

Thesis Report on Fake Currency Detection using Image Processing Method



Inspiring Excellence

Supervised by: Dr. Md. Haider Ali

Co-supervised by: Md. Saiful Islam

Submitted by: Munshi Md. Alimushwan (13301148)

Akiful Mohaimin (12101139) Rifat Islam (12101142)

Shahriar Chowdhury (11201016)

Department of Computer Science and Engineering

Abstract

Fake notes area problem of almost every country. For country like Bangladesh it is becoming big hurdle. Fake Bangladeshi Currency of 1000 seems to have flooded the system and there is no proper way to deal with them for a common person. Therefore this has led to the increase of corruption in our country hindering country's growth. Common man became a scapegoat for the fake currency circulation, let us suppose that a common man went to a bank to deposit money in bank but only to see that some of the notes are fake, in this case he has to take the blame. Because of the advances in printing, scanning technologies it is easily possible for a person to print fake notes with use of latest hardware tools. Detecting fake notes manually becomes time consuming and untidy process hence there is need of automation techniques with which currency recognition process can be efficiently done. The issue of efficiently distinguishing counterfeit banknotes from genuine ones via automatic machines has become more and more important. However, The main objective of this project is fake currency detection using MatLab. This process can be automated in a computer using the application software. The basic logic is developed using Image acquisition, gray scale conversion ,edge detection, image segmentation, feature extraction and comparison. The magnified image of the original currency is fed to the Matlab database. The features of the note to be tested are compared with the dataset formed from the original magnified image and finds out whether it is fake or original. The most important challenge is systematically and methodologically repeating the analysis process to reduce human error and time.

Keywords: Image Acquisition, Gray Scale Conversion, Edge Detection, Image Segmentation, Feature Extraction, Magnification, Comparison

Contents

Abstract.....	2
Chapter1.....	5
Introduction.....	5
BACKGROUND	5
MOTIVATION	5
Chapter2.....	9
Literature review.....	9
BANKNOTE RECOGNITION	10
CURRENCY SECURITY FEATURES	10
Chapter3.....	12
Methodology.....	12
INTRODUCTION	12
REVIEW OF SIMILAR STUDIES	13
Color features	13
Texture features	14
THE RESEARCH QUESTIONS ANDHYPOTHESES	14
HYPOTHESIS	16
TEMPLATE MATCHING	16
THE RESEARCH DESIGN	17
DATA REQUIREMENTS	18
LIMITATIONS OF RESEARCH	19
Chapter4.....	22
Findings	22
APPROACH	22
PRE PROCESSING.....	22
EXPERIMENT RESULTS	26
Chapter5.....	29
Discussion.....	29
REFLECTION	29
EVALUATION	29
JUSTIFICATION	30
Chapter6.....	32
CONCLUSION.....	32
SUMMARY	32
FUTURE WORK	32
References	34

Chapter1

Introduction

BACKGROUND

Since the beginning of civilization, societies have relied substantially on the ability to trade with one another, the ability to trade with one another is fundamental to the existence of our society as we know it. This ability to trade with one another is often a key enabling factor to an individual societies' strength to both survive and progress.

Trade has evolved from the elementary system of bartering to the complex combination of banknotes, coins, and electronic currency in use today. Interestingly what was once a system of trade facilitated by items of real intrinsic comparable value, has now evolved to a system where the primary medium for exchange holds no intrinsic value, yet value is exchanged. Historically, coins were the preferred medium for exchange, due to their composition, consisting primarily of valuable precious metals, the trading parties involved would gain what could be seen as 'true value'. The use of precious metals as a common medium for exchange suffers from the fundamental problem of limit on supply (Bender, 2006; Kersten, 2009), whereas paper and electronic currency is in abundance.

In an attempt to mitigate the shortage of precious metals, issuing authorities such as governing entities and banks issued promissory notes redeemable for actual precious metals stored in bank vaults. It was discovered with the issuance of promissory notes that the stocks held in vaults were seldom withdrawn in full, stocks held in vaults could be loaned out at interest generating a profit (Tarnoff, 2011). Promissory notes were easier to carry around than precious metals and therefore became the primary medium for exchange. Promissory notes were troublesome, each issuing authority used a unique design, as issuing authorities consisted of banks a multitude of notes were in circulation at any moment. Fundamentally paper held no intrinsic value and it could be reproduced fraudulently without too much effort (Tarnoff, 2011), and widespread counterfeiting was a major problem. The value held within promissory notes was not concrete, the reputation of the issuing bank for keeping their promise directly influenced the actual trading power held in each note. For an issuing authority to keep their promise, their stocks of precious metals must match the amount redeemable in circulation, widespread counterfeiting led to an inability to redeem promissory notes. Therefore the level of counterfeit notes in circulation of a specific issuing authority at any moment influenced their reputation and thus trading power.

