Indian currency database for forensic research

Saheb Chhabra, Gaurav Gupta, Garima Gupta, Monika Gupta

Chapter 12

INDIAN CURRENCY DATABASE FOR FORENSIC RESEARCH

Saheb Chhabra, Gaurav Gupta, Garima Gupta and Monika Gupta

Abstract Criminals are always motivated to counterfeit currency notes, especially higher denomination notes. Low-quality counterfeits are created using high-resolution scanners and printers whereas high-quality counterfeits are created using sophisticated currency printing presses and raw materials, often with the assistance of hostile nation states. Identifying counterfeit currency notes is a challenging problem that is hindered by the absence of a publicly-available database of genuine and counterfeit currency notes due to legal constraints. On November 8, 2016, the Government of India declared all 500 and 1,000 denomination notes of the Mahatma Gandhi Series as invalid tender. This research was able to collect and investigate genuine and counterfeit versions of the demonetized notes. Several new security features in the demonetized currency notes were identified and a database of microscope and scanner images has been created for forensic research.

Keywords: Counterfeit currency, security features, database

1. Introduction

Rapid advancements in printing and scanning technologies have simplified the task of creating fake documents. Creating counterfeit currency, especially high denomination notes, is on the rise. Low-quality counterfeit currency is easily produced using high-resolution scanners and printers. In contrast, producing high-quality counterfeit currency requires sophisticated printing presses and specialized raw materials. Access to printing equipment and raw materials are next to impossible for individuals, which is why high-quality counterfeits are typically created with the assistance of hostile nation states.

Over more than 150 years, sovereign nations have taken strong steps to prevent the creation and use of counterfeit currency. On November

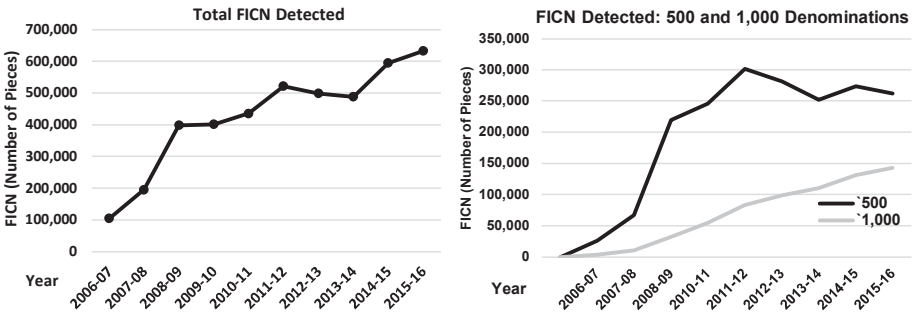

Figure 1. Detection of fake Indian currency notes by year.

8, 2016, the Government of India declared 500 and 1,000 denomination notes of the Mahatma Gandhi Series as invalid tender. This was done to combat the massive amounts of "black money" (i.e., unreported income) and to flush out counterfeit currency. The same day, India released new 500 and 2,000 denomination currency notes, claiming that their security features made it next to impossible to make counterfeits.

However, shortly after the release, counterfeit currency notes with the new 500 and 2,000 denominations were seized at the India-Bangladesh border [13]. Forensic analysis revealed that the seized counterfeit currency was printed on official Bangladesh stamp paper. Moreover, 11 of the 17 security features of the new currency notes were replicated [13], indicating that criminal entities can quickly produce high-quality counterfeit currency notes.

According to the Reserve Bank of India (India's Central Bank) [16], the number of fake Indian currency notes (FICN) detected increased from 104,743 in 2006-2007 to 632,926 in 2015-2016, an increase of more than 500% over ten years. Additionally, the number of counterfeit 1,000 denomination notes that were seized increased by more than 164% over the six-year period from 2010-2011 to 2015-2016. Figure 1 shows the total numbers of fake currency notes detected annually (left-hand side) and the numbers of fake 500 and 1,000 denomination notes detected annually (right-hand side).

Information about anti-counterfeiting technologies, including security features such as intaglio printing, micro-printing, magnetic ink character recognition (MICR), optically-variable ink (OVI) and watermarks, is readily available on the Internet. Since this information is leveraged by counterfeiters to design counterfeit currency, it is important to identify new security features in currency notes that can forensically verify their authenticity.

With input from forensic experts, this research has identified new security features that have the potential to distinguish between genuine and counterfeit currency notes with high accuracy. To advance these efforts, a database of demonetized Indian 500 and 1,000 denomination currency notes has been created. The database comprises 6,173 images of genuine and counterfeit currency notes captured using a microscope and/or scanner. The currency samples cover every year from pre-2005 to 2013 and incorporate the different inset letters. Indeed, this database of currency notes is the first of its kind to be created for forensic research and to advance the development of automated systems for currency authentication and counterfeit currency detection.

