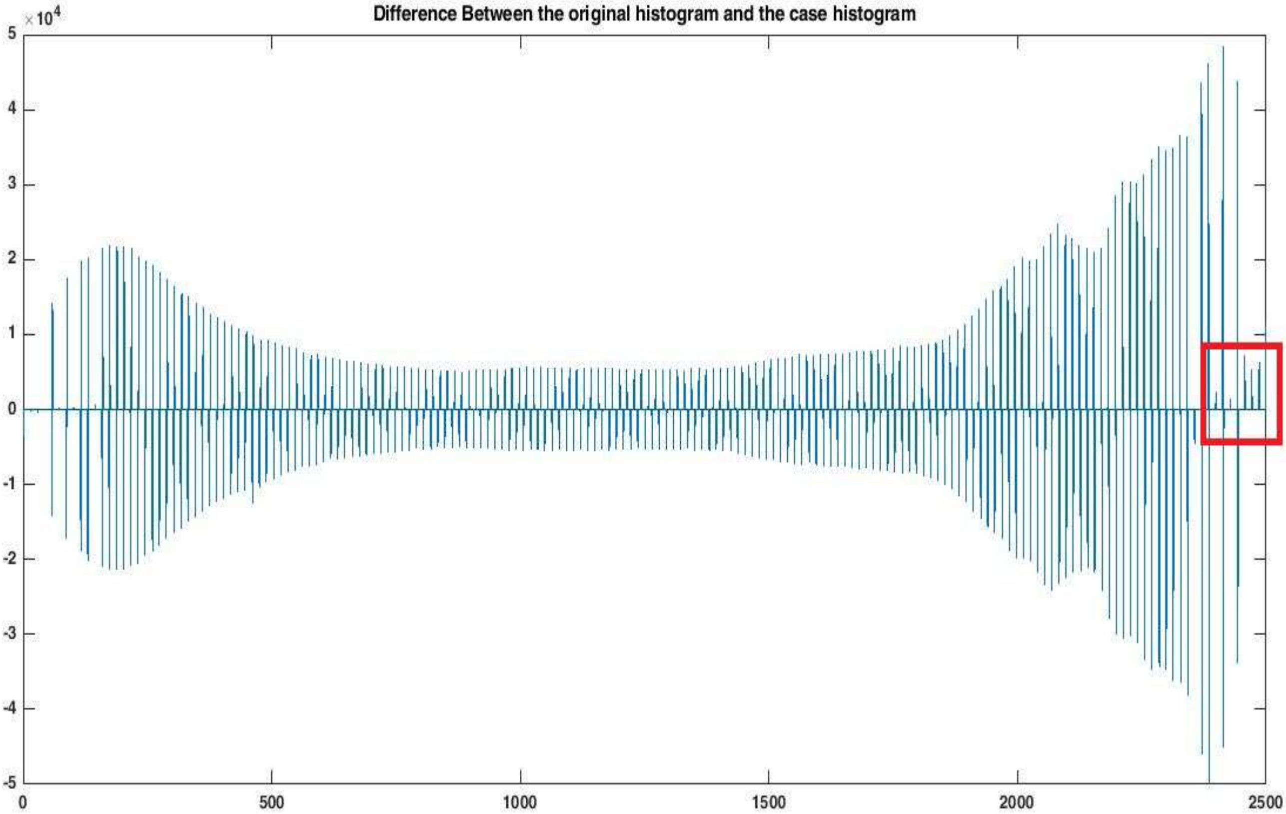

Figure 12. *Histogram comparison sample and base on 20$, the top of the axis corresponds to the base and The bottom axis corresponds to the sample.*