MOTIVATION

Throughout history, currency issuers have faced one common threat, the threat of counterfeiting. Despite the introduction of electronic currency, banknotes remain in abundance. The amount of counterfeit currency in circulation at any moment threatens the confidence in the currency. Confidence influences the inherent value and stability of the currency. Banknotes hold higher value than coins making them more susceptible to counterfeiting, and a higher economical risk. It is observed throughout history opponent societies have used counterfeit currency production of their enemies' currency as a weapon

(Burger, 2009; Bender, 2006) in an attempt to weaken their opponents, reducing their financial bargaining power.

Today our currency system is composed of a complicated mix of coins, bank notes and electronic currency variants. Coins consist of a composition of raw materials, none of which are particularly valuable, functionally they are the same as banknotes. However coins hold lower denominations and are therefore a lower financial risk and target for counterfeiting. Paper currency holds higher denominations, and with the abundance of desktop publishing equipment available to the public this makes it a much higher risk for counterfeit reproduction.

Interestingly, although counterfeiting has been heavily reduced, even in today's environment counterfeiting of banknotes remains an issue and appears to be on the rise. Banknotes employ a wide array of security features, the design, composition of raw materials, combined with difficult to replicate printing methods such as Intaglio and offset lithographic methods add inherent security. The composition of raw materials is unique to a series of currency. The printing methods employed require specialized equipment and are extremely difficult to replicate, even by master printers (Kersten, 2009). There are three print phases: offset lithography, Intaglio and letterpress, each printing method layers a different part of the design onto the banknote surface. Offset lithography is used to print the main background design typically consisting of the primary scene, patterns and variations in color. A subsequent security feature applied by offset lithography, is precise alignment of the designs of the obverse and reverse for a seamless flow from front to back.

Level 1	Level 2	Level 3
Substrate Fidelity	Micro-text	Magnetic Ink
Print Fidelity	UV Glowing	Screen Traps
Color Fidelity		Manufacture
Acoustic Fidelity		Materials Interaction
Serial Number		Complicated Patterns
Holograms		Complicated Design
Watermark		Fluorescence
Security Thread		Texture Analysis
Security Fiber		
Planchets		
Tactile Fidelity		
Color-shifting Ink		
Clear Window		
Matching Sides		
Latent Image		

Table 1: Level 1, 2, and 3 security feature classification in banknote design.

Currency forensics is the application of systematic methods to determine authenticity of questioned currency. Questioned currency is one which is suspected to have been produced fraudulently. To determine the authenticity of questioned currency, banknotes are individually inspected for fidelity of specific characteristic features shown in table Table 1.1. Ultimately the final decision is made by performing a side-by-side comparison between a known good template and the suspect note, when a note is found to fall below satisfactory requirements it is not authentic. Clearly, making a final decision is subjective, the complexity involved in investigating each component directly relates to the quality of the banknote being examined.

As much of the necessary information required to determine authenticity of banknotes remains secret, forensic analysis often requires specialist trained individuals. Clearly, analysis is therefore reliant on the availability of highly sought after individuals. Such analysis is an ad-hoc process and subject to human error, to our knowledge there is no existing systematic formulated approach to ensure consistency. Similarly, to our knowledge there is no research to suggest the availability of an automated system to determine authenticity.

It is a fundamental requirement that forensic analysis be performed systematically to produce consistent results, if this fundamental requirement is not met, any such evidence may be questionable. Hence, it is imperative for legal proceedings that developed forensic analysis processes produce consistent, accurate, and verifiable results.

Therefore, the primary motivation for this study is to explore the security of banknotes, and formulate forensic analysis methods from a purely computational perspective for counterfeit banknote identification. As the security printing industry is very secretive, the fundamental mechanics enhancing security remain largely as closely guarded trade secrets. By developing a system to computationally analyze questioned currency the human error component can be minimized or reduced. Subsequently, computational analysis of banknotes leans towards a more systematic approach, whereby the analysis approach remains the same from one investigation to the next. By automating the analysis process, results are not only consistent across investigations, they are verifiable through understanding of the algorithms used.