2. Related Work

Researchers have proposed several techniques for distinguishing counterfeit currency from genuine currency. Frosini et al. [8] proposed a neural-network-based recognition and verification technique that uses an inexpensive optoelectronic sensor to check banknote dimensions; this information is combined with a multilayer perceptron that recognizes the orientation and obverse side of banknotes. Other techniques for recognizing currency notes are based on size, color and texture [1, 10].

Principal component analysis and wavelet transformation techniques have been used to recognize single-country as well as multi-country banknotes [2, 6, 14]. Gai et al. [9] have proposed a scanner-based system for banknote classification based on the quaternion wavelet transform. The transform is applied to banknote images for feature extraction, which yields a shift-invariant magnitude and three phases for each sub-band. Generalized Gaussian density is then used to obtain the parameter means and standard deviations. The feature vectors are input to a backpropagation neural network for classification. This system has been tested on U.S. dollars, Chinese renminbi and European Union euros.

Other techniques for currency recognition leverage edge detection, region properties and similarity measurements [3, 11, 19]. Lee et al. [12] have designed a paper-based chipless tag system for recognizing banknotes. Xie et al. [20] compute texture roughness from Chinese renminbi currency note images to identify counterfeits. They claim that the surface of the printing layer in genuine notes tends to be rougher than in counterfeit notes; eight parameters are computed, four parameters represent statistical information whereas the other four express characteristics of gray-scale profiling.

Other researchers have extracted size, color and texture features to authenticate currency notes [4, 15, 21]. Roy et al. [18] have developed

a system to authenticate paper currency, including Indian banknotes. Security features such as printing techniques, ink properties, security threads and artwork were evaluated. The system has been tested on genuine and counterfeit samples of Indian 500 denomination banknotes. In other work, Roy et al. [17] have proposed a technique for extracting gray-level, color and texture features to recognize and authenticate Indian currency notes.

Bozicevic et al. [5] have developed a non-destructive, micro-Raman spectroscopy method to detect color-printed counterfeit notes. They analyzed cyan, magenta and yellow toner cartridges from one manufacturer against a printer and toner cartridges from another manufacturer. The analysis indicated that the cyan toners have similar spectra, but there are considerable differences for the other colors.

Cozzella et al. [7] encode information about the positions of random security fibers that glow under ultra-violet light and create 2D barcodes with the encoded information. The authenticity of a banknote is verified by passing an image taken under ultra-violet light and comparing barcodes.

Research has primarily focused on authenticating currency notes in non-forensic contexts. The principal reason is the lack of a currency database that supports forensic research. The research described in this chapter has sought to collect and investigate genuine and counterfeit versions of currency notes. Several new security features in the demonetized currency notes have been identified and a database of microscope and scanner images has been created for forensic research.

3. Indian Currency Security Features

Numerous security features are incorporated in currency notes to combat forgery and verify authenticity. Countries have unique currency designs, security features, colors, sizes and paper types. Indian currency is printed by the Reserve Bank of India. Details about the paper and raw materials used to print Indian currency notes are kept secret. Vendors are forbidden from selling them to any other entity.

Printing currency notes involves several stages. Some security features such as watermarks and security threads are incorporated when the paper is manufactured. Other features such as guilloche patterns, micro-letters and intaglios are incorporated using sophisticated printing technologies. Features such as security fibers and fluorescent ink are hidden and are only visible when illuminated by ultra-violet light.

In general, currency security features are categorized into three levels based on their complexity and protections against counterfeiting.