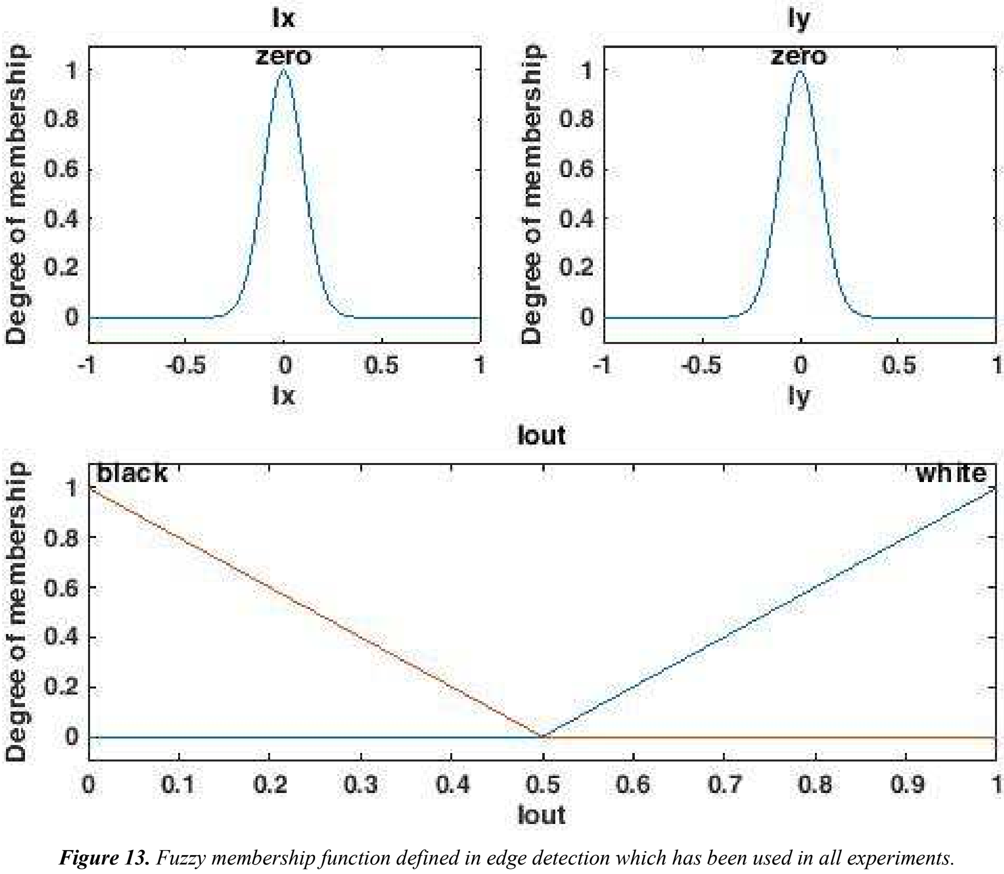

Figure 13. *Fuzzy membership function defined in edge detection which has been used in all experiments.*

In this comparison, the size of 20 sample banknotes was different from the base.