In this thesis, banknotes are taken into consideration, the contribution provided by this thesis, is an empirical approach to automation of the currency forensics analysis process. A method for verifying the level of authenticity of banknotes is formulated based on the image and color fidelity of questioned banknotes. Banknotes are primarily a visual medium, typically characterized by their visual appearance consisting of intricate patterns, scenes, and combinations of color. Subsequently, as such methods result in a unique end result, the image and color fidelity of captured banknotes is suitable as the primary basis for analysis. Any image can be characterized by two characteristics: color fidelity specifies how similar two images are in color, and texture fidelity characterizes an image by the distribution of observed color throughout the image. Texture and color features when used individually may only partially describe an image, but when combined creates suitable characteristics to computationally describe an image or a scene (García-Lamont et al., 2012).

A model is formulated to computationally describe and compare captured banknote images, computationally, color at each picture element (pixel) is represented by three components red, green and blue (RGB). Using gray world algorithm each pixel is averaged to a single gray level value describing the color intensity, thus reducing data complexity whilst maintaining suitable information to differentiate color. The important information for analysis of color is the frequency of specific values, banknotes of a specific denomination result in a histogram with similar shape and distribution. A gray level histogram is computed where six shape descriptors are calculated to describe the shape.

A two-part feature vector firstly comprised of gray level histogram shape descriptors: central moment, mean, skew, variance, standard deviation and kurtosis. The second part comprises the texture descriptors: entropy level and GLCM (gray level co-occurrence matrix) features: contrast, correlation, energy and homogeneity. The feature vector is classified by a Feed forward Neural Network (FNN), finally a side-by-side comparison is made accompanied by a similarity measurement.

Chapter2

Literature review

Supporting literature exists focusing on banknote recognition software intended for a variety of applications, such as assisting the visually impaired (Grijalva, Rodríguez, Larco, & Orozco, 2010), banknote sorting and Automatic Teller Machine (ATM) machine software (Gou, Li, Li, & Yi, 2011), and banknote fatigue detection (Daraee & Mozaffari, 2010). A trend observed is that an image is acquired, it is preprocessed then classified and finally the result is output. Various methods are employed at each stage, the correct combination to use is subjective to the currency in question. The same work flow is employed by the digital currency forensics system to classify the note.

Image acquisition and image preprocessing techniques are employed, either the entire note or distinct Regions of Interest (ROI) are acquired and compared independently. The serial number uniquely identifies an individual banknote, in some cases the location of manufacture can be pinpointed (Bender, 2006). Therefore this adds a layer of security and can be computed (L. Li, Yu-tang, Yu, & Liang, 2010). If a note is found to have an incorrect or duplicate serial number it is not authentic. Image acquisition techniques are explored, the aggregation of RGB color with ultra-violet information (Chae, Kim, & Pan, 2009). Under ultra-violet light, a different visual appearance is observed, specific areas of the note glow displaying otherwise hidden information, this places extra complexity on the casual counterfeiter.

The fluorescence lifetime is investigated (Chia & Levene, 2009), it is found using a two-photon laser excitation and Time-Correlated Single Photon Counting (TCSPC) method, significant differences in the duration of fluorescence are observed when comparing genuine and counterfeit notes. This approach is an alternative to the image processing and classification model used by this thesis, yet due to the requirement for specialized equipment may not be a practical solution.

Image processing techniques are employed to extract key characteristics, key characteristics are numerical measures computationally describing a banknote image. There are two primary categories of key characteristics used. Color measurements describe the level of colour by creation of an intensity or grey-level histogram, shape descriptors are key colour characteristics. Texture describes the pattern of pixel colour and their relationship with one another (Verma, Singh, & Agarwal, 2011). It is found that using a vector space composed of both texture and colour features may improve classification accuracy (García-Lamont et al., 2012). The feature vector is input into a classifier where it is essentially compared against known good values. In literature, many classification techniques are employed on a wide array of currencies, the classification method chosen is subjective to the currency in question and characteristics extracted. Many variants of the classical Artificial Neural Network (ANN) are proposed, using the Back Propagation (BP) learning model with Genetic Algorithm (GA) improves learning performance (Cao & Liu, 2010).