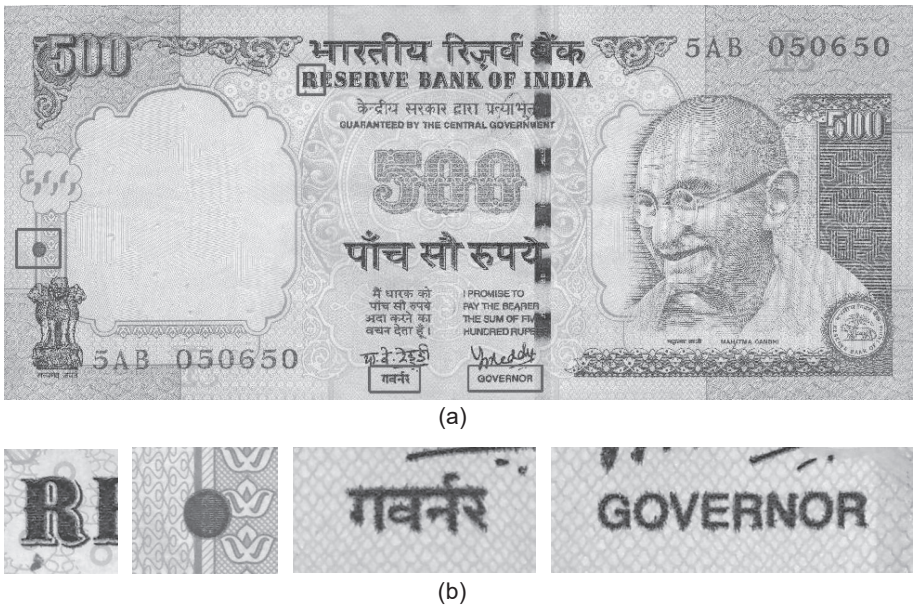

Figure 2. Indian currency note with intaglio security features.

First-level features such as watermarks, color-shifting inks and security inks are designed to enable individuals to verify the authenticity of currency notes. Second-level security features such as guilloche patterns and micro-printing are intended to counter forgery and are visible under magnification. Third-level features such as fluorescent inks, printing inks and security fibers are difficult to replicate and typically provide the ground-truth for authentication. All the security features must be considered when conducting forensic examinations of currency notes.

Figure 2 shows images of an Indian 500 denomination currency note and its security features. Figure 2(a) shows the obverse side of the note and Figure 2(b) shows detailed images of the intaglio security features.

Before the November 8, 2016 demonetization, valid Indian currency notes included the 5, 10, 20, 100, 500 and 1,000 denominations. After the old 500 and 1,000 denominations were declared invalid, new designs and series of 500 and 2,000 denomination currency notes were released. The Reserve Bank of India currently prints Indian currency notes at presses in four cities. Each printing press is assigned specific inset letters to be printed on currency notes. Table 1 shows the mappings of inset letters to currency printing presses.

Table 1. Mappings between inset letters and currency printing presses.

Inset Letters	Printing Press
Nil, A, B, C, D	Press 1
E, F, G, H, K	Press 2
L, M, N, P, Q	Press 3
R, S, T, U, V	Press 4

4. Indian Currency Database

Creating the Indian currency database comprising genuine and counterfeit 500 and 1,000 denomination notes involved three phases: (i) sample collection, (ii) security feature identification and (iii) database creation.

4.1 Sample Collection

Collecting counterfeit currency samples is always a challenging task. The primary barriers are legal constraints that restrict access to and collection of seized counterfeit currency. The invalidation of Indian 500 and 1,000 denomination notes enabled the collection of genuine and high-quality counterfeit samples. A total of 599 currency samples were collected, 464 genuine and 135 counterfeit notes.

The year that an Indian currency note is printed is recorded on the reverse side of the note and a designated inset letter corresponding to the printing press is printed in the background of the number panel. It was relatively easy to collect genuine currency notes printed every year from pre-2005 through 2013 that covered all the designated inset letters. To make the database more realistic, genuine currency note samples of varying quality (e.g., lightly used, heavily used and very heavily used) were included. The counterfeit currency samples were obtained from law enforcement and other agencies only after providing assurances that the database would be used exclusively for forensic research.

4.2 Security Feature Identification

The Reserve Bank of India issues guidelines for distinguishing genuine Indian currency notes from counterfeit notes. However, some of the guidelines are unreliable for identifying counterfeits. Manual analysis of genuine and counterfeit currency notes was conducted using a microscope. The analysis revealed several new security features that could be used to distinguish between genuine and counterfeit currency. In

Table 2. Security features identified in 500 and 1,000 denomination notes.

500 Denomination Notes		
Watermark lines	See-through	Braille marks
Emblem	Number panel 2	Governor in Hindi
Flower	Governor in English	Mouth
Eye	Tiger	Latent
Micro-letters	500 on obverse	Number panel 1
Security thread 1	Security thread 2	Optically-variable ink
R	Paper fibers	Language panel
Gandhi	500 on reverse	Floral design
Lady		
1,000 Denomination Notes		
Watermark lines	See-through	Braille marks
Emblem	Number panel 2	Governor in Hindi
Flower	Governor in English	Mouth
Eye	Tiger	Latent
Micro-letters	1000 on obverse	Number panel 1
Security thread 1	Security thread 2	Optically-variable ink
R	Paper fibers	Language panel
Satellite	1000 on reverse	Floral design
Girl		

fact, 25 potential security features were identified in the 500 and 1,000 denomination notes in the currency database.

