Design and Implementation of Paper Currency Recognition with Counterfeit Detection

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***Abstract*—Advancement of technology over the recent past has led to an increase in circulation of counterfeit notes in today's economy. To combat this issue, it is essential that there exists an efficient mechanism to detect fake banknotes. The main problem with current systems is the trade-off between speed and complexity. This paper proposes a system that can classify and subsequently verify Indian paper currency using fundamental image processing techniques. It uses the comparison between the input banknote and the calculated reference values for different parameters of original banknotes in a similar environment. This system maintains its simplicity while still having high accuracy of 100% for classification and 90% for validity verification.**

***Keywords*—counterfeit; denomination; image processing;**

I. INTRODUCTION

Currency is used as the medium of exchange for goods and services. Human error is a huge concern in cases where large amounts of cash transactions are conducted, leading to a push for increase in automation of transactions in the banking sector. Indian paper currency consists of six major denominations (₹10, ₹20, ₹50, ₹100, ₹500, ₹1000), with each having distinguishing features, such as size, prominent colour, identification mark, represented in Table I.

TABLE I: FEATURES OF INDIAN CURRENCY

Denomination (₹)	*Length (mm)*	*Width (mm)*	*ID Mark*	*Colour*
10	137	63	N/a	Orange-Violet
20	147	63	▮	Red-Orange
50	147	73	■	Violet
100	157	73	▲	Blue-Green
500	167	73	●	Olive-Yellow
1000	177	73	◆	Pink

With the development of sophisticated printing techniques, counterfeit currency has become a significant concern. Some of the consequences of counterfeit notes on society are a reduction in the value of real money, increase in prices due to more money being circulated in the economy and decrease in acceptability of money.

To prevent circulation of counterfeit notes, a system to detect fake notes must be developed. Notes with the legal sanction of the government possess certain security features such as intaglio printing, fluorescence and watermark, as seen in Fig. 1.

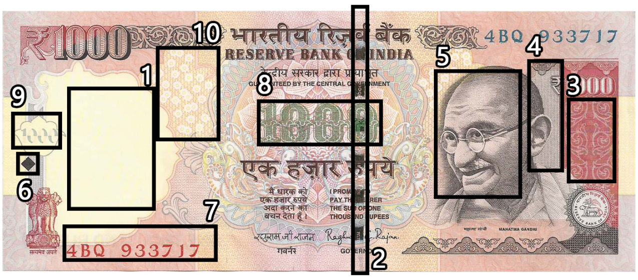

Fig. 1. Indian banknote with security features marked. (1) Watermark (2) Security Thread (3) Latent Image (4) Microlettering (5) Intaglio Printing (6) Identification Mark (7) Fluorescence (8) Optically Variable Ink (9) See-through Register

So far, many different approaches have been proposed to solve the problem of paper currency recognition and verification. The trade-off between accuracy, complexity and response time becomes the main hurdle to overcome.

In [1] the main feature of the paper currency recognition system is the recognition phase of the image. Symmetrical masks are used for considering specific signs of paper currency. Using this method, the summation of non-masked pixel values in each banknote is computed and fed to a Neural Network. The overall recognition accuracy of the system is computed as 91.5%. It focuses on the image area with both Prewitt Method and Canny Method masks to distinguish between the different denominations. As the number of features considered is high, processing time is large because symmetric masks need to be generated for each feature and each denomination.

In [2] the authors introduce LBP (Linear Binary Pattern) as a texture analysis technique. It is used for the texture analysis

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and feature extraction of Indian paper currency. In LBP, the neighbourhood pixels are converting to binary code 0 or 1 by using the grey value of the centre pixel as a threshold. Then, all these codes form an ordered pattern according to their relative position to the centre pixel. With good quality images as the input, the accuracy of this system reaches 90%. Although speed as well as accuracy of the LBP algorithm is high, it fails to distinguish counterfeit notes from genuine ones. In addition to this, the LBP algorithm is only suitable for systems with low noise levels, thus making recognition of eroded notes difficult.

In [3,4,7,10] six different features of paper currency are extracted, viz. colour information, shape, number, ashoka emblem, RBI seal and signature identification. These features are used to detect the denomination of the currency, which helps the system to select the currency template. The system will compute similarity for each feature that is extracted from the input currency image with the corresponding feature template of that particular denomination. The dimensions of the notes are then obtained and the aspect ratio is calculated. To study the I.D. mark, the portion of the note or the region of interest (ROI) is extracted and the artificial neural network is employed to classify the shapes, and finally, the denomination is determined. The high success rate of this system is limited to new, clean notes, and the requirement of a highly complex system.

