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Banknote Verification using Image Processing Techniques

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Abstract: Automatic verification of the graphical data plays an increasingly essential role in the global financial system. Verification of banknote is a challenging problem for a human being to check the genuine currencies correctly. In dealings, generating counterfeit banknotes causes loss to the banks, individual, money exchange companies and many more. It has become tough for a human being to verify the currencies easily and appropriately. To avoid counterfeit banknotes, every nation-state comprises numerous kinds of security features such as watermark, flag, micro-printing and many more. Limited banknote verification models have been proposed in the past. Though, the earlier models suffer from a number of limitations which place strong obstacles to the real world banknote data sets. There is a dire need for a reliable technique to detect fake banknote. Based on this evaluation, the new framework is proposed to help the human being to discriminate between genuine and counterfeit banknotes. The proposed technique is based on the statistical features of a banknote such as color, shape, texture. The selective set of features is extracted with the help of Gray Level Co-occurrence Matrix (GLCM) and later on features are optimized using Principal Component Analysis (PCA). After extracting the set of features, three machine learning classifiers is applied to check the performance of banknote namely Decision Tree, Support Vector Machine (SVM) and K-Nearest Neighbor (KNN). The experiment results outperform the accuracy of proposed method.

Keywords: Paper Currency Verification; Banknote Authentication; Fake Banknote Detection; Back Propagation Neural Network; Cross-validation; Gray Level co-occurrence Matrix.

1. Introduction

Centuries ago, people used to purchase goods through the barter trade system. But over the time coin, which was the electrum mixture of gold and silver, was introduced as the method of payment to acquire merchandise. Moreover, coins were taken over by notes with the passage of time. Every country has a different structure of coins and currencies, which varies in size, color, and pattern [1]. Recent years have seen an increasingly significant role in verifying currencies globally. It's circulated all over the world for the transaction of buying and selling merchandise. Paper currency recognition, as well as verification systems, has become important in various fields such as banks, large scale merchandise, and foreign currency exchanges. Definitely, paper currency recognition is unavoidable for the modern banking system in intellectual systems. In this advancing world, it is essentially necessary as well.

It is difficult for common people to differentiate between the genuine and counterfeit banknotes at places where heavy physical transactions are conducted. Many different techniques have been proposed to solve the problem of counterfeiting banknotes. Still, there are some issues which need to be solved [2]. To make counterfeit banknotes people use computational devices. For instance, Scanner is used to capture the image of the genuine banknote, applying some processing and then printing the counterfeit banknote. With the development of fashionable printing techniques, the counterfeit currency has become a major concern to counter which must be able to verify the banknotes from each angle and side. It is, therefore, very essential to have currency recognition systems to bring effectiveness during financial transactions.

There is a dire necessity to plan a structure that will help to discriminate between genuine and counterfeit banknote [3]. Currently, counterfeit banknote had brought considerable losses to the common people lobally. Proper pattern verification algorithm needs to be implemented to verify the banknote correctly. There are machines which help to verify different kinds of currencies. It is very difficult to pick out counterfeit banknotes from a bunch. No one can ever be completely sure about the manual verification [4]. It would be very useful in encountering the counterfeit banknote that is flowing throughout the economy. Therefore, the latest pattern or similar system is required to be implemented on a machine which recognizes the banknote. Moreover, there is an increasing necessity to recognize and verify multiple currencies correctly and efficiently. Our aim is to propose an image processing techniques to verify the currencies in an improved and powerful manner.

Different banknote verification methods have been proposed by various researchers from all around the globe using different currencies [6-20]. Most of them have used the methods which consist of three phases. These are image pre-processing, feature extracted and classification. Due to refined methods working by counterfeiters in preparation of fake banknotes, it is a challenging task to discriminate between genuine and counterfeit banknote manually. To ensure unique nature of each currency, embedded features exists to verify the genuine banknotes. These features include: Watermark, Security thread, Latent Image, Intaglio printing, See through, and Micro printing, color, size, texture and serial number. Unfortunately, few security features are considered such as Serial number and flag portion [6]. Hence, we can't rely on these features on a system in real time environment. For banknote verification, it is necessary to perform detailed analyses of all security features contained in genuine banknotes.

In this study, another method of banknote verification system is being proposed for Pakistani banknotes called as rupees. Our method will be tested on all seven denominations of Pakistani banknote, Rs. 10, Rs. 20, Rs. 50, Rs. 100, Rs. 500, Rs. 1000, and Rs. 5000. After creating data sets, security features will be taken for further processing. Back Propagation Neural Network (BPN), Support Vector Machine (SVM), and K-NN will be used as a classifier to discriminate between fake and genuine banknote.

2. Related Work

In this section, we will provide discussion of the previous work published in the well known journals during the last five years. This study presents related work for recognizing banknotes in the three main groups; these are verification, recognition and fitness of banknotes. Many researchers presented different paper currency classification methods in the past. A review of these is categorized and given in the following sections:

2.1. Banknote verification:

Banknote verification in general concerns about the technique to distinguish the genuine and counterfeit banknotes [5]. Banknote contains security features such as a watermark, portrait, identification mark and many more. The following literature therefore explores the various aspects and approaches of banknote verification.

Rehman et al. [6] describe that progress in image equipment for printing and scanning counterfeit banknote made the manufacture easy but tough to identify. The distinct system has been made for the monetary organization to combat this issue. This study shed light on verifying Pakistani banknote focusing android based smartphone. The research work was based on the surface roughness and statistical features of the banknote. The objective of this study was to make systems feasible for individuals while dealing with a banknote in daily life. This research focuses on Android Based Smartphone using Support Vector Machine (SVM) to verify rupees. Crucial regions of banknotes i.e. flag and serial number has been considered the security feature which gave maximum verification results between counterfeit and genuine banknote. A data set of 263 Pakistani banknotes was prepared to denote each selected denomination including 50 images of counterfeit banknotes. During the circulation of the banknote, noise takes place which later on effects the performance of the overall system. To increase the accuracy of the proposed model, it is important to reduce the noise from the banknote images. To remove noise from the banknote, the Medium filter was applied to the RGB images during the pre-processing step. The smaller denomination was no longer examined due to a low rate of counterfeiting banknote. The research was tested on large denominations such as Rs. 500, Rs. 1000, and Rs. 5000. The (SEM) Scanning Electron Microscopy (XRD) and X-ray Diffraction techniques were used to extract the security features of banknotes. The XRD method attains data about the chemical composition of resources at the microscope level. While the SEM method absorb high energy electron beam on the surface object. After extracting distinctive features, Support Vector Machine (SVM) was used as a classifier to calculate the accuracy. 213 banknotes were used while 50 banknotes were used for testing purpose. The accuracy achieved by the proposed technique appeared to be 92 %. Authors planned to apply same technique in future research to other currencies like pound, yuan, dollar, and yen.

Counterfeit banknotes are not easily detectable by human being using visible light. Especially, blind people face even more problems in verifying the banknotes correctly. The objective of this research was to detect counterfeit banknote as well as recognize the value of Euro banknote. To overcome this problem, Bruna et al [7] proposed a solution based on hardware and software components to detect counterfeit banknotes of Euro currency. Initially, banknote images were captured by infrared (IR) camera. An image of white sheet paper was captured in lightening condition, to calculate the brightness map. However, the captured frame was very noisy, so multiple frames have been captured. The Gaussian filter was applied to remove the noise from the image. Brightness map was then used with input image to normalize the data. A data set containing 2,750 images of Euro banknotes including both counterfeit and genuine images. The author conducted the experiment on all denomination of Euro banknotes such as 5 Euro, 10 Euro, 20 Euro, 50 Euro, 100 Euro, 200 Euro, and 500 Euro. To extract the security features from the banknote, Scale Invariant Feature Transform (SIFT) algorithm was applied on the denomination. 1,000 images were used for training whilst 1,750 images were used for testing purpose. The percentage of training data should be more than that of testing data. Support Vector Machine (SVM) classifier was applied to calculate the accuracy of Euro banknote images. The proposed model showed 100 % accuracy on the counterfeit banknote and 95.7 % on genuine banknotes. The experiment will be tested on other currencies and also audio command will be added in a system to make blind people comfort.