Table 2 lists the security features identified in the 500 and 1,000 denomination notes. Some of the security features are mentioned in the Reserve Bank of India guidelines whereas others were identified via the manual analysis of currency notes.

Figures 3(a) and 3(b) show the labeled security features on the obverse and reverse sides of 500 and 1,000 denomination notes, respectively.

4.3 Database Creation

The database comprises images of genuine and counterfeit 500 and 1,000 denomination notes captured using a microscope or scanner. An ISM PM200SB digital microscope was used to capture images of security features in the currency note samples. The microscope images were captured at magnifications from 10x to 200x under light intensities ranging from 2,500 to 3,000 lux; two Phillips lamps were to used obtain the required light intensities. A Canon 9000F Mark II scanner was used to capture images of the obverse and reverse of currency note samples at a resolution of 1,200 dpi. A total of 6,173 images were captured.

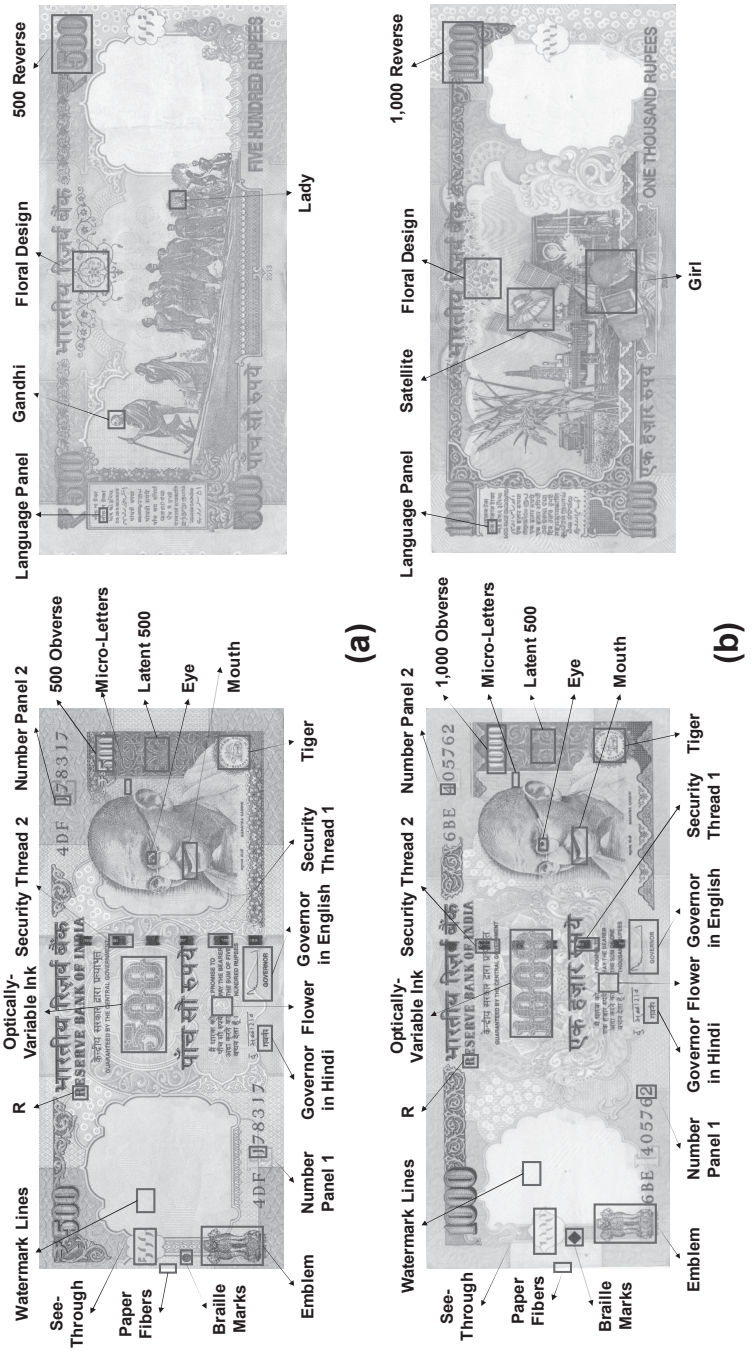

Figure 3. 500 and 1,000 denomination notes with all the identified security features.

Table 3. Dataset A details.

Currency Note Type	**Samples**	**Microscope Images**	**Scanner Images**
500 Genuine	118	118 × 25	118 × 2
500 Counterfeit	27	27 × 25	27 × 2
1,000 Genuine	46	46 × 25	46 × 2
1,000 Counterfeit	8	8 × 25	8 × 2
Total	199	4,975	398

The database is divided into Dataset A and Dataset B. Dataset A comprises microscope and scanner images whereas Dataset B comprises only scanner images.