In [5] the system takes advantage of recognition of the material of paper currency, a blend of cotton and paper, to determine authenticity. The polarisation properties of cellulose are used to detect polarised light from the note and test if the concentration of polarised light is consistent with the output expected from the level of cellulose in currency. Along with detecting the fluorescent sections under UV light, the system achieves adequate results which may be used in conjunction with other systems, but not independently.

In [6] the system uses infrared light to reveal the intaglio printing of paper currency, which is the raised printing used to identify the currency by touch. Since the contrast of the infrared image is not very good, the original infrared images are embossed and converted to binary, before making use of template matching techniques. This system achieves near perfect accuracy, but with the high cost of requiring embossing and other such difficult techniques.

To overcome the disadvantages of the existing methods, a system is proposed that maintains its simplicity by making use of basic image processing techniques. The high success rate is achieved by considering of a variety of features, including those only visible under conditions such as backlight or UV light. This method begins by calculation of a set of reference values for each feature of the banknote. Each input is taken under all required conditions and converted to a form that is conducive to analysis. On comparison of reference values and input values by shape recognition, hue analysis, pixel intensity comparison, object detection etc., a likelihood algorithm is used to determine its denomination and subsequently verify its validity.

II. Reference Database

A database was formed of 10 samples of each denomination of currency, with the obverse and reverse taken into consideration. Each image is captured under the influence of natural light, white backlight and UV backlight independently. A standardised environment was created to facilitate consistent conditions for image capture by placing each note within a closed box and placing the capture device at a fixed height keeping in mind the resolution and exposure of the camera. The note is placed on a thin, white sheet, beneath which the required lights are arranged such that the white backlight is present behind the left panel and along the security thread and the UV backlights are spread throughout the note. The lights are turned on and off with the help of a microcontroller and the images are captured by a camera which is controlled directly by MATLAB. The system design described is displayed in Fig. 2.

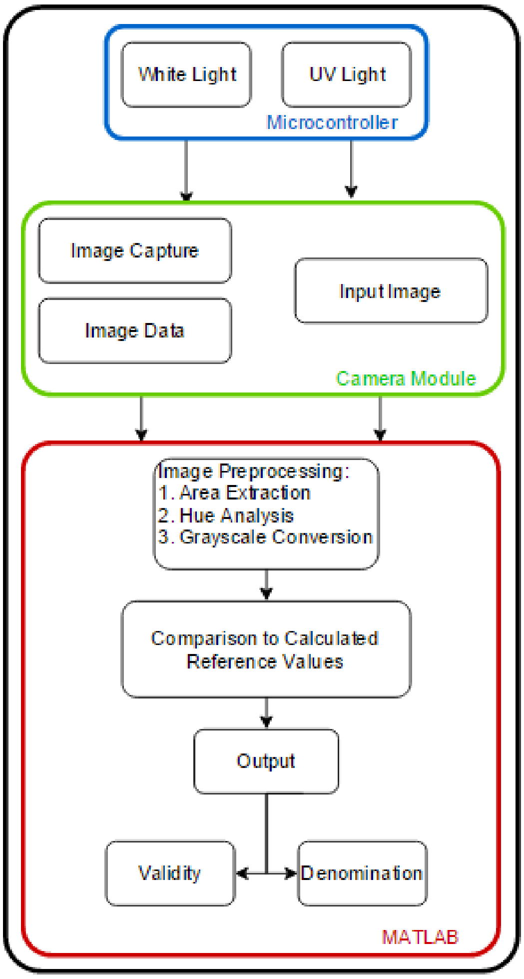


Fig. 2. System Design

III. Image Preprocessing

The image captured consists of the banknote on a white background. To increase the efficiency of both detection algorithms, the image is subjected to a preprocessing system, which extracts the regions of interest and converts them into a binary form. For example, to analyse parameters such as hue calculation, the RGB image is converted into HSV format while mean pixel intensity is calculated over a greyscale image [8].

IV. Classification Based on Denomination

The Indian currency notes consist of various salient features indicating denomination, the most prominent ones being size, colour, identification mark and pixel intensity. First, the typical parameter values for each denomination are calculated using the images from the created standard database. These are set as the reference values for classification. To determine the denomination of the input note, it undergoes the same scanning procedure and preprocessing technique. The parameter values for the input are determined and then compared to the reference values. As each parameter is measured differently, it is necessary to normalise them.

$$F(i,d) = \left| \frac{F_{input}(i) - F_{reference}(i,d)}{F_{reference}(i,d)} \right| \tag{1}$$

In (1), $F_{input}(i)$ is the value of the i^{th} parameter for the input image, $F_{reference}(i, d)$ is the value of the i^{th} parameter for the d^{th} denomination determined from the reference database, and F(i, d) is the normalised parameter value. A likelihood factor is formed, which shows the relative likelihood of an input note belonging to a particular denomination. Each parameter contributes to the likelihood factor, increasing or decreasing its value based on the similarity to the denomination reference.

$$l(i,d) = \frac{1}{F(i,d)} \tag{2}$$

$$Likelihood = L(d) = \sum_{i=1}^{n} l(i,d) \tag{3}$$

In (2) and (3), l(i, d) is the likelihood factor contributed by the i^{th} parameter for the d^{th} denomination, and it is denoted by the inverse of F(i, d). The likelihood L(d) of each denomination is finally calculated as the sum of the likelihood factors. Finally, the denomination with the highest cumulative value of likelihood is selected and the note is classified.