Example 2: 50$ Comparison

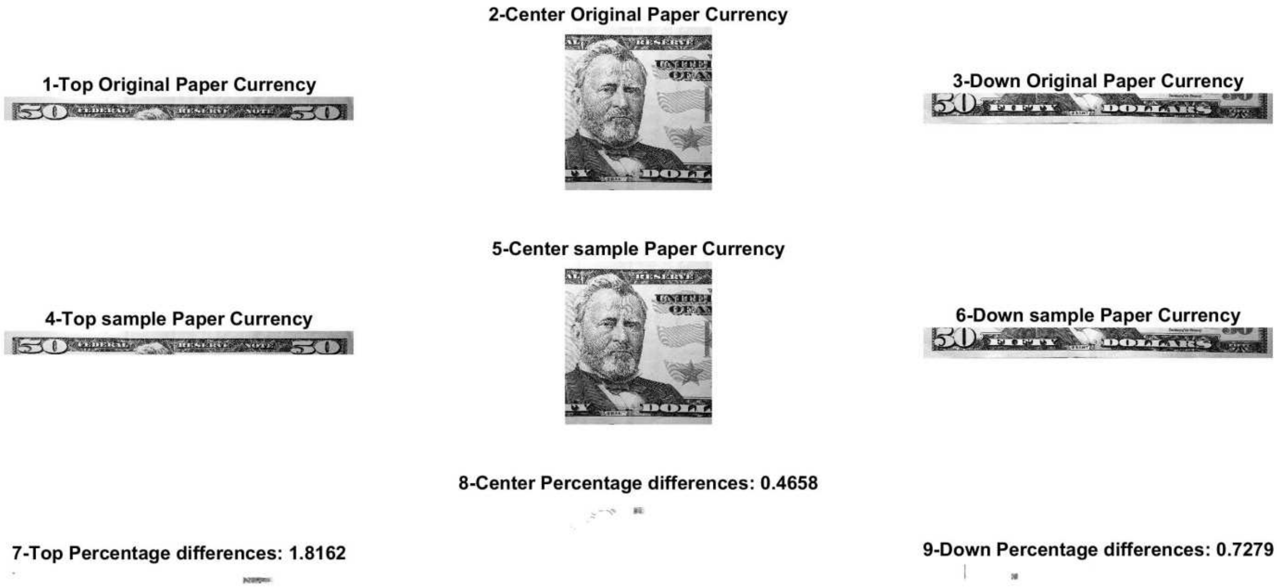

Figure 14. *Compare on $ 50 in a top, center, and bottom position, image 7, 8, and 9 show the difference between the sample and the base in three positions.*

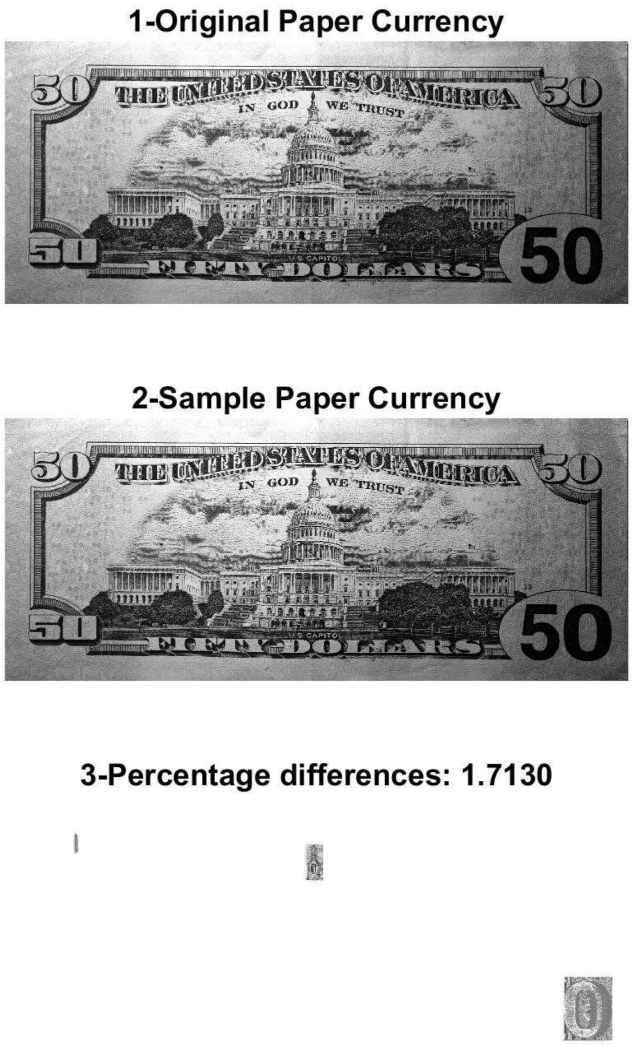

Figure 15. *Compare back of $ 50, image 3 shows the difference between the sample and the base. (1.7130$).*