To determine banknote authenticity a measurement is calculated upon comparison of the suspect note and template image. The measurement is used as the determination factor of similarity, the distance measurement is used specifically on ROIs (Daraee & Mozaffari,

2010) to determine the fatigue of banknotes. It is anticipated, synonymous to fatigue determination, discrepancies occurring during counterfeit production will provide dissimilarity measures which substantially deviate from known good templates. Different from the existing work, in this thesis the research scope is currency security and forensics, here work is presented in currency feature selection and classifier selection. To the best of our knowledge, this is the first time the Feed forward Neural Network (FNN) classifier with the combined color and texture feature vector combination has been used to automate the process of comparing banknotes.

BANKNOTE RECOGNITION

A considerable amount of works exist focusing on the area of banknote recognition software intended for application in Automatic Teller Machines (ATMs), automatic banknote sorters, recognition software for the visually impaired (Liu, 2008; Par-louar, Dramas, Macé, & Jouffrais, 2009; Papastavrou, Hadjiachilleos, & Stylianou, 2010; Paisios, Rubinsteyn, Vyas, & Subramanian, 2011; Grijalva et al., 2010) and counterfeit detection.

CURRENCY SECURITY FEATURES

1. The size of this note is 160×70mm duly signed by Mr. Fazle Kabir, Governor, Bangladesh Bank.
2. This note is printed on highly durable paper containing synthetic fiber.
3. This note contains the following watermarks: The Portrait of Bangabandhu Sheikh Muzibur Rahman, the Father of the Nation Numerical '1000' as very bright electrotpe watermark just below the portrait; Bangladesh Bank's logo on the left side of the portrait which is brighter than the portrait.
4. This note contains the following things in intaglio ink which are felt rough when rubbed by finger, Seven parallel slanted straight lines in the right hand side, Portrait of the Father of the Nation Bangabandhu Sheikh Muzibur Rahman in the left hand side, Five small dots at the right hand side for the blinds to recognize the note, Bengali 1000, English 1000, relevant text of the middle portion of the front side, Photograph of National Parliament building.
5. The color of '1000' printed with Optically Variable Ink (OVI) in the upper right hand side will shift from golden to green and vice versa in the event of oscillation of the note.
6. The note has a 4mm security thread embedded on the left side of the note containing the logo of the Bangladesh Bank and the text '1000 uàNà'. Both the 'Bank logo' and the text '1000 UvKv' appears white when seen directly and black when seen from 90 degree angle.
7. '1000' printed latently in the lower border will be found if the note is hold horizontally.
8. Repeated micro prints of the texts '1000 TAKA' and 'BANGLADESH BANK' in two distinct vertical straight lines can be found on the left to the security thread. Also there are vertical straight lines of the text 'BANGLADESH BANK' just inside the pattern on the back-left side and of the text 'ONE HUNDRED TAKA' on the back-right side. These micro prints can only be seen with the help of a magnifying glass.
9. The text 'BANGLADESH BANK' is printed on the 'Iridescent Stripe' in light blue colour. The colour will vary when the note is oscillated.

10.The front left-side of the note contains the portrait of Bangabandhu Sheikh Muzibur Rahman, the Father of the Nation. The picture of National Monument is printed in light color in the middle of the front side of the note.

11.There are repeated micro prints of the text ‘BANGLADESH BANK’ over the denomination ‘1000’ which is printed in light color at the bottom-left corner on the back side of the note. The micro prints can only be seen with the help of a magnifying glass.

12.There is a photograph of National Parliament building printed in intaglio ink on the back side of the note

Chapter3

Methodology

INTRODUCTION

A comparatively infinitesimal amount of literature exists in support of forensic analysis of questioned currency, when compared to other areas of specialization requiring forensic investigation. There are continual technological advancements promising high levels of security, whilst allowing for stronger security, and more robust currency, these advancements also allow for unauthorized currency reproduction.

Since the epoch of formal currency systems, currency issuers have faced one common threat, the threat of counterfeit currency. This continual technological advancement of tools and techniques available to both the issuing authorities, and the general public have fueled an incessant battle.