V. Verification of Validity

There are ten security features embedded in each Indian currency note as a method to prevent production of counterfeit notes. To analyse the different features, the ROI for each is extracted independently.

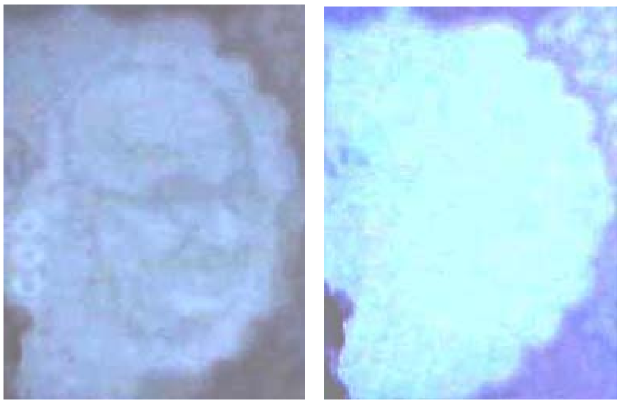
A. Watermark

Mahatma Gandhi watermark is visible in the left panel when seen against a light. This is detected using a white backlight in the scanning system. The ROI of a counterfeit note will have a different mean pixel intensity as well as standard deviation than that of the reference values, indicating its validity. The parameters are calculated as shown in (4) and (5).

$$Mean = \bar{I} = \frac{\sum_{x=1}^{l} \sum_{y=1}^{w} I(x,y)}{l \times w} \tag{4}$$

$$Standard\ Deviation = \sqrt{\frac{\sum_{x=1}^{l} \sum_{y=1}^{w} (I(x,y) - \bar{I})^2}{l \times w}} \tag{5}$$

I(x, y) is the pixel intensity at each point and l and w are the length and width respectively. The difference in the watermark of a real and counterfeit banknote is seen in Fig. 3.



(a) (b)

Fig. 3. Watermark area under backlit condition (a) Real note (b) Counterfeit note

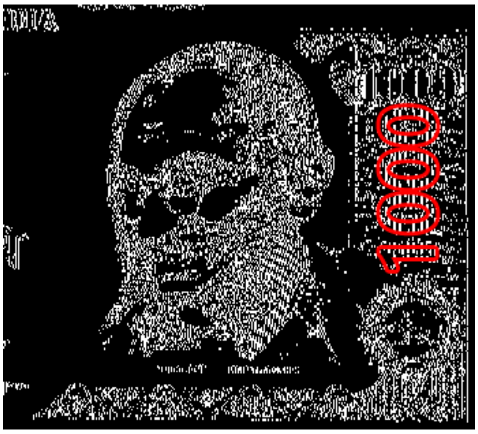
B. Security Thread

A security thread is partially visible on the front under normal conditions, completely visible as one continuous line when seen against a light and not visible on the back of the banknote. This is analysed by counting the number of whole objects in the region from the front and the back under normal and backlit conditions.

C. Latent Image

A latent image is seen in the panel to the right of Gandhi, containing the respective denomination in numerals. In this panel, the threads of the banknote are horizontal, while the denomination is shown using vertical threads. To detect the latent image, an algorithm for vertical line detection is applied to the ROI. In counterfeit notes, no vertical lines will be detected. The latent image seen as prominent vertical lines is highlighted in Fig. 4.

(a)



(b)

Fig. 4. Latent Image (a) Input image (b) Output of vertical line detection

D. *Microlettering*

Microlettering is visible between the latent image and Gandhi, which reads “RBI” followed by the denomination for ₹500 and ₹1000, but “RBI” alone for the remaining denominations. This is detected using advanced OCR (Optical Character Recognition) techniques on an enhanced image.

E. *Intaglio Printing*

Raised printing is seen in the denomination numeral, RBI seal, identification mark, the promise clause, the ashoka emblem, RBI Governor’s signature and the portrait of Gandhi on the right panel. An edge detection algorithm with Canny operator is applied to each region. The result of this process leads to unique patterns for real notes which are not present in counterfeit notes [9].

Fig. 5 displays the effect of preprocessing and edge detection on counterfeit and real notes. Real notes clearly produce coherent images displaying the intaglio printing as seen in Fig. 5(b). Counterfeit notes, as in Fig 5(c), give very inconsistent patterns after undergoing edge detection, without any distinctive outline of any raised design.