Dataset A. Dataset A comprises images of the 25 security features of currency note samples captured using the microscope, and complete obverse and reverse images of currency note samples captured using the scanner. Dataset A contains a total of 5,373 images corresponding to 199 currency note samples.

Figure 4 shows the labeled security feature images of genuine (left-hand side images) and counterfeit (right-hand side images) 500 denomination notes, respectively. All the images were captured using the microscope.

Figure 5 shows the labeled security feature images of genuine (left-hand side images) and counterfeit (right-hand side images) 1,000 denomination notes, respectively. All the images were captured using the microscope.

Table 3 provides details about the images in Dataset A.

Table 4 provides details about the genuine 500 and 1,000 denomination note images in Dataset A. Dataset A contains images of genuine currency notes printed each year from pre-2005 through 2013. The currency note images collectively cover all the inset letters that were printed during each year.

Dataset A also includes images of genuine currency notes with different levels of wear and tear (i.e., lightly used, heavily used and very heavily used samples). Note that the microscope images cover all 25 security features for each sample and the scanner images cover the obverse and reverse sides of each sample. For example, in the case of the 13 genuine 500 denomination note samples from 2006, Dataset A con-

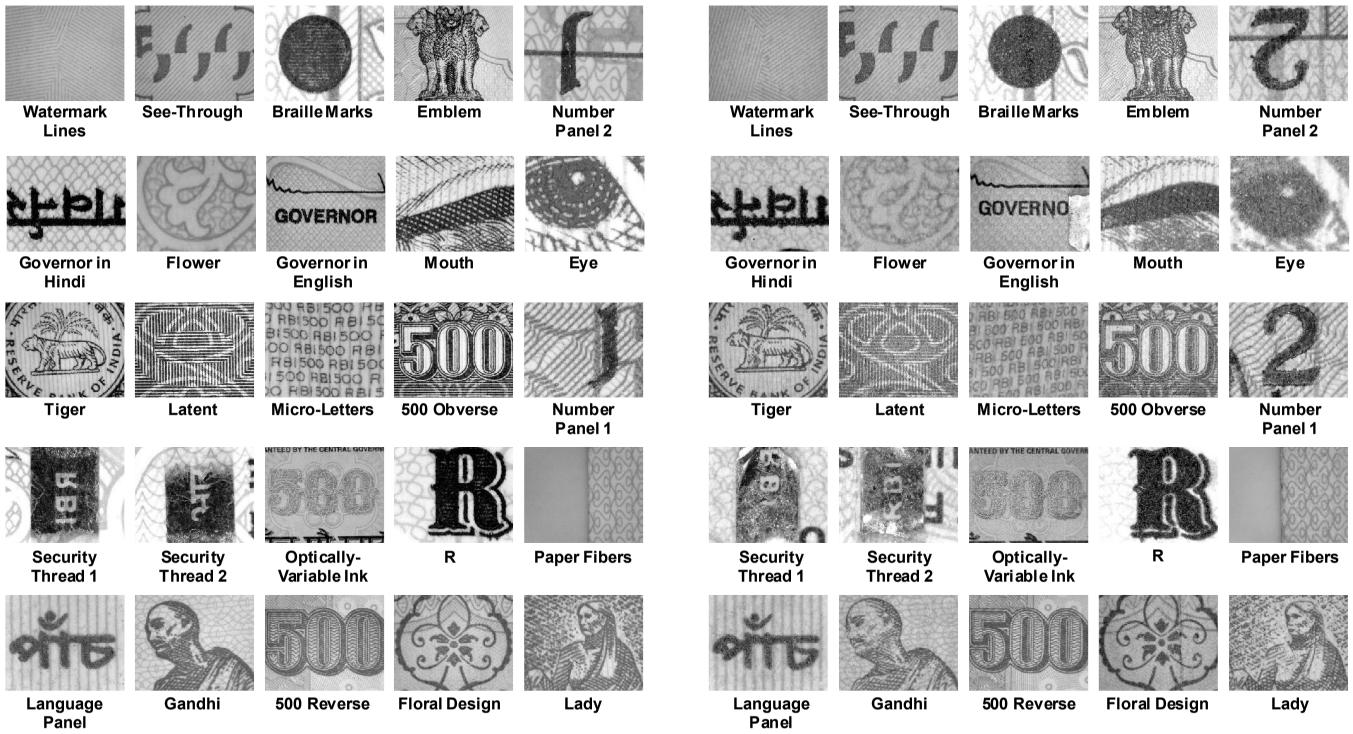

Figure 4. Security features of genuine and counterfeit 500 denomination notes.