It is well known that the purpose of forensic investigation is to answer questions of a legal nature, this requires scientific investigation to understand the fundamental mechanics of questioned phenomenon. Much of the fundamental mechanics of currency systems is unknown, and shrouded by great mystery, and trade secret style secrecy.

This presents one fundamental problem, forensic science will remain in the wake of counterfeiter skills and manufacturer technologies. With the increasing array of currency variants, and the corresponding lack of forensically motivated literature there is much room to explore. Clearly there is much opportunity to develop currency forensic analysis methodologies and more robust currency.

Design of the thesis: It has been identified that the security of currency is constantly being compromised, the primary motivation for this thesis is to solve the problem and provide a solution, building the foundations for further research. It is envisaged that such a solution be in marketable prototype form with supporting blueprints, therefore a prototype will be designed and developed through research efforts.

Design science research was identified as the ideal research paradigm to follow; design science research supports the design, and development of an artefact to solve an identified problem, where there is no clear literature base, or methods available for solution.

Incrementally, and iteratively a prototype will be developed to satisfy requirements identified during initial investigation, at each increment new requirements which will be fed back into the beginning of the next iteration.

Following the design science methodology, seen in figure 1, there are six high level phases which will be used to manage this research and development project. Following is an explanation of what will be done in each phase, accompanied by a time frame estimate.

Problem Identification and Motivation: Initial investigations have identified that a problem exists, specifically the relentless battle between currency designers and criminals. This has motivated a thesis in developing secure currency and defining forensic investigative methods.

Definition of Objectives for a Solution: It has already been identified that the main objective is to understand and define the mechanics of currency, while

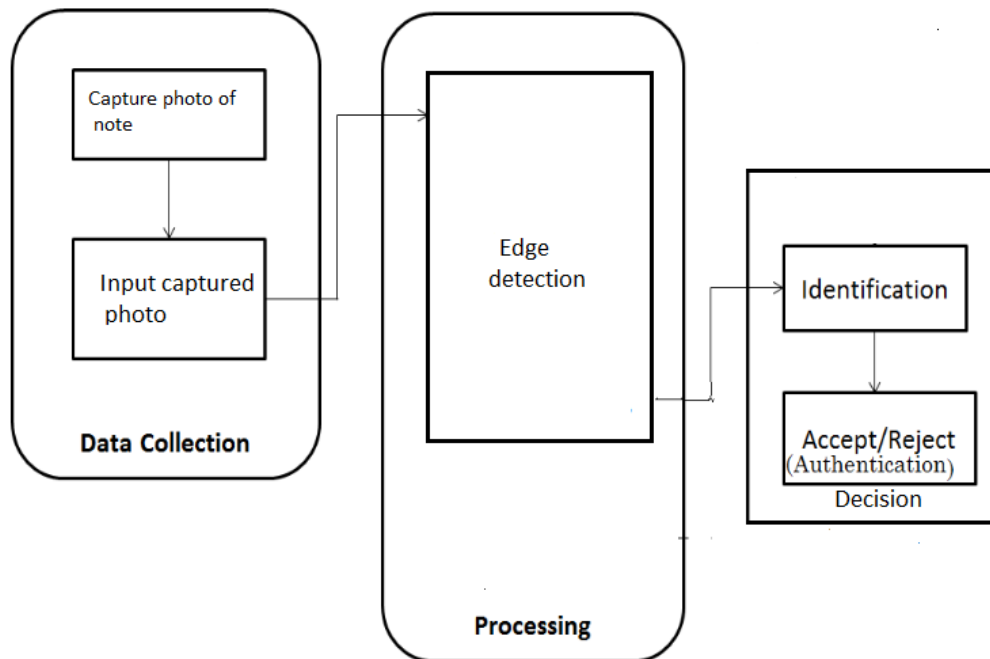


Figure 1: Design science research methodology process

emphasizing the weaknesses so that specific improvements can be made to address identified weaknesses. Objectives will continue to surface as this exploration takes place.

Design and Development: The envisaged artifact is not yet known, and cannot be known at this stage. However, the process will be to use the objectives defined in the previous two phases to influence the required output. Depending on the exact artifact requirements identified in previous phases, specific development methodologies may be employed at this stage.

Demonstration: Demonstration will address the key issues being solved at each iteration end, potential stakeholders will be invited to take part and provide feedback.