(a)

(b)

(c)

Fig. 5. Intaglio Printing (a) Input image (b) Real note (c) Counterfeit note

F. *Identification Mark*

Special intaglio identification marks are printed in the left panel next to the watermark for notes in different shapes for different denominations. Once the region is isolated, a shape recognition algorithm is applied for verification of its validity.

G. *Fluorescence*

Fluorescent number panels and optical fibres are visible when exposed to ultraviolet light. Hue analysis with the application of ultraviolet backlit along with calculation of pixel intensity over the entire image is used to detect this feature.

H. *Optically Variable Ink*

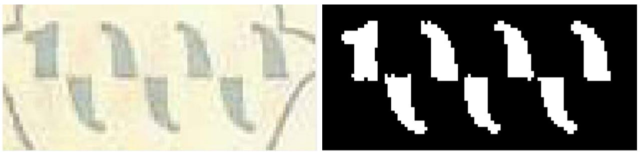
The numeral is seen in optically variable ink as green up front, but blue when seen at an angle. By analysing the hue of the ROI under the influence of UV light, the optically variable ink can be detected.

I. *See-Through Register*

The floral design printed on the obverse(hollow) and reverse(filled) may be seen as one complete pattern when viewed against the light. The number of objects on each side is detected, along with OCR performed against a backlight. The input ₹500 note seen in Fig. 6(a) is converted to binary and the threshold is found to isolate the objects according to their area, generating the result in Fig. 6(b), containing 6 objects. Similarly, the ₹1000 banknote in Fig. 7 contains 7 distinct objects. Each note contains a different number of objects in the register.

(a) (b)

Fig. 6. See-through Register for ₹500 (a) Input (b) Isolated objects



(a) (b)

Fig. 7. See-through Register for ₹1000 (a) Input (b) Isolated objects

J. *EURion Constellation*

A constellation of rings present in every banknote that allows systems to digitally identify that a banknote exists in the image, preventing reprinting using colour photocopiers.

Validity of the input note is done by checking for all of the aforementioned features by comparing them with the reference values. The absence of any one of these features indicates that the input is a counterfeit note.

VI. RESULTS

The performance of the proposed algorithm is evaluated on the Indian paper currency system, considering 60 real notes and 10 counterfeit notes. Using the proposed classification algorithm, the banknotes are classified according to denomination with 100% success rate. The expected parameter values for each denomination have been summarised in Table II. The parameters with the most influence on denomination classification are length, width, aspect ratio, hue, pixel intensity and intensity standard deviation. By comparing the values of the input to the reference values, the denomination with the highest amount of significant similarity is selected. These reference values, specific to the resolution of the camera used, can be easily modified to suit other cameras.

The various security features for each denomination were analysed and the expected values for real notes are seen in Table III. If the values of the input note do not match with the expected value of real notes, the note is determined to be counterfeit. Using this algorithm, the success rate of counterfeit identification is 90%.

VII. CONCLUSION

Counterfeit currency recognition systems have become an

TABLE II: DENOMINATION REFERENCE VALUES

Denomination (₹)	*Length*	*Width*	*Aspect Ratio*	*Hue*	*Pixel Intensity*	*Intensity Standard Deviation*
10	713.75	327.25	2.181732	117.4467	123.8183	163.0993
20	758.5	327.5	2.316034	129.8307	146.3573	167.751
50	763.5	381.75	2.000091	155.7939	168.2702	221.2844
100	814.5	386.25	2.108846	144.9097	168.3574	222.4487
500	862	376.75	2.287981	172.8731	175.3214	207.9447
1000	912.5	380.75	2.396663	179.8047	191.7329	227.4919

TABLE III. COUNTERFEIT REFERENCE VALUES

Denomination (₹)	*Watermark Intensity*	*Security Thread Intensity*	*Fluorescence*	*Optically Variable Ink*	*Register Objects*	*ID Mark*
10	225.843	203.8607	143.2679	0.637634	3	None
20	223.6577	206.4238	139.8646	0.63645	4	▮
50	224.2177	204.0688	140.9733	0.64384	4	■
100	225.8541	204.4918	141.6862	0.646419	5	▲
500	226.0997	208.3501	141.7085	0.640727	6	●
1000	227.7732	192.1577	140.513	0.643216	7	◆

important part of the banking sector. The proposed methods to classify denomination and identify counterfeit notes have high accuracy of 100% and 90% respectively, while still maintaining low system complexity. As systems to take pictures of both the obverse and reverse of the note already exist, using them in conjunction with the proposed algorithm allows for the time taken for computation to be low. As the techniques used have the advantage of low processing time, low intricacy and reliability, it is suitable for real time applications.

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