The sensors were used to distinguish between the counterfeit and genuine banknote which are expensive to use. It was not possible for everyone to purchase the expensive equipment. The main objective of the author was to design an algorithm to reduce the rate of counterfeit banknote using image processing techniques. The recognition algorithm was proposed to detect the counterfeit banknotes using Multispectral images by Baek et al [8]. Both the front and back side of banknote images were scanned using sensors. However, the author only considered the front side of the banknote images in the experiment. The transformation was applied to the images to correct the rotation of banknote using the de-skewing technique. To separate the banknote from the background, Region of Interest (ROI) method was applied. Images containing (color) RGB and Infrared (IR) channels were used as security features. Furthermore, neural network (NN) classifier was applied on features to differentiate between counterfeit and genuine banknote. 90 % of data was used for training and 10 % of data was used for testing purpose. The proposed model shows 100 % accuracy to detect counterfeit banknote of INR, USD and EUR currencies while 99.32 %, 99.5 % and 100% accuracy for genuine banknotes. The author will compare the proposed model with other classifiers to check the performance of the overall system.

To verify the banknotes manually, it is a quite difficult task for a common people as well as for professional. It takes a lot of time to verify the banknote correctly. Fentahun et al. [9] proposed a software and hardware based solution to verify the Ethiopian currency. The proposed model has the ability to recognize the banknote and to differentiate between the genuine and counterfeit banknote. Initially, the images were captured using scanner and camera devices. Considering, all the denomination of Ethiopian currency such as 1 Birr, 5 Birr, 10 Birr, 50 Birr, and 100 Birr. Then, four-level classifiers were used to classify the banknotes based on local features. The Ethiopian paper currency recognition system consists of four major components: image acquisition, feature extraction, currency recognition, and currency verification. In first step, image of banknotes was captured using scanner and camera devices. Then, to remove the noise from banknote, the Gaussian filter was applied at the stage of pre-processing. In the next step, images were resized to an equal size to make the computation easy. Still, the images were not clearly visible for the system to recognize the banknote easily. So, the contrasts of images were enhanced with the help of histogram equalization. Based on the color as a security feature, the currencies were only recognized. To extract the security features of the banknote, (SURF) Speed up Robust Feature (SURF) technique was applied. To verify the banknote, the wide golden strip was selected as a security feature from all denomination except 1 Birr. The Region of interest (ROI) technique helped to extract the features from banknote images. Before classification, extracted images were converted into black and white images. Then, Correlation Coefficient (CC) classifier was applied to compute the results. The experiments showed 90.42 % average accuracy of the proposed model. In this study, scanner and camera are used as hardware component to acquire the images of Ethiopian currency whilst feature extraction, recognition, and verification were used as software components. In future research, the author planned to improve the model further, to increase the performance of the proposed model to verify the banknote correctly.

According to the researchers, developing the banknotes systems are not enough to recognize the currencies. There is a need to completely reject the unknown banknotes. The main objective was to detect and reject the counterfeit banknotes. The authors in [10] proposed a method to recognize the Indian Banknote correctly, considering three denomination such as 100, 1000, 5000 Indian rupees. The structure of the proposed model is divided into three phases; namely pre-processing, feature extraction and recognition. To reduce the size of data, pre-processing phase is carried out. Then, security features were extracted based on Hue Saturation Value (HSV) which is Optical Variable Ink (OVI), Latent Image, Security Thread, Micro lettering, and Watermark. Finally, banknotes were recognized using neural network (NN). The proposed model achieved 100 % accuracy to reject the unknown banknotes. In future research, the author planned to work on other security features to reject the counterfeit banknotes.

Pratik Wade et al. [11] proposed a fake currency detection technique for Indian currency. In this study, serial number, security thread, latent image, watermark, and identification mark were used as features of the banknote. These images were extracted by digital camera and segmentation was applied to extract the features from banknote. The proposed model achieved 70% accuracy in verification of banknote.

A fake currency detection method was proposed by Engdaw Ayalew et al. [12] for Ethiopian banknote using Support Vector Machine (SVM). The system can obtain an image from a digital camera and scanner. Then, noise removal and image adjustment was applied on images to improve the quality of banknote. In this study, identification mark, watermark, thin and wide strip line were used as features of the banknote. These features were extracted with local binary pattern (LBP) and SVM was applied as classifier which gives 93% accuracy to detect fake banknote.

Preetam Ozarde et al. [13] proposed a technique for counterfeit Indian banknotes using Support Vector Machine (SVM). In this technique they have taken security thread and latent image as a feature of banknote using segmentation. To classify the accuracy of proposed model, 90% accuracy achieved using Support Vector Machine (SVM).

An identification of fake banknote procedure was proposed by Deepak et al. [14] using Neural Network (NN). Initially, images were captured and converted into gray scale images. With the help of adaptive filter, noise present on banknote was removed. Then, texture features were extracted from image using gray scale co-occurrence matrix (GLCM). Based on neural network, 98.8% accuracy accomplished better results to verify the banknote.

Bhavani et al. [15] proposed a technique to detect counterfeit banknotes using image pattern classification. Initially, the banknote was segmented into distinct number of partitions. Then, texture features were extracted from each partition of banknote using GLCM. SVM was applied as a classifier to distinguish between genuine and fake banknote achieving 87.85% accuracy.

An efficient method to detect counterfeit banknote was proposed by Chi-Yuan Yeh et al. [16] using Support Vector Machine (SVM). In this study, watermark and color was taken as feature of banknote. Later, these features were taken as the input of the system. To discriminate between genuine and counterfeit banknote, SVM was used as a classifier which showed 80.6 %accuracy.

A new feature extraction based system for detecting the fake Egyptian paper currency was proposed by W.K. ElSaid [17]. The images were acquired by a scanner and digital camera and then resized to lower the computation cost. Texture and shape were taken as a feature from banknote using Gray scale co-occurrence matrix (GLCM). The proposed model showed 90 % accuracy to verify the banknote correctly.

Aman Shakya et al. [18] proposed an empirical approach for automated digital currency identification based on image processing techniques. The digitized images of genuine and fake currency banknotes of Nepalese rupees of denomination were collected. Then, correlation coefficient classifier was used to classify the banknote based on color and texture features.

Jaya Tripathi et al. [19] proposed an automatic detection of fake paper currency using image processing techniques. Initially, images were captured by digital camera and then converted into gray scale images. In this study, identification mark, security thread, latent image, watermark, number panel, micro lettering, intaglio printing and fluorescence features were extracted to verify the currency. Based on correlation coefficient as a classifier, 95% accuracy achieved to classify the banknote.

Counterfeit detection on Philippine banknotes was proposed by Ballado et al. [20] using canny edge detector. One side of the banknote was captured by camera and then three features were extracted through canny edge detection technique. The proposed model showed 95% accuracy to verify the banknote.

2.2. Banknote recognition:

Banknote recognition in general concerns about the classification of banknotes by their denomination [5] such as the value of banknote of a particular nation. The following literature review is based on exploring the various aspects and approaches of banknote recognition.

According to the other, there was no intelligent system available to recognize the Pakistani banknote. To carry out successful financial transactions, an intelligent system for the classification of Pakistani paper currency was proposed by Sargano et al. [21]. It is comprised of five stages, which are banknote collecting, scanning, pre-processing, feature extraction and classification using the Back Propagation Neural network (BPN). Initially, images were scanned and the data set of 350 Pakistani banknotes was created containing all the seven denominations such as Rs. 10, Rs. 20, Rs. 50, Rs. 100, Rs. 500, Rs. 1000, and Rs. 5000. As lots of noise carried out during circulation, pre-processing step was performed to dispose of artifacts from worn, torn banknote images. The author reduced the effect of noise from banknote images with the help of a Wiener filter. It is Adaptive Low Pass Filter which is used to filter out gray scale images. Also, reserves the fine details of edges and reduces the error of overall images. Thirdly, the banknote ratio, effective color, See-through, Lettering block, and identification marks were extracted from the banknote images as a security feature. The researcher didn't mention or explained the technique applied in the feature extraction step. Feed-forward Back Propagation Neural network (BPN) classifier was used to distinguish among the counterfeit and genuine banknotes. A data set was divided into three sections; namely training, validation, and testing. 70% of the data was used as a testing and the remaining 15% was used for validating and testing purpose. The experiment was tested on 175 Pakistani banknotes images which showed 100% recognition result. The accuracy of the overall system was calculated by taking the ratio of a number of correctly accepted banknotes with the total calculated number of banknotes images. The proposed model was not compared with any another model. In future research, the author will explain the techniques used to extract the security features.