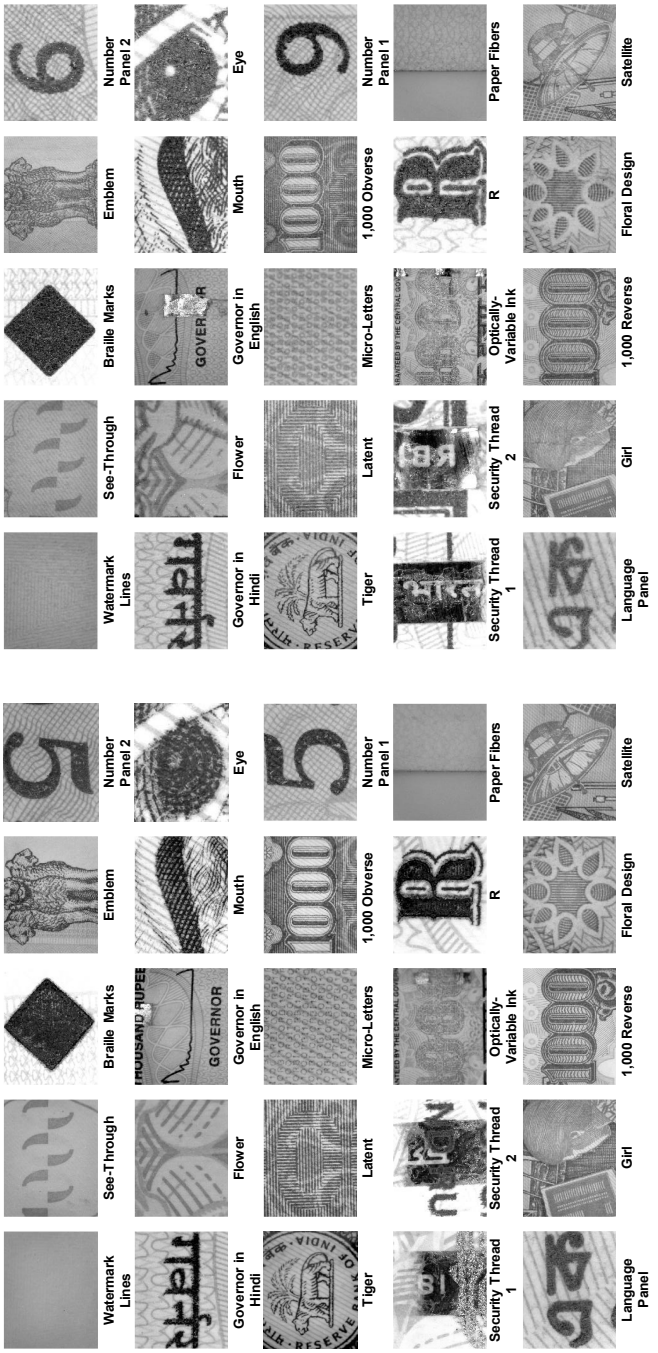

Figure 5. Security features of genuine and counterfeit 1,000 denomination notes.

Table 4. Dataset A details (genuine currency notes).

Year	Samples	Microscope Images	Scanner Images	Total Images
Genuine 500 Denomination Notes				
Pre-2005	23	25 × 23	2 × 23	621
2005	4	25 × 4	2 × 4	108
2006	13	25 × 13	2 × 13	351
2007	12	25 × 12	2 × 12	324
2008	12	25 × 12	2 × 12	324
2009	12	25 × 12	2 × 12	324
2010	14	25 × 14	2 × 14	378
2011	11	25 × 11	2 × 11	297
2012	11	25 × 11	2 × 11	297
2013	6	25 × 6	2 × 6	162
Total	118	2,950	236	3,186
Genuine 1,000 Denomination Notes				
Pre-2005	6	25 × 6	2 × 6	162
2005	1	25 × 1	2 × 1	27
2006	4	25 × 4	2 × 4	108
2007	7	25 × 7	2 × 7	189
2008	6	25 × 6	2 × 6	162
2009	6	25 × 6	2 × 6	162
2010	4	25 × 4	2 × 4	108
2011	6	25 × 6	2 × 6	162
2012	5	25 × 5	2 × 5	135
2013	1	25 × 1	2 × 1	27
Total	46	1,150	92	1,242

tains $25 \times 13 = 325$ security feature images and $2 \times 13 = 26$ obverse and reverse scanner images, corresponding to a total of 351 images.