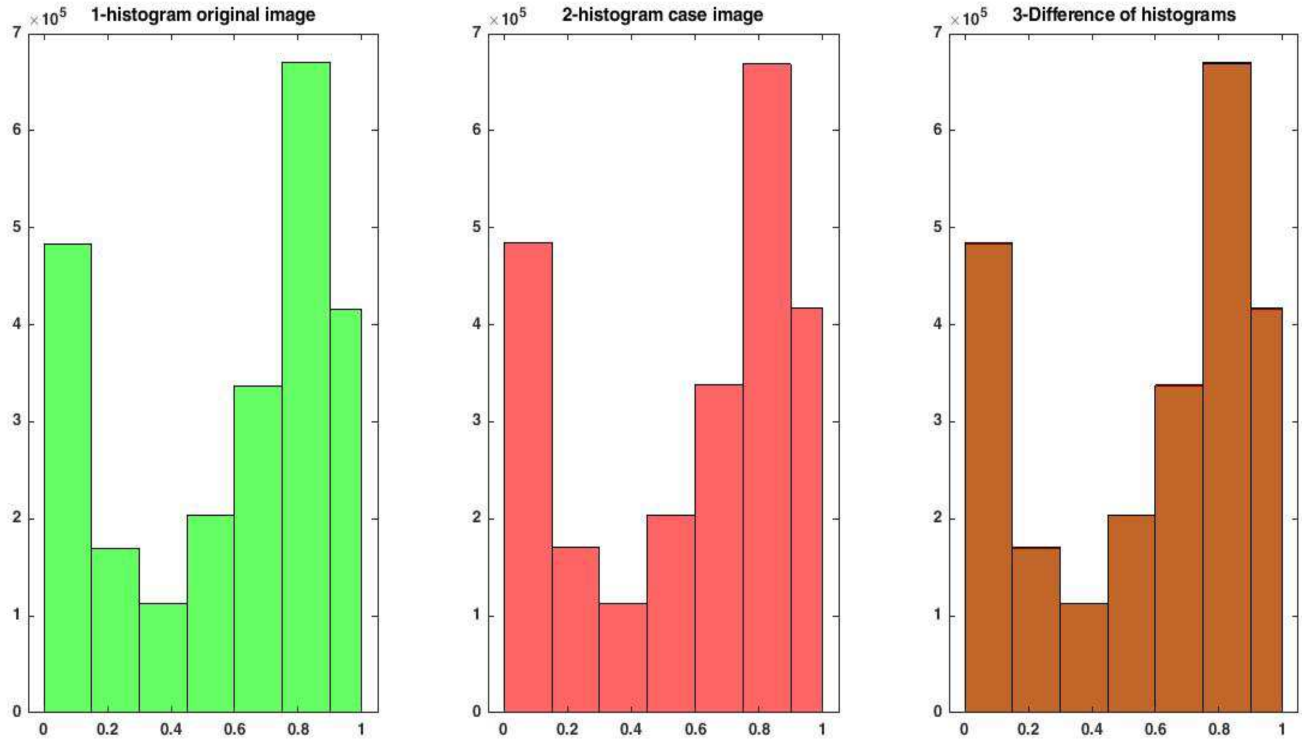

__Figure 16.__ Histogram comparison sample and base on 50$ and show difference.

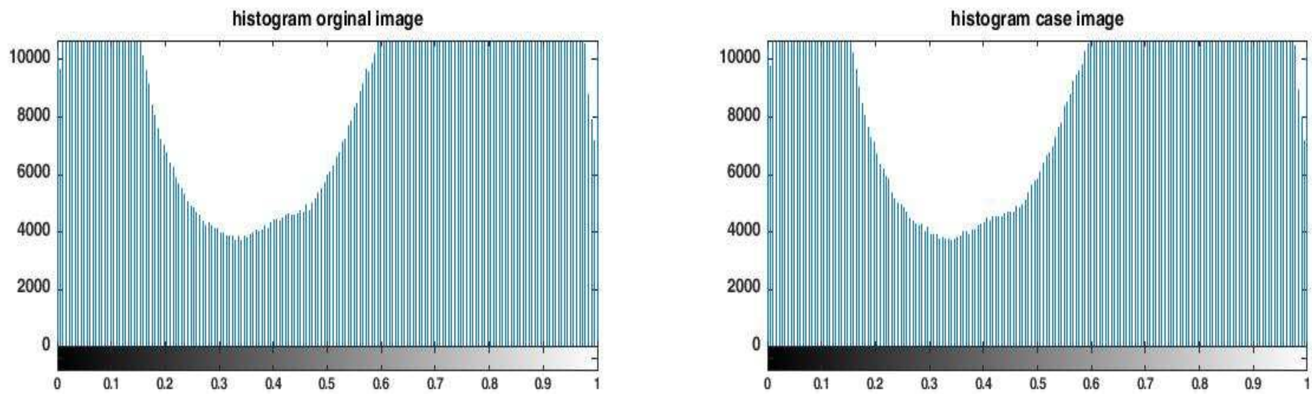

__Figure 17.__ The difference on the banknote tested with the original sample is negligible on top of 50$ sample and base.

Example 3: 100$ Comparison.