To overcome the risk of misclassified banknote, pattern recognition based approach was proposed by Altaf et al. [22] for Pakistani paper currency. An automatic recognition of banknote systems has increased the popularity in recent years because of its applications, such as monitory systems, banks, and money exchanges. The objective of this research was to identify the banknotes automatically using pattern recognizing technique. A data set of 1,750 Pakistani banknotes was prepared comprising of worn, torn, light varied and dirty banknotes. It includes all the seven denominations of banknote captured from both the front and back sides of the image which comprised of Rs. 10, Rs. 20, Rs. 50, Rs. 100, Rs. 500, Rs. 1000 and Rs. 5000. Both geometric and textual security features were extracted from the banknote images, including Region of interest (ROI) on worn, torn, light varied and dirty notes. The normalization and de-noising techniques were applied on banknotes images to make noise free at the time of pre-processing. To resize the image, Bicubic interpolation method was used and the median filter was applied to remove the blurring effect from the banknotes. The texture features were extracted with the help of the Region of Interest (ROI) due to low computational cost. Later, extracted images were converted to gray scale images. The experiment was performed only on five security features; these are watermark, security thread, latent image, optical variable ink, and micro printing. Classifiers are either supervised or unsupervised learning algorithm but here all the classifiers were considered as supervised. Four recognition models such as PART, LogitBoost, K*, and Random Forest were used to classify the performance parameter such as accuracy of the overall system. Among all these classifiers, K* classifier achieved 100 % result. K* is sometimes called the memory based classifier due to the usage of similar function to validate the supposition. In future research, the algorithm will be tested on other currencies to reduce the computational cost of the system.

To improve the accuracy of the banknotes sorting machine, an algorithm was proposed to detect the cracks and scratches present on the banknote images by Gai [3]. It plays an essential part in financial organizations. To extract the security feature from image was an important phase within every banknote sorting machine to recognize the banknote properly. The objective of this research was to improve the performance of the machine for the people to recognize the banknotes efficiently and correctly. Firstly, both quaternion wavelets transform (QWT) and least square method was used for banknote image registration. Secondly, the features were extracted using edge difference between the test and reference images by Kirch operator. The banknotes were divided into numerous constant length square areas which are determined by calculating the defect rate. The experiment was conducted on Yuan, Euro, and Dollar with size 400 * 216. All containing 10,000 samples wherein China having five values ¥ 5, ¥ 10, ¥ 20, ¥ 50, and ¥ 100; dollar having six values $ 1, $ 2, $ 10, $ 20, $ 50, and $ 100; euro having six values 10 euro, 20 euro, 50 euro, 100 euro, 200 euro, and 500 euro. The system was robust with low quality images. The value of recognition rate has been increased up to 99.15 %, 98.53 % and 98.15 % for RMB, USD, and EUR currencies. To prove the efficiency of the proposed system, the researcher compared the model with the other four algorithms which gave better result as compared to others. Also, the system meets the real time requirement of the banknote sorting machine. In future research, the author should enhance the algorithm to verify the genuine among counterfeit banknotes.

Recognition of multiple banknotes has been the main issue due to limited calculating power of Automatic Teller Machine (ATM). Youn et al. [23] proposed a fast and efficient algorithm to recognize the banknote images using multi-template correlation matching and size. Size map was generated to group the banknotes using size information. Multiple templates have been selected from each banknote and later classification algorithm was used to recognize the images. Concurrently, both front and back side of images were scanned to identify the banknotes. The experiment is conducted using 84,400 banknotes images captured by Contact Image Sensor (CIS). The Pixel wise adaptive Wiener filter method was applied to handle the artifacts at the pre-processing level, such as noise elimination. Each banknote was resized to the same height and width using the nearest neighbor interpolation technique due to its low complexity. After resizing, the size of banknotes was 150 * 70 pixels. The author tested the result of image resizing with bi-linear and cubic interpolation technique. The results were the same as compared to the nearest neighbor interpolation technique. Furthermore, Median Filter was applied to remove the stains from banknote images such as hand writing. The experiment was tested on 55 banknotes of 30 distinct values from five nations; these are RUB CNY, EUR, USD, and KRW currencies. The experiment results showed 100% recognition accuracy for the clean banknotes and 99.8% accuracy for the unclean banknotes using Correlation Coefficient (CC) classifier. The banknote reaches 4.83 ms time to execute the whole process. The experiment results were compared with the other two methods to check the performance of the overall system. In future research, the author should enhance the algorithm to discriminate between genuine and counterfeit banknote.

The crimes of counterfeit banknotes were gradually increasing day by day. There should be a mechanism to deal with counterfeit banknotes to save the money of a people. To combat this issue, Feng et al [24] conducted the experiments on RMB currency. The author compared the results of different techniques used for feature extraction, classification and rejection pattern. The serial number was used as a security feature printed at a lower corner of paper currency. It comprises of 10 machine printed alphanumeric characters. Two versions of RMB (1999 and 2005) were collected with the denomination of 100 Yuan. It included 35 classes, 17,262 training samples, and 7,000 test samples as it mixes the two distinctive variations of RMB serial numbers. The author applied and compared the results of feature extraction technique such as Gradient direction, Gabor feature and Convolution Neural Network (CNN). The best results are achieved using Gabor feature, used in the feature extraction method. Likewise, the results of classifiers such as (SVM) Support Vector Machine, Linear Discriminant Function (LDF), and Modified Quadratic Discriminant function (MQDF), and CNN was also compared. The MQDF performed well on (RMB) Renminbi data sets. Further, two rejection classifiers were also applied on banknotes to reject the misclassified banknote such as cascade and LDA. The cascade classifier gave good results to reject the misclassified banknote. The experiment was conducted using Chinese currency RMB (Renminbi banknote). The test results confirmed that the MQDF reaches the accuracy of 99.59 % using Gabor feature. In the future, the author intends to increase the recognition by applying new classification technique to compute the results.

The mechatronic system faces two main challenges, which are speed and cost, to recognize the banknotes. Both these elements are important for profitable purpose. The main objective was to lower the cost of hardware and increase the performance of the overall system. To avoid extra processing time on recognizing currencies and angle correction, a mechanical solution was proposed by Behjat et al. [25]. Microcontroller based hardware ATmega32 with clock frequency of 16MHz for implementation was designed. Images were taken from different print versions of distinct years because different versions vary in color. A data set of Persian banknote images comprised of 3,200 ordinary images for training purpose and another 800 images for testing purpose is used. The images were converted from RGB image to gray scale images. Furthermore, to enhance the contrast of banknotes, histogram equalization technique was applied on images. The color, size and texture features were extracted from the gray scale images of Persian banknote. The banknotes were recognized at about 480 ms for single - sided and 560 ms for double – sided detection. Multi-Layer Perceptron (MLP) neural network was used to recognize the banknotes to reduce the processing time. 15 neurons were used in the hidden layer using the sigmoid function. The 99.06 % accuracy recognized for each side which may be expanded using double-sided mode. The little damage to a banknote fails the overall system. In future research, the author will apply this technique to other currencies.

To improve the performance of banknotes recognition, Gai et al. [26] proposed an approach using quaternion wavelet transform framework (QWT). The structure of the proposed model includes four stages: banknote image pre-processing, transformation, feature extraction, and classification. The transformation was applied on banknote using Quaternion Wavelet Transform (QWT) during image acquisition. The Generalized Gaussian density (GGD) was used to extract the features. For classification, Back Propagation Neural Network (BPN) was used as a classifier to recognized banknote. A data set of three currencies was made using the dollar, the Renminbi, and the euro, each includes 15,000 samples. The brightness and slant correction was applied at a stage of pre-processing. To enhance the brightness of banknote, the histogram equalization technique was used. The author didn’t apply any technique to remove the noise from the banknote. The Generalized Gaussian density (GCD) was used to capture statistical characteristics of banknote using contact image sensor (CIS) with the 200 dpi. The experiment performed well on the average classification of 99.90 %, 99.65 %, and 99.50 % for USD, RMB, and EURO currencies. The performance of the proposed method was compared with other currencies which gave better results. In future research, the main focus will be on the quality of banknote.