Table 5 provides details about the counterfeit 500 and 1,000 denomination note images in Dataset A. Due to the difficulty obtaining counterfeit notes, the number of counterfeit samples in Dataset A are less than the number of genuine samples. Moreover, the samples do not cover all the print years and all the inset letters.

Dataset B. Dataset B comprises obverse and reverse images of genuine and counterfeit currency notes captured using the scanner. Figure 6(a) shows the obverse and reverse images of 500 denomination notes (genuine samples in the top row and counterfeit samples in the bottom row). Likewise, Figure 6(b) shows the obverse and reverse im-

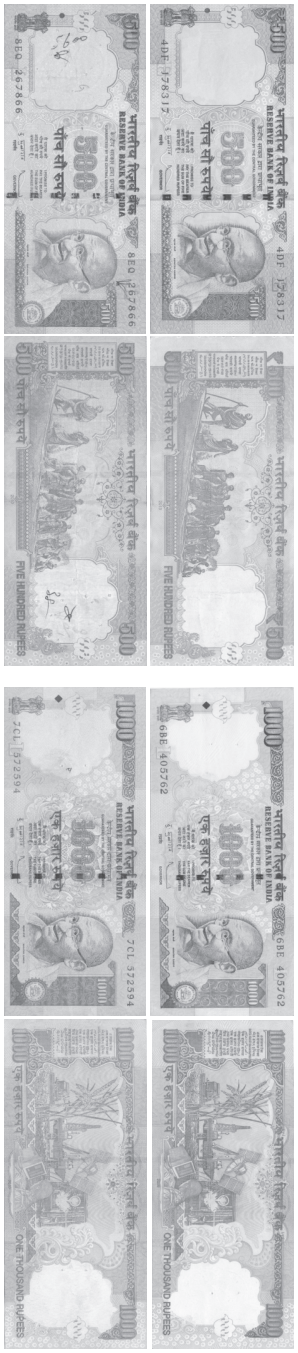

Figure 6. Scanned obverse and reverse images of genuine and counterfeit notes.

Table 5. Dataset A details (counterfeit currency notes).

Year	Samples	Microscope Images	Scanner Images	Total Images
Counterfeit 500 Denomination Notes				
Pre-2005	18	25 × 18	2 × 18	486
2007	2	25 × 2	2 × 2	54
2008	3	25 × 3	2 × 3	71
2010	4	25 × 4	2 × 4	108
Total	27	675	54	729
Counterfeit 1,000 Denomination Notes				
Pre-2005	2	25 × 2	2 × 2	54
2007	2	25 × 2	2 × 2	54
2010	4	25 × 4	2 × 4	108
Total	8	200	16	216

ages of 1,000 denomination notes (genuine samples in the top row and counterfeit samples in the bottom row).

Table 6. Dataset B details (genuine and counterfeit currency notes).

Currency Note Type	Samples	Scanner Images
Genuine 500 Denomination (Series 1 to 100)	100	200
Genuine 1,000 Denomination (Series 1 to 100)	100	200
Genuine 1,000 Denomination (Mixed)	100	200
Counterfeit 1,000 Denomination	100	200
Total	400	800

Table 6 provides details about the genuine and counterfeit 500 and 1,000 denomination note images in Dataset B. Specifically, Dataset B includes the obverse and reverse images of 100 samples each of genuine 500 and 1,000 denomination notes in series (i.e., the two sets of notes are in exact serial order from 1 to 100). Also, Dataset B includes the obverse and reverse images of 100 samples of genuine 1,000 denomination notes in mixed order (i.e., from different series) and 100 samples of counterfeit 1,000 denomination notes.

5. Conclusions

Rapid advancements in printing and scanning technologies have simplified the task of creating counterfeit currency. Low-quality counterfeit currency is easily produced using a high-resolution scanner and printer. In contrast, producing high-quality counterfeit currency requires sophisticated currency printing presses and specialized raw materials that are only available to nation states. Nevertheless, high-quality counterfeits abound. Shortly after the Government of India released new 500 and 2,000 denomination currency notes with 17 advanced security features on November 8, 2016, high-quality counterfeits were seized at the India-Bangladesh border. The seized currency was printed on official Bangladesh stamp paper and 11 of the 17 security features were replicated, indicating that criminal entities can rapidly produce high-quality counterfeit currency notes.

Counterfeit currency is a serious problem that must be addressed. Security features specified in the guidelines for authenticating genuine notes are not reliable. This research has identified 25 security features in demonetized Indian 500 and 1,000 denomination currency notes that can potentially be used to distinguish between genuine and counterfeit currency notes. It has also created a database comprising 6,173 microscope and scanner images of genuine and counterfeit currency notes in the 500 and 1,000 denominations. This database is the first of its kind to be created for forensic research with the goal of spurring the development of automated systems for currency authentication.