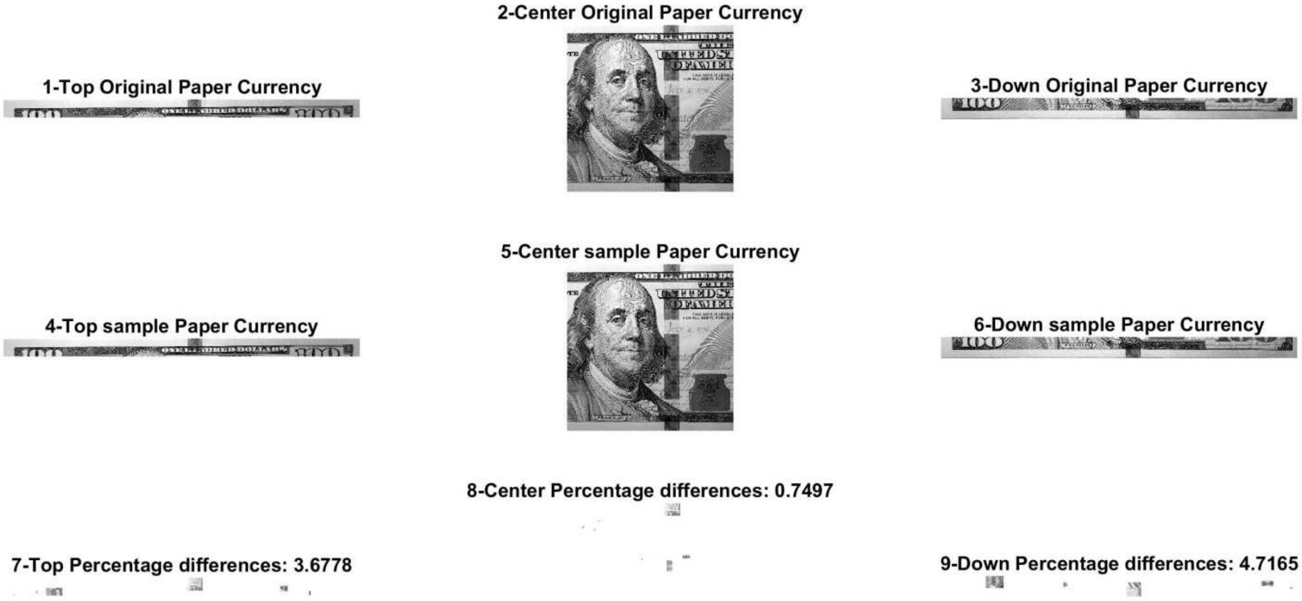

Figure 18. *Compare on $ 100 in a top, center, and bottom position, image 7, 8, and 9 show the difference between the sample and the base in three positions.*

Figure 19. *Compare back of $ 100 in, image 3 shows the difference between the sample and the base.*