Previously, there was a limited focus to recognize on a number of denomination and national currencies. To resolve these problems, the visible light images were captured by one-dimensional line sensor for multi-national banknote classification. The images were entered to the device; capturing both front and back side of banknote and then pre-processed. The banknotes were separated from a background with the help of segmentation. Images were resized to give the same size of images to Convolution neural network (CNN) to recognize the banknotes. A data set containing six nations’ banknotes were used; these are JPY, EUR, CNY, KRW, USD, and RUB, comprised of 62 currency denominations. The Convolutional neural network (CNN) has been used by Pham et al. [4] considering the size of every denomination. A total 64,668 images were captured in four directions. Later the data was divided into two parts namely training and testing. The performance of proposed model was calculated with the help of two-fold cross validation technique. The 100 % accuracy achieved on a data set of six countries with 62 denominations. However, using CNN applied on all banknotes has been correctly recognized due to the robustness of captured images. The proposed model was evaluated with other models to check the results. In future research, the author intends to investigate and apply CNN classifier in case of the serial number and counterfeit recognition.

A blind person faces the problem of identifying the banknotes correctly. There was a dire need to recognize the currencies correctly during financial transactions. The main objective to develop a convenient system for blind people was to detect and classify banknotes efficiently and accurately. To recognize the value of banknotes, Dunai et al. [27] proposed a system with the help of an electronic instrument. It consists of the Raspberry Pi electronic instrument and camera inserted into a pair of sunglasses that visually impaired and permit blind people. Images were captured in any direction through camera integrated with the LED light fix in glasses. The recognition of banknote was done on a Smartphone which not only display the results plus generate the voice command. The Banknote image detection and classification consist of two parts: training and testing. Training was used to train the data set and testing was used to check the results with the train images. An AdaBoost algorithm was used to detect the banknote. This technique permits for a drastically decreased computational time. To compute the results, Speed up Robust Features (SURF) method was applied on banknote. The 97.5 % accuracy was used to recognize the banknotes. The communication between glasses and phone was established with the help of Bluetooth. In future research, the focus will be on the performance of results by applying different algorithms.

According to the researcher, there was a little research conducted on discriminative areas of the banknote to recognize currencies correctly. To recognize banknotes efficiently, Park et al [28] address the distinct regions based on similarity mapping using one-dimensional visible light line sensor. The overall proposed method consists of three main blocks namely pre-processing, feature extraction and recognition. Images were captured with one-dimensional line sensor. A data set consist of 99,236 samples of USD from both front and back side of banknotes images considering all the denomination of banknotes such as $ 1, $ 2, $ 5, $ 10, $ 20, $ 50, $ 100. The segmentation technique was applied to separate the banknote from the background. Images were resized to 64 * 12 pixels to reduce the processing time. Features were extracted from the similarity map using Principal Component Analysis (PCA). PCA help to reduce the features having the little information. K-means algorithm was implemented to determined banknote type and direction of banknote images. The experiment showed 99.998 % accuracy on USD banknote. Furthermore, the proposed model was applied on other banknote images to check the performance of the overall system. The experiment was verified on Angolan kwanza (AOA), Malawian kwacha (MWK) and South African rand (ZAR) currencies. A data set consists of 1,366 samples of AOA, 2,464 samples of MWK, and 760 samples of ZAR banknote. 100% recognition accuracy classified in AOA and ZAR currencies and 99.675% accuracy in MWK. In future research, the recognition model will be combined with fitness classification of the banknote to reject the unusable banknote.

Frequent occurring of misalignment and distortion captured images degrades banknote recognition performance. To overcome these problems Kwon et al [29] captured images by the one-dimensional line sensor. A data set of 61,240 (USD) was considered including all denomination of banknote images such as $ 1, $ 2, $ 5, $ 10, $ 20, $ 50, $ 100. At the stage of pre-processing, captured images were resized into 32 * 6 pixels to reduce the computational time. Rich informative features were extracted using Principal Component Analysis (PCA) for banknotes images instead of Gabor filter. Gabor filter takes more time in processing as compared with the PCA technique. Both the front and back side images were used to pre-classify the banknote in a hierarchical way using Support Vector Machine (SVM). SVM was used to differentiate between the classes in four directions. Finally, the K-means algorithm was used to recognize the banknotes. K-mean is un-supervised learning algorithm which groups the data based on the smallest distance between the class center and sample data. The experiment was conducted on USD dataset which achieved 99.886 % accuracy. The proposed model showed wrong recognition results when tested on damaged banknotes. In the future research, the experiment will be performed to handle poor quality banknote images.

During circulation of banknotes, images get different types of noise, such as ink stain, hand writing. There was a problem to identify imperfect banknote images. Wang et al [30] studied only ink stain defect identification method based on Convolution Neural Network (CNN). To reduce the computational time, images were resized to 48 * 48 pixels. A data set consists of 825 banknote images which later divided into training and testing data sets. 625 images were used for training and 200 images were used to test the proposed model. Convolution Neural Network (CNN) was used as a classifier to recognize the banknote using the Sigmoid function as an activator. The proposed model showed 95.6 % recognition accuracy on 300 iterations. The experiment was compared with the Support Vector Machine (SVM) technique results for performance. In future research, the proposed model should be conducted on other defects present on banknote images such as hand writing and muddy.

In this study [31], the authors recognized the denomination of banknote. The structure of the proposed model was divided into three phases namely feature extraction, classification, and authentication. A color feature was taken as a security feature. After extracting the features, Feed Forward Neural Network was applied as a classifier (BPN) to accomplish best accuracy results. The motivation of authors behind this classifier was to reduce the error of the overall system. Once denomination of banknote has been determined, the data set was tested with training data set for banknote authentication. The proposed model achieved 98 % accuracy on dollar currency. In future research, the author should consider other security feature to authenticate the banknote correctly.

Sarfraz et al. [32] proposed an approach to achieve the accuracy of banknote recognition with the lowest cost. The system was design based on the correlation between images based on the size. Images were acquired by the scanner, containing 110 images of Saudi Arabian Currency. The experiment was conducted on all denominations of banknote such as 5 riyal, 10 riyal, 50 riyal, 100 riyal and 500 riyal. Initially, the pre-processing step was measured to reduce the computational speed. Banknote images were converted from RGB images to gray scale image and later to black and white images. With the help of Prewitt technique, the edges of images were detected. Further, Canny's algorithm was applied to extract the feature of binarization image from the background. Radial Basis Neural Network (RBF) was used for classification to recognize the Saudi Arabian paper currency. The data set was divided into two phase namely training and testing data sets. The experiment showed 91.51 % accuracy with 25 neurons used in the hidden layer. According to the authors, the proposed model was fully automatic which don't require human involvement. In future research, different classifiers will be applied to increase the performance of the overall system.

During acquisition, images comprises of some defects such as noise which increased the need for a robust system to lessen these flaws. [33] presented an approach for recognition of Nigerian Naira, US, Canadian and European currency using Multi-Class SVM. The work was distributed on three stages namely image pre-processing, feature extraction, and classification. Initially, images were captured via digital camera and perform binarization to fill holes using imfill function. Later on, binary images were converted into gray-scale for further processing. Furthermore, the denomination feature was extracted using the gradient of the histogram (GOH) and then normalization (min-max) was performed on the histogram to smooth the images. Principal Component Analysis (PCA) was computed on normalization values to reduce the size of the vector. Finally, the Multi-class classifier was applied and achieved Canadian 96 %, USD 97 %, EURO 98 %, Naira 99 % accuracy which comprises of 1000, 1000, 1400, 1800 samples. In future research, the author will consider the model which will verify the genuine banknote among counterfeit banknote.

An intelligent system for Myanmar banknote was designed of classifying pattern to read its denomination using K-NN classifier. The authors in [34] focus on textual features which comprised of mainly four chunks. First, RGB images were converted into gray scale image to reduce the computation time. Edges were detected using canny edge detection method to rotate the images. In addition, pre-processing was applied to remove the noise from banknote using a median filter. To reduce more computational time, banknote images were resized to an equal size. The Gray Level Co-occurrence Matrix (GLCM) technique was applied to extract the statistical features based on gray level intensities. Finally, K-NN classifier was used to recognize the note accurately with K=1. The data set was scanned from the Central Bank of Myanmar including 500 images considering five different denominations. GLCM achieved 99.2 % maximum performance with K-NN classifier. In future research, the author should consider another security features to recognize the banknotes.