References

[1] A. Abbasi, A review of different currency recognition systems for Bangladesh, India, China and Euro currency, *Research Journal of Applied Sciences, Engineering and Technology*, vol. 7(8), pp. 1688–1690, 2014.

[2] A. Ahmadi, S. Omatu, T. Fujinaka and T. Kosaka, Improvement of reliability in banknote classification using reject option and local PCA, *Information Sciences*, vol. 168(1-4), pp. 277–293, 2004.

[3] A. Ali and M. Manzoor, Recognition system for Pakistani paper currency, *Research Journal of Applied Sciences, Engineering and Technology*, vol. 6(16), pp. 3078–3085, 2013.

[4] R. Bhavani and A. Karthikeyan, A novel method for counterfeit banknote detection, *International Journal of Computer Sciences and Engineering*, vol. 2(4), pp. 165–167, 2014.

[5] M. Bozicevic, A. Gajovic and I. Zjakic, Identifying a common origin of toner-printed counterfeit banknotes by micro-Raman spectroscopy, *Forensic Science International*, vol. 223(1-3), pp. 314–320, 2012.

[6] E. Choi, J. Lee and J. Yoon, Feature extraction for bank note classification using wavelet transforms, *Proceedings of the Eighteenth International Conference on Pattern Recognition*, pp. 934–937, 2006.

[7] L. Cozzella, C. Simonetti and G. Spagnolo, Is it possible to use biometric techniques as authentication solutions for objects? Biometry vs. hylemetry, *Proceedings of the Fifth International Symposium on Communications, Control and Signal Processing*, 2012.

[8] A. Frosini, M. Gori and P. Priami, A neural-network-based model for paper currency recognition and verification, *IEEE Transactions on Neural Networks*, vol. 7(6), pp. 1482–1490, 1996.

[9] S. Gai, G. Yang and W. Minghua, Employing quaternion wavelet transform for banknote classification, *Neurocompuing*, vol. 118, pp. 171–178, 2013.

[10] H. Hassanpour, A. Yaseri and G. Ardeshiri, Feature extraction for paper currency recognition, *Proceedings of the Ninth International Symposium on Signal Processing and its Applications*, 2007.

[11] V. Jain and R. Vijay, Indian currency denomination identification using an image processing technique, *International Journal of Computer Science and Information Technologies*, vol. 4(1), pp. 126–128, 2013.

[12] W. Lee, H. Jang, K. Oh and J. Yu, Design of chipless tag with electromagnetic code for paper-based banknote classification, *Proceedings of the Asia-Pacific Microwave Conference*, pp. 1406–1409, 2011

[13] S. Mishra, Pakistan finds a way to counterfeit "high security" Rs. 2,000 currency notes; 11 out of 17 security features copied in fake currency, *India.Com*, February 13, 2017.

[14] J. Ok, C. Lee, E. Choi and Y. Baek, Fast country classification of banknotes, *Proceedings of the Fourth International Conference on Intelligent Systems, Modeling and Simulation*, pp. 234–236, 2013.

[15] M. Rahmadhony, S. Wasista and E. Purwantini, Validity currency detector with optical sensor using backpropagation, *Proceedings of the International Electronics Symposium*, pp. 257–262, 2015.

[16] Reserve Bank of India, Annual Report 2020-2021, Mumbai, India (`www.rbi.org.in/scripts/AnnualReportPublications.aspx?Id=1181`), 2021.

[17] A. Roy, B. Halder and U. Garain, Authentication of currency notes through printing technique verification, *Proceedings of the Seventh Indian Conference on Computer Vision, Graphics and Image Processing*, pp. 383–390, 2010.

[18] A. Roy, B. Halder, U. Garain and D. Doermann, Machine-assisted authentication of paper currency: An experiment on Indian banknotes, *International Journal on Document Analysis and Recognition*, vol. 18(3), pp. 271–285, 2015.

[19] N. Semary, S. Fadl, M. Essa and A. Gad, Currency recognition system for the visually impaired: Egyptian banknotes as a case study, *Proceedings of the Fifth International Conference on Information and Communications Technology and Accessibility*, 2015.

[20] J. Xie, C. Qin, T. Liu, Y. He and M. Xu, A new method to identify the authenticity of banknotes based on texture roughness, *Proceedings of the IEEE International Conference on Robotics and Biomimetics*, pp. 1268–1271, 2009.

[21] W. Yan and J. Chambers, An empirical approach for digital currency forensics, *Proceedings of the IEEE International Symposium on Circuits and Systems*, pp. 2988–2991, 2013.