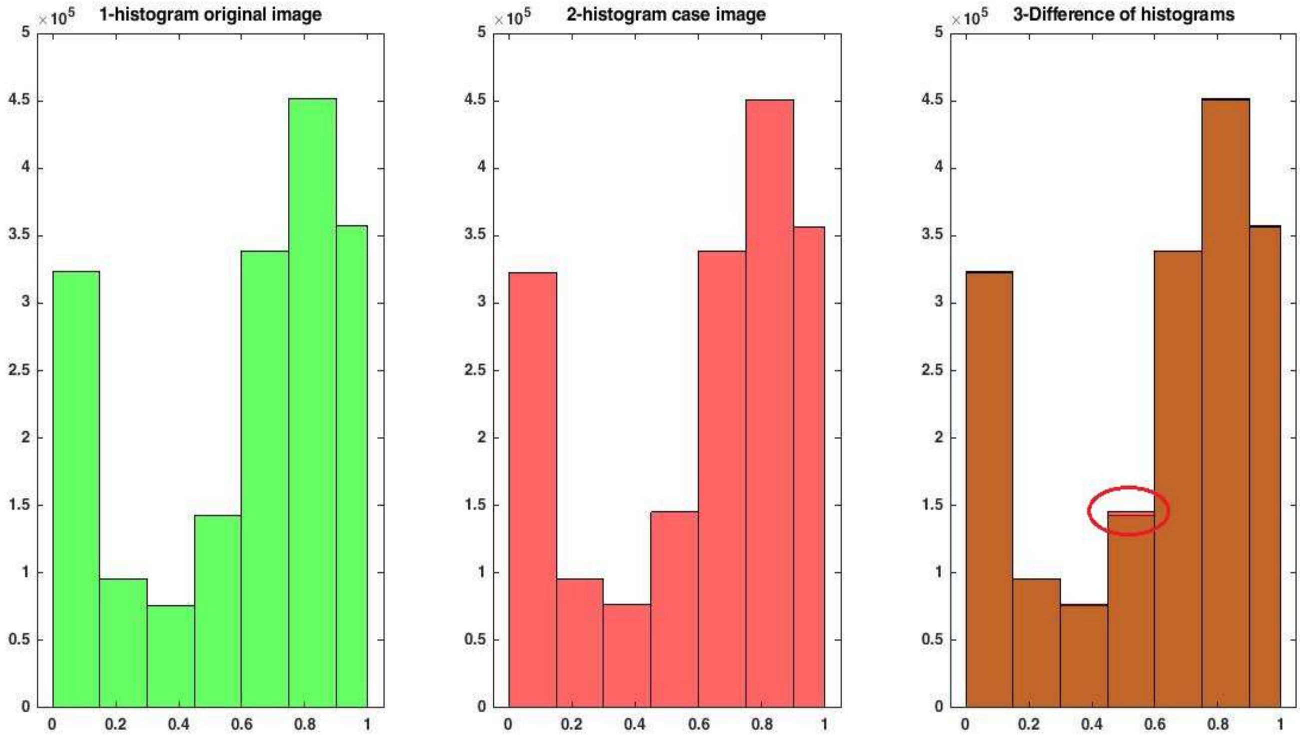

Figure 20. *Histogram comparison sample and base on 100$ and show difference.*

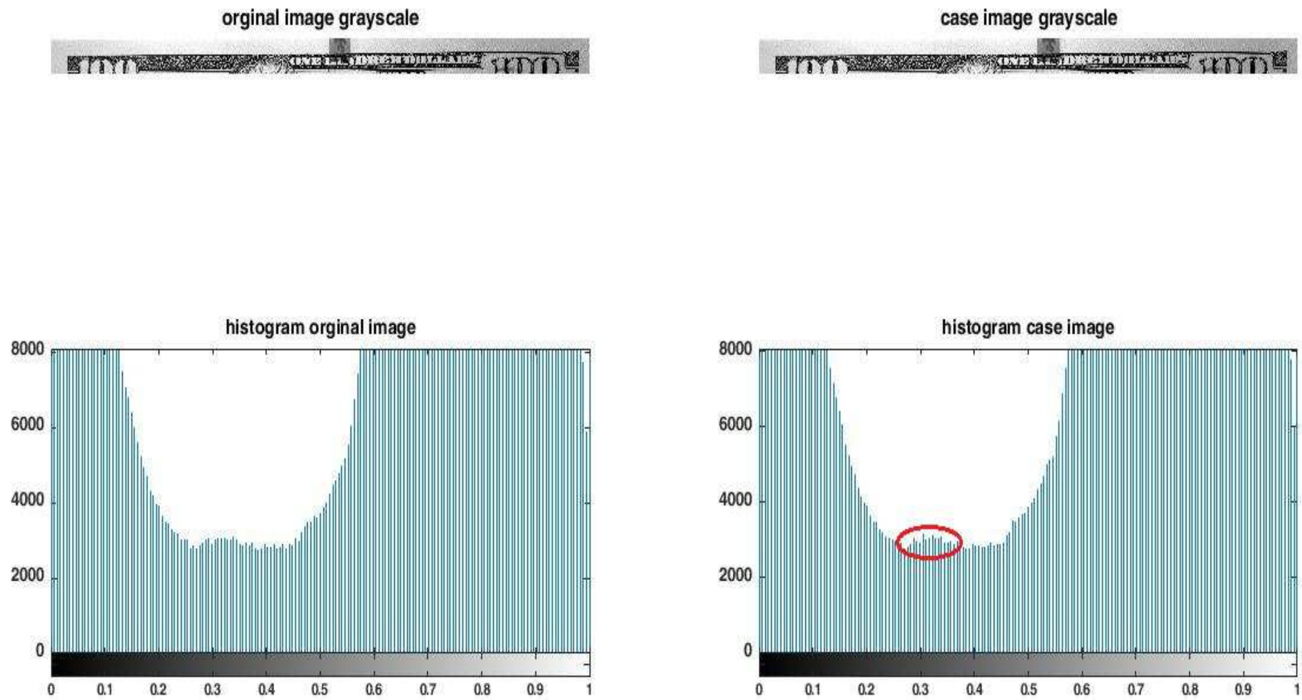

Figure 21. *Histogram comparison sample and base on 100$ and show difference.*

The speed of authentication software was measured at an average of 20 seconds, which depends on the type of processor.

Figure 22. *An example of a banknote counter that is completed by adding a user to measure authenticity.*

4. Discussion

As presented in the proposed model and description, paper banknotes in most countries have serial numbers and variable letters that change their numbers and letters in their similar banknotes. In previous research, this issue has not been paid enough attention, which imposes a big error on the model, so in the proposed model, this issue has been observed with proper imaging and removal of any serial numbers and letters, and as we have shown, the model error to cognition the original paper money from fake is 0.0001, in other words, the accuracy of the model is 99.9999, provided that the items mentioned in the error reduction section are carefully observed. In a similar study in the past Using Hidden Markov Models for paper currency recognition 98% accuracy was measured [17], but accuracy in the proposed model is 99.9999%.

5. Implication

The proposed model can be implemented and used for any paper banknote or paper currency or other credit documents and it is only necessary to prepare their images following the model conditions and introduce them to the library and evaluate them according to the presented model. Also, according to the model, a physical device for paper currency authenticity recognition or other financial documents can be produced, It is enough to prepare and update the library of basic images according to the currency of that country.

6. Conclusion

Using the framework of Industrial Information Integration, fuzzy interface system, machine vision, image processing, and the integration of information and the capability of each of them resulted in an efficient model with high accuracy to achieve the applied goal. In this research, using the mixed method, some features of banknotes have been extracted and compared. It is suggested that in the future study, preparing a database of all the features of the sample banknotes, should research the design of intelligent applications on mobile phones.

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i FIS
ii Fuzzy System
iii Fuzzy Inference System
iv Structural Similarity Index