Through the establishment of the banknotes number sequence file, the circulation of the banknotes in the financial market was monitored and tracked, and crimes like currency counterfeiting, robbery, stealing need to be controlled. Therefore, it is of great importance and application prospect to do research on the identification of RMB word numbers [35]. The automatic RMB number identification system consists of following modules: image pre-processing, number region location and tilt correction, character segmentation and normalization, feature extraction and character recognition modules. To remove the noise from an image median filter was used. Segmentation was used to get every single character of the numbers. After that, Sobel operator is applied to get the gradient feature of every character and K-NN was used as a classifier. The experimental result shows 95.2 % accuracy for recognition of the banknotes. In future research, the author will apply or test the proposed model on other currencies such as pound, dollar.

To improve the performance of the system, Iyad [36] proposed an algorithm to recognition the Jordanian banknote in different perspective views and scales. For example, banknote may not be in a perfect position due to the deviation of distance from the camera. There will be lightening problems while capturing images. Banknote recognition in a movable situation was a complex problem because of abandoned conditions which affect the image quality. To ensure that the system has effective recognition a pre-processing step was applied. In order to reduce the computational time and to increase the memory efficiency, both the front and back side of images were resized. The author didn't remove any artifacts from banknote to produce the better results. Then, the banknotes were separated from its background in order to detect the edge of an image. Color feature was selected to recognize the banknote. Before extracting images, images were converted into bit map format. Bitmaps are defined as a regular rectangular cells called pixels, each pixel has a color value. The features were extracted by Scanning Invariant Feature Transform (SIFT). The proposed model showed 72 % accuracy to recognize the banknote. In future research, the author will remove the artifacts to increase the performance of the overall system.

To reduce the financial crime and improving financial market stability and social security was the main objective of the author. Suen et al [37] proposed character recognition method based on RMB (Renminbi) currency. The author didn't remove any artifacts at the stage of pre-processing. Security features are important when recognizing the banknotes. The author considered serial number to extract to identify the banknote using the Difference-of-Gaussians (DoG) detector technique. To calculate the performance of the proposed model, Support Vector Machine (SVM) was used as a classifier to provide a confidence vector for each part. The experiments conducted on a RMB serial number which showed 98 % accuracy. In future research, the recognition method will also be tested on other types of banknotes, such as Euro, U.S. and Canadian dollars. In addition, the author will consider other security features to recognize the banknotes.

Krishna et al [38] proposed another method to recognize four different currencies namely United Kingdom (Pound), Japan (Yen), Europe (Euro) and India (Rupee). The model has been divided into four components such as image acquisition, pre-processing, feature extraction and recognition. Initially, high resolution scanner has been used to acquire the banknote images. To remove the noise from images, banknotes were first converted into gray scale image and then median filter was applied. Median filter remove artifacts from banknote images and also preserve the fine details of edges. The banknotes were recognized based on the security features. The proposed model considered color, shape and texture features to identify the banknotes. Canny's technique was used to detect the gray scale images which work best on fine details. To extract the texture features, (GLCM) Gray level co-occurrence Matrix was applied. Finally, four different currencies were recognized using (BPN) Back Propagation Neural Network. 100 samples of different currencies were used to train the model. The result of the experiment shows 93.8 % accuracy to recognize specifically four different banknotes. Future work is to test proposed framework with other technique to increase the accuracy.

Rashmi et al. [39] proposed an algorithm for an existing automated teller machine (ATM) which applies recognition on Indian Rupee (INR). The main objective was to recognize the currency denomination and store it on the database for future reference. The banknote can be given back to people in case of counterfeit. Banknote of Indian paper currency was captured with the help of scanner or digital camera. Initially, to reduce the computational cost, RGB images were converted into gray scale images. The security feature of banknote such as INR serial number was extracted based on Region of Interest (ROI). To recognize the banknote, images were converted from gray scale to binary images. The serial numbers were loaded into database for later template matching. While matching the extracted serial number with the template, the results were displayed and generate the receipt. The proposed algorithm was tested on 1000 (INR) rupee banknotes which provides an accuracy of 86% on serial number and takes time 0.568079 seconds to execute the process. The new algorithm was user friendly for people to recognize the banknotes efficiently and user friendly, especially for the customers at the time of withdrawing money from ATM machines. In future research, the author will increase the accuracy of proposed model and recognize other denominations of banknote.

Only External features such as width, length, and thickness are not enough to recognize the banknotes. According to the authors in [40], internal properties also play an essential role to identify the banknotes. Because of various countries may have same size of banknotes which lead to wrong detection. In this study, Principal Component Analysis (PCA) was used to extract the security features such as denomination, Intaglio printing, Micro printing, and Latent image. The structure of proposed model comprises of two parts namely feature extraction and recognition. Initially, the author captured 200 currencies from scanner considering four denominations such as Rs. 50, Rs. 100, Rs. 500, and Rs. 1,000 of Indian currency. With the help of Region of Interest (ROI), features of banknote were extracted. Later on, to reduce dimensions of extracted features, PCA was applied on specific features separately. The data set was divided into two main phase namely training and testing. Among 200 currencies, 120 banknotes were taken as training and 80 banknotes were taken to test the model. SVM was used as a classifier to calculate the performance of the proposed system. The experiment shows 100 % accuracy to recognize the Indian banknote. In future research, the author will apply different algorithms on the data set such as decision tree (J-48), Neural Network (NN), and LDA (Linear Differential Analysis).

Akinola et al. [41] proposed an algorithm to recognize the Nigerian banknotes based on Decision Tree and Naïve Bayes classifiers. A data set consisting of 400 samples, considering all denomination of Nigerian banknote such as 5 naira, 10 naira, 20 naira, 50 naira, 100 naira, 200 naira, 500 naira, and 1000 naira, is used. All the denominations were scanned from both the front and back side of banknotes. The authors considered both internal and external properties of banknote such as size, color and texture. To reduce the computation time of proposed model, banknotes were converted into gray scale images. The Wiener filter was applied on gray scale image to remove noise from banknote images. To extract the edges, Sobel operator technique was applied on the banknote images. On the other hand, Mean and standard deviation method were used to extract the color and texture features from banknote. To calculate the performance of the overall system classification was applied on data set. The experiment showed 98 % accuracy by decision tree and 69 % accuracy by naïve based classifiers. In future research, the author will increase accuracy of the proposed model by applying different algorithms.

2.3. Fitness classification

Banknote fitness in general concerns about the physical condition of banknote for instance stain [5]. It arises because of note in circulation or due to some other reasons. Unfit note should also be recognized to check the quality of note is usable or not. The following literature review is based on exploring the various aspects and approaches for fitness classification.

Different researchers used the fitness of image to correctly identify the banknote. Jeong et al [42] address the problem to evaluate the quality of banknotes. The objective of this research was to make people convenient to classify the note correctly. Using visible light reflection (VR) and near infrared light transmission (NIRT) banknote images were recognized based on the fuzzy system. The proposed method designed to classify the fitness level based on input direction and denomination of banknote images. The KRW, INR, and USD currencies were considered to check the banknote fitness. The input banknote images were captured by visible light and infrared light. Considering, four directions of banknote images. The size of VR and NIRT were 1584 * 350 pixels and 1584 * 175 pixels respectively. The images were separated from the background with the help of the Region of Interest (ROI). The values of images were not normalized and the pixels values were not in range. To make the values normalized, the min-max function was applied. But normalization doesn't effect on the quality of banknote. The fuzzy system was applied to calculate the accuracies of banknote images. A data set consists of United State (USD) having 3,856 notes, 3,956 banknotes of Korean Currency (KRW) and 2,300 banknotes of Indian Currency (INR). The accuracies of banknote were KRW 97.612%, INR 99.637 with three fitness levels, and USD 96.985% with two fitness levels respectively. The proposed model was compared with other techniques such as (DWT) Discrete Wavelet Transform and (SVM) Support Vector Machine to evaluate the performance. In future research, the method would be applied to other currencies.

According to the researcher, there was little research on the fitness of banknote using visible light. Yoon et al [43] proposed method for classification of Indian paper currency with a one-dimensional line sensor. First, banknote images were captured with visible light and then ROI was considered for processing with the help of DWT. ROI values are then resized to 256 * 256 pixels to reduce the processing speed. 1-level DWT was used to extract the features such as horizontal and vertical direction to indicate between unfit and fit banknotes. High correlation values were selected for the classification based on linear regression. SVM was used as a classifier to recognize banknote of Indian Rupees. The experiment showed highly accurate classification of fit and unfit banknotes using 10, 20, 50, 100, 500 rupees.

3. Resources and Procedures

In the proposed model, dataset comprises of Pakistani currencies to discriminate genuine notes from counterfeit notes. The model covers basic phases such as Image acquisition, Pre-processing, Feature extraction, Feature optimization and Classification. The details of these phases are defined in following segments. The flowchart of proposed model is shown in Figure 1.

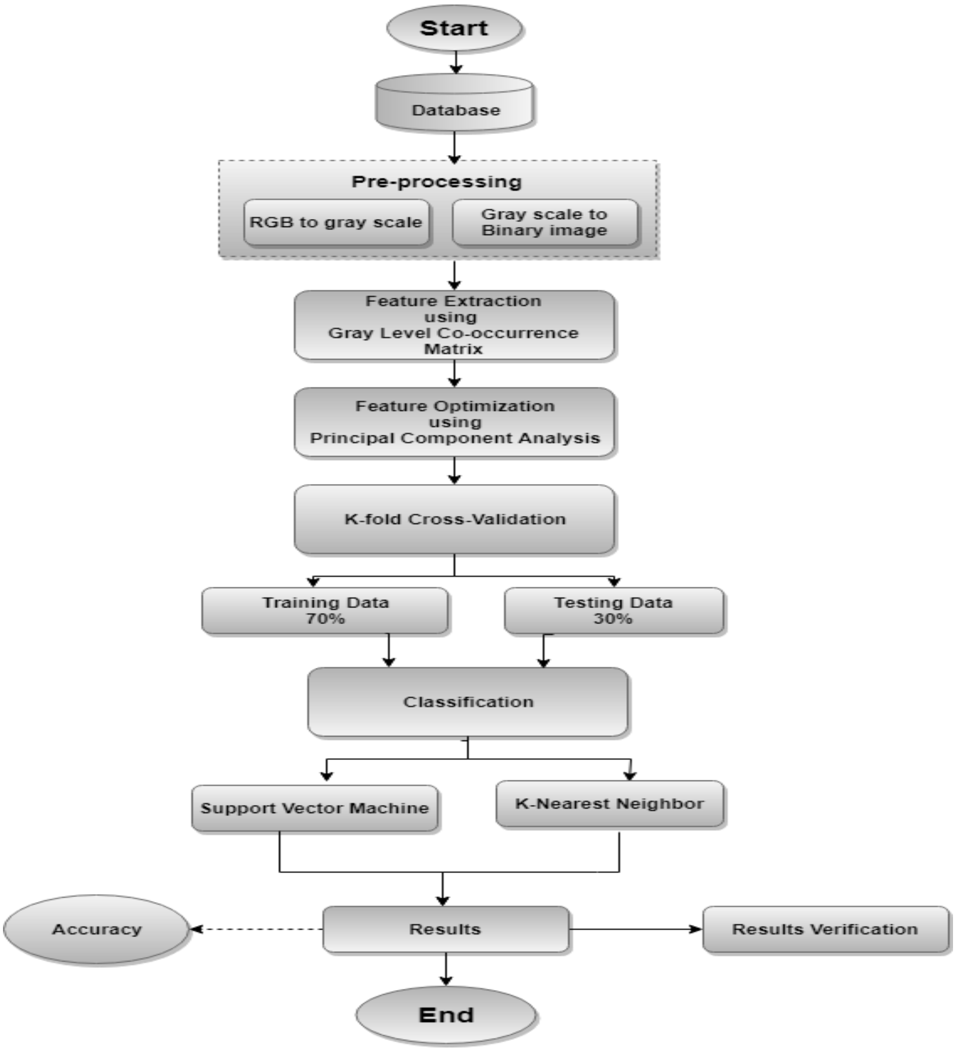

Figure 1. Proposed Model

3.1. Image acquisition

A database of Pakistani currencies including 500, 1000 and 5000 denominations were taken from [6]. These banknotes were first acquired from android phone and then auto cropped for further processing.

3.2. Pre-processing:

To reduce the complexity of algorithm, it's vital to convert RGB image to gray scale image using rgb2gray and then to the binary image via im2bw. The results of image conversion are shown in Figure 2, 3 and 4.

Figure 2. RGB Image

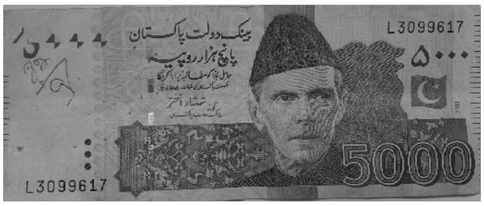

Figure 3. Gray Scale Image

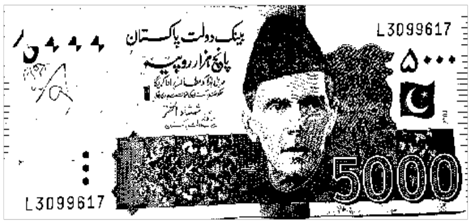

Figure 4. Binary Image

3.3. Feature Extraction

In machine learning, the most important step is to extract the most relevant feature. Researchers in the past extracted various features in image processing problems. Texture based features are used in most of the studies for capturing the spatial distribution of pixels information which is hidden inside the images. In this study, we proposed the texture based GLCM features to detect the fake currency.

3.3.1. Gray Level Co-occurrence Matrix (GLCM)

In this study, we extracted the texture based GLCM features from the Pakistani currency. The GLCM features were proposed in 1973 by [22] by characterizing texture using different quantities obtained from second order statistics of image. From the given image, GLCM features can be obtained in two steps. In the first step, for computing GLCM, the spatial co-occurrences of image pixels pair wise separated by the distance d and in a particular direction angle θ are computed. In this phase, a spatial relationship is created between the 2 pixels; first one is the reference pixel and second is the neighboring pixel. In the second step, GLCM matrix can be formed to compute a set of scalar quantities which is used to characterize various characteristics of the original texture features.

With the help of texture features the validity of banknote is proved based on numerous statistics via graycoprops. A few of them are listed as subsequent:

3.3.1.1. Contrast:

The measure of variance between a pixel and its neighbour over the entire image is known as contrast. The contrast will be equal to zero when it contains a constant image. The equation 1 is used to calculate the contrast:

Contrast: $\sum_{i,j=0}^{N-1} P_{ij}\,(i-j)^2$ **(1)**

3.3.1.2 Correlation

The measure of relationship between a pixel with its neighbor over the entire image is known as correlation. The correlation will be NaN when it contains a constant image. The equation 2 is used to calculate the correlation:

Correlation: $\sum_{i,j=0}^{N-1} P_{ij} \frac{(i-\mu)(j-\mu)}{\sigma^2}$ **(2)**

3.3.1.3. Energy

The measure of sum of squared elements in the gray level co-occurrence matrix is known as energy. The energy will be equal to 1 when it contains a constant image. The equation 3 is used to calculate the energy:

Energy: $\sum_{i,j=0}^{N-1} \left(P_{ij}\right)^2$ **(3)**

3.3.1.4. Entropy

The measure of diversity in the entire image is known as entropy. The equation 4 is used to calculate the entropy:

Entropy: $\sum_{i,j=0}^{N-1} -ln\left(P_{ij}\right)P_{ij}$ **(4)**

3.3.1.5. Cluster Shade

Measuring the skewness is known as cluster shade. The equation 5 is used to calculate the cluster shade:

Cluster Shade: $sgn(A)|A|^{\frac{1}{3}}$ **(5)**

3.3.1.6. Homogeneity

To acquire encoded information from an image is said to be homogeneity. The equation 6 is used to calculate the homogeneity:

Homogeneity: $\sum_{i,j=0}^{N-1} \frac{P_{ij}}{1+(i-j)^2}$ **(6)**

3.3.1.7. Mean

Mean is to calculate the average intensity of all the pixels. The equation 7 is used to calculate the mean:

Mean: $\mu_i = \sum_{i,j=0}^{N-1} i(P_{i,j})\ , \mu_j = \sum_{i,j=0}^{N-1} j(P_{i,j})$ **(7)**

3.3.1.8. Standard Deviation

The standard deviation is to estimate the grey pixels from its mean value. The equation 8 is used to calculate the standard deviation:

Standard Deviation: $\sigma_i = \sqrt{{\sigma_i}^2}\, , \sigma_j = \sqrt{{\sigma_j}^2}$ **(8)**

3.3.1.9. Skewness

To obtain the degree of asymmetry of any pixel around its mean is said to be skewness. The equation 9 is used to calculate the skewness:

$\frac{1}{N\ x\ N} \sum_{i=0}^{N} \sum_{j=0}^{N} \left[\frac{p(i,j)-\mu}{\sigma}\right]^3$ **(9)**

3.3.1.10. Kurtosis:

To estimate the sharpness of curve in frequency distribution is known as kurtosis. The equation 10 is used to calculate the kurtosis:

$Kurtosis: \frac{\sum_{i=1}^{N} \frac{(X_i-\bar{X})}{N}}{s^4}$ **(10)**

3.3.1.11. Root Mean Square

Root mean square is defined as square root of mean square. The equation 11 is used to calculate the root mean square:

$$Root\ Mean\ Square: \frac{\sum_{i=1}^{n} a_i^2}{n} \quad \textbf{(11)}$$

3.3.1.12. Inverse Difference Moment:

Inverse difference is to measure local homogeneity of an image. The equation 12 is used to calculate the inverse difference moment:

$$\text{Inverse Difference Moment:} \frac{\sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} P_{ij}}{1+(i-j)^2} \quad \textbf{(12)}$$

3.4. Feature Optimization

To make the model more effective and efficient, its necessary to optimize the set of features. In the proposed model, principal component analysis technique is applied for feature optimization.

Principal Component Analysis: Principal component analysis is a method which is useful to compress the data. Here, PCA technique is applied to optimize the set of features and getting a new data which is quite smaller than the original one. It keeps the significant information of the data.

It's very tricky task to discriminate between genuine and counterfeit banknote. The above Figure 5 demonstrates genuine banknote on the other hand Figure 6 present counterfeit banknote.

Figure 5. Genuine banknote

Figure 6. Counterfeit banknote

3. 5. Classification

In this study, we extracted Gray level co-occurrence matrix features from genuine and fake Pakistani currency of 500, 1000 and 5000 notes. Later on, PCA is used to optimize the set of features. The performance was evaluated with the help of 06 fold cross validation technique in terms of total accuracy (TA). A dataset was divided into two subsets such as training and testing and recurring the procedure with alternating these two subsets. We employed robust machine learning classifiers such as decision tree, support vector machine (SVM) and K-Nearest Neighbor (KNN) [44-50].

4. Comparison Analysis with other Image Processing Techniques

The confusion matric is most widely used as a performance measuring matric on a given set of testing data. The performance was evaluated in terms of sensitivity, specificity, positive predictive value (PPV), negative predicted value (NPV), false positive rate (FPR), area under curve (AUC) and total accuracy (TA) as reflected in the table 1. We employed robust machine learning classifiers such as decision tree, support vector machine and k-nearest neighbour. The highest detection performance was obtained using KNN with total accuracy (96.44%), followed by SVM with total accuracy (93.85%); Decision Tree with (72.17%) accuracy [51-55]. Table 1 shows the result comparison in tabular form and figure 7 in graph.

Table 1. Results comparison with different image processing techniques

Classifiers	Decision Tree	SVM	KNN
Sensitivity	0.6970	0.9621	0.9773
Specificity	0.8667	0.8000	0.8889
PPV	0.9684	0.9658	0.9810
NPV	0.3277	0.7826	0.8696
FPR	0.1333	0.2000	0.1111
AUC	0.8953	0.8953	0.9733
TA	0.7217	0.9385	0.9644

Figure 7. Results comparison with different image processing techniques

5. Conclusion

In this study, another method is proposed to differentiate between genuine and counterfeit banknotes using image processing techniques. According to the State Bank of Pakistan, there are security features which are important to identify the genuine banknote. These features will be match based on the banknote using GLCM texture techniques which will help them to verify the banknote. After extracting set of security features, PCA is applied to reduce the feature dimension. The robust machine learning classifiers such as Decision Tree, SVM, K-NN is used for recognition of genuine and fake banknote. The data sets includes larger denomination of Pakistani currency, such as Rs. 500, Rs. 1000, and Rs. 5000. The proposed model considered accuracy as a performance parameter to compute the results. In the future, the proposed model can be extend to classifiy currencies of different countries such as Euro (EUR), and USD (Dollor).

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References

1. N. Panah. and. H. Masoumi, "Banknotes detected using Image Processing Techniques," IJCSMC, vol. 6, pp. 34-44, 2017.
2. W.K.ElSaid, "Fake Egyptian Currency Detection System using Texture and Shape Characteristics," International Journal of Computer Applications, vol. 143, 2016.
3. S. Gai, " New banknote defect detection algorithm using quaternion wavelet transform, " Neurocomputing, vol. 196, pp. 133-139, 5th July 2016.
4. [Dong EunLee. T.Pham, and K.Park, "Multi-national Banknote Classification Based on Visible-light line Sensor and Convolutional Neural Network," Sensors, 8th July 2017.
5. Ji. Woo. Lee,. Hyung. Gil Hong. and . Kang Ryoung Park, “A Survey on Banknote Recognition Methods by Various Sensors, " Sensors, 2017.
6. [A. B. Sargano. Ubaid Ur Rahman, and Usama Ijaz Bajwa, " Android-Based Verification System for Banknotes, " Journal of Imaging, vol. 3, 24 November, 2017.
7. G. M. F. Arcangelo Bruna, Giuseppe Claudio Guarnera and Sebastiano Battiato, " Forgery Detection and Value Identification of Euro Banknotes, " Sensors, vol. 13, pp. 2515-2529, 18 February 2013.
8. E. C. Sangwook Baek, Yoonkil Baek, and Chulhee Lee, " Detection of counterfeit banknotes using multispectral images,” Digital Signal Processing, pp. 1051-2004, 2018.
9. J. F. Zeggeye. and. Yaregal Assabie, " Automatic Recognition and Counterfeit Detection of Ethiopian Paper Currency, " International Journal of Image, Graphics and Signal Processing, vol. 2, pp. 28-36, February 2016.
10. S. B. K. Pragati D. Pawar, " Recognition of Indian Currency Note Based on HSV Parameters " International Journal of Science and Research (IJSR), vol. 3, June 2014.
11. T. Agasti, G. Burand, P. Wade and P. Chitra, “Fake currency detection using image processing”, IOP Conf. Series: Materials Science and Engineering vol. 263, 2017.
12. A.Kamble, and M. Nimbarte, “Fake Currency Detection using Clustering and SVM Classification”, International Journal of Scientific Research in Computer Science, Engineering and Information Technology, vol.3, 2018.
13. M. Singh, P. Ozarde, and K. Konidena, “Image Processing based Detection of Counterfeit Indian Banknote”, IEEE, 2018.
14. M.P.Deepak and Prajwala N.B, “Identification of Fake Notes and Denomination Recognition”, International Conference on Communication and Signal Processing”2018.
15. R. Bhavani, and A. Karthikeyan, “A novel method for Counterfeit Banknote Detection”, International Journal of Computer Science and Engineering, 2014.
16. C. Yuan, W. Pin, and S. Lee, “Employing multiple-kernal support vector machines for counterfeit banknote recognition”, Applied Soft Computing, 2011.
17. W.K. ElSaid, “Fake Egyptian Currency Detection System using Texture and Shape Characteristics”, International Journal of Computer Applications, vool. 143, No. 2, 2016.
18. S. Lamsal, A. Shakya, “Counterfeit Paper Banknote Identification Based on Color and Texture”, Proceeding of IOE Graduate Conference, 2015.
19. J. Tripathi, N. Dixit, and Pankaj, “Automatic detection of fake paper currency using MATLAB”, IEEE, 2014
20. D. Cruz, Echano, and B. Paquiz,”Philippine Currency Paper Bill Counterfeit Detection through Image Processing using Canny Edge Technology”, IEEE, 2015.
21. A.B.Sargano, and Nuhman Ul Haq, " An intelligent system for paper currency recognition with robust features, "Journal of Intelligent and Fuzzy Systems, vol. 27, pp. 1905-1913, 2014.

22. Z. Altaf, S. Farhan, and A. Fahiem, " An Automated Pattern Recognition Based Approach for Classification of Soiled Paper Currency Using Textural and Geometrical Features, " Journal of Testing and Evaluation, vol. 45, pp. 2224-2242, 17th February 2017.
23. E. C. Sungwook Youn, Yoonkil Baek, and Chulhee Lee, "Efficient multi-currency classification of CIS banknotes," Neurocomputing, vol. 156, pp. 22-32, 25th May 2015.
24. M. R. Bo-Yuan Feng, Xu-Yao Zhang, Ching Y. Suen, " Automatic recognition of serial numbers in bank notes, " Pattern Recognition, vol. 47, 28 February 2014.
25. M. Behjat, and. P. Moallem, " Fast and Low-cost Mechatronic Recognition System for Persian Banknotes, " International Journal of Advanced Robotic Systems, 27 December, 2013.
26. S. Gai, G.Yang,and M. Wan, "Employing quaternion wavelet transform for banknote classification," Neurocomputing, vol. 118, pp. 171-178, 22nd Oct 2013.
27. L. Dunai, M. Chillaron, Guillermo, P. Fajarnes and I. Lengua, " Euro Banknote Recognition System for Blind People, " Sensors, vol. 17, 20 January 2017.
28. P. Tuyen, Pham, S.Yong Kwon, K. Park, D. Jeong, and S.Yoon, " Efficient Banknote Recognition Based on Selection of Discriminative Regions with One-Dimensional Visible-Light Line Sensor, " Sensors, vol. 16, 4 March 2016.
K. Young Ho Park, T. Pham, Kang Ryoung Park, . Jeong and S.Yoon, "A High Performance Banknote Recognition System Based on a One-Dimensional Visible Light Line Sensor," Sensors, vol. 15, pp. 14093-14115, 15 June 2015.
29. W. H. Wang Ke, Shu Yue, Mao Li, and Qiu Fengyan, " Banknote Image Defect Recognition Method Based on Convolution Neural Network, " International Journal of Security and Its Applications, vol. 10, pp. 269-280, 2016.
30. J. C. Wei Q. Yan, and A. Garhwal, "An empirical approach for currency identification" Multimedia Tools Applications, vol. 74, 2015.
31. M. Sarfraz, "An intelligent paper currency recognition system," ScienceDirect. vol. 65, pp. 538-545.
32. T.V. Dittimi,A. K. Hmood, and C.Y.Suen "Multi-Class SVM Based Gradient Feature for Banknote Recognition," IEEE, 2017.
33. K.Hlaing, and A. Gopalakrishnan, "Myanmar paper Currency Recognition Using GLCM and k-NN " in IEEE 2016 Second Asian Conference on Defence Technology (ACDT).
34. X. Z. Mingwu. Ren, "A Recognition Method of RMB Numbers Based on Character Features", 2nd International Conference on Information, Electronics and Computer, 2014
35. [B. Iyad abu Doush, "Currency recognition using a smartphone: Comparison between color SIFT and gray scale SIFT algorithms," Journal of King Saud University - Computer and Information Sciences, 23 June 2016.
36. R. Bo-Yuan Feng, Xu-Yao Zhang, and Ching Y. Suen, "Part-Based High Accuracy Recognition of Serial Numbers in Bank Notes," Springer International Publishing Switzerland, pp. 204-215, 2014.
37. Ch.Ratna Jyothi, Y.K. Sundara Krishna, V. Srinivasa Rao, PhD, "Bank Notes Authentication System based on Wavelet Features and Artificial Neural Network", International Journal of Computer Applications, May 2016
38. [G. Rashmi C, "Image Processing Approach for INR Currency Note Number Recognition System for Automated Teller Machines," International Journal of Computer Applications Technology and Research, vol. 5, pp. 539-542, 2016.
39. O. Vishnu R, "Principal Features for Indian Currency Recognition," in IEEE India Conference (INDICON), 2014.
40. T. Adigun, "Data mining model for classifying and prediction Nigeria paper currency notes," The Journal Of Computer Science And Its Applications, vol. 19, December, 2012.
41. [P. Seung Yong Kwon, Kang Ryoung Park, Dae Sik Jeong, "Recognition of Banknote Fitness Based on a Fuzzy System Using Visible Light reflection and Near-infrared Light Transmission Images," Sensors, vol. 16, 11 June 2016.

42. P. Tuyen Danh Pham, Seung Yong Kwon, Dat Tien Nguyen, Husan Vokhidov, Kang Ryoung Park, Dae Sik Jeong, and Sungsoo Yoon, "Recognition Banknote Fitness with a Visible Light One Dimensional Line Image Sensor," Sensors, vol. 15, 27 August 2015.
43. Latif, J., Tu, S., Xiao, C., Ur Rehman, S., Imran, A., & Latif, Y. (2022). ODGNet: a deep learning model for automated optic disc localization and glaucoma classification using fundus images. SN Applied Sciences, 4(4), 98.
44. Mahmood, T., Akhtar, F., Rehman, K. U., Azeem, M., Mudassir, A. I., & Daudpota, S. M. (2020). Introducing robustness in DBR routing protocol. International Journal of Communication Networks and Distributed Systems, 24(3), 316-338.
45. Imran, A., Aslam, W., & Ullah, M. I. (2017). Quantitative prediction of offensiveness using text mining of twitter data. Sindh University Research Journal-SURJ (Science Series), 49(1).
46. Rahman, H., Bukht, T. F. N., Imran, A., Tariq, J., Tu, S., & Alzahrani, A. (2022). A Deep Learning Approach for Liver and Tumor Segmentation in CT Images Using ResUNet. Bioengineering, 9(8), 368.
47. Mahmood, T., Li, J., Pei, Y., Akhtar, F., Imran, A., & Yaqub, M. (2021). An automatic detection and localization of mammographic microcalcifications ROI with multi-scale features using the radiomics analysis approach. Cancers, 13(23), 5916.
48. Bilal, A., Sun, G., Mazhar, S., & Imran, A. (2022). Improved Grey Wolf Optimization-Based Feature Selection and Classification Using CNN for Diabetic Retinopathy Detection. In Evolutionary Computing and Mobile Sustainable Networks: Proceedings of ICECMSN 2021 (pp. 1-14). Singapore: Springer Singapore.
49. Wang, Y., Li, J., Hongbo, S., Li, Y., Akhtar, F., & Imran, A. (2019). A survey on VV&A of large-scale simulations. International Journal of Crowd Science, 3(1), 63-86.
50. Bhatti, D. S., Saleem, S., Imran, A., Iqbal, Z., Alzahrani, A., Kim, H., & Kim, K. I. (2022). A Survey on Wireless Wearable Body Area Networks: A Perspective of Technology and Economy. Sensors, 22(20), 7722.
51. Akhtar, F., Li, J., Pei, Y., Imran, A., Rajput, A., Azeem, M., & Liu, B. (2020). Diagnosis of large-for-gestational-age infants using a semi-supervised feature learned from expert and data. Multimedia Tools and Applications, 79, 34047-34077.
52. Sohail, M., Imran, A., Rehman, H. U., & Salman, M. (2020, January). Anti-social behavior detection in urdu language posts of social media. In 2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET) (pp. 1-7). IEEE.
53. Zhang, T., Zhu, X., Liu, Y., Zhang, K., & Imran, A. (2020, April). Deep learning based classification for tomato diseases recognition. In IOP Conference Series: Earth and Environmental Science (Vol. 474, No. 3, p. 032014). IOP Publishing.
54. Azeem, M. Z., Imran, A., Akhtar, F., Wajahat, A., Latif, J., & Memon, S. A. (2020, January). Effects of code cloning in mobile applications. In 2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET) (pp. 1-6). IEEE.
55. Ijaz, S., Lali, M. I., Shahzad, B., Imran, A., & Tiwana, S. (2017, December). Biasness identification of talk show's host by using twitter data. In 2017 13th International Conference on Emerging Technologies (ICET) (pp. 1-6). IEEE.