Evaluation: Evaluation, immediately following demonstration of outputs, a critical evaluation will take place to determine how well the output satisfies requirements. Based on the type of output at each iteration, specific metrics will be defined for measuring the effectiveness to solve the following problems.

REVIEW OF SIMILAR STUDIES

Color features

Color has been used widely as a prominent feature by banknote designers for the differentiation between denominations; colour features are suitable for computation and analysis, as statistics can be derived for computational description of an image or a scene. A large majority of banknote recognition technology and research in literature applies the use of colour, it is observed that where currencies apply a dominant colour for differentiation, the dominant colour can be calculated and used as part of a feature vector and even as a single feature (García-Lamont et al., 2012).

Texture features

The texture of the Indian Rupee banknotes is considered a more robust descriptive characteristic than color (Verma et al., 2011). The Mazda tool was employed to extract texture features, in total Mazda is capable of gathering 320 useful texture features; the Fisher Linear Discriminant Analysis (LDA) was used for reducing the total number and complexity of actual features selected for end use. Feature reduction is performed by using the Linear Discriminant Analysis (LDA) method. The determination of key features is obtained from a given set D , the d best features on a $d \times D$ linear transformation matrix, A is performed. Following this, a determination of the between class scatter matrix, and within-class scatter matrix where the most discriminating feature is obtained, and used as the key characteristics.

A method was formulated for the recognition of the Mexican Peso banknotes, based on their color and texture features (García-Lamont et al., 2012). It was concluded, many countries globally use color as a key defining feature for the differentiation of banknote denominations, and color is a suitable computable characteristic. The average color is taken at every pixel location and summed to obtain the dominant color of the image:

$$\vec{C}_s = \sum_{i=1}^N \sum_{j=1}^M \vec{C}(i, j)$$

the dominant color is used as the key defining color. It was determined, using this characteristic alone gave a 93.34% accuracy rate on classification with a Linear Vector Quantization (LVQ) classifier; when combined with texture characteristics using the Logical Binary Pattern (LBP) accuracy was increased to around 97.50%.

THE RESEARCH QUESTIONS AND HYPOTHESES

Primarily, the objective is to define the key mechanics of banknotes from a security perspective, and to develop an authentication system to facilitate the forensic analysis of such security mechanics. Initially, a synthesis of the literature was conducted in the form of a literature survey. This survey was conducted over areas of interest specifically related to currency forensics, whilst identifying the major security components, their associated mechanics, and associated attacks. Subsequently, the survey provides an insight into current trends; whilst suggesting future directions to begin design and development of suitable algorithms, and a functional software prototype for demonstration purposes.

Resulting from this survey, further questions were raised regarding the most suitable algorithm design to automate the analysis process.

As there are three channels, there is essentially three individual arrays, for illustrative purposes each channel has been shown as its respective color shown in figure Figure 3.3. Computationally, the individual arrays are represented as intensity values within the respective channel, shown in figure Figure 3.3, thus each channel stores different aspects of

the images, the individual channels may provide information which may be lost when converting to single intensity channel.



Figure 2: 1000 BDT Note of Bangladesh

Each of the individual R, G, and B channels are represented computationally as arrays of equal dimensions, where each corresponding array element of the same coordinate defines the colour characteristics of its respective channel at the (x,y) location. The average at each (x, y) location is calculated, thus for each of the 640×312 elements, the average is taken as $I = \frac{(R+G+B)}{3}$, and the resulting average value is stored as a value between 0 and 255 at the corresponding (x,y) location in the newly created intensity image.

HYPOTHESIS

During this thesis, certain comparisons must be made to determine the most suitable methods for use in the resulting system, currently, the system is designed as such: a banknote image is input, the image is: 1) classified, and 2) authenticated. There are two primary functions namely: 1) classification, and 2) authentication. Classification is imperative to determine the current banknote denomination under examination, once the note is classified it is then authenticated against a known good value in the database, and an estimation of similarity is output.

A series of hypotheses are formulated, first, the motivation is to determine which of the key characteristics is the most effective in contributing the most to overall classification accuracy; if there is no suitable performance by either colour features or texture features alone, a comparison must be made to identify the most important rotation of vector. Finally, analysis of individual key features within each of the two-part vector is necessary to verify individual characteristic effectiveness. Subsequently, to optimize overall classifier effectiveness and accuracy it has been identified through review of similar applications, the most suitable color space for the intended application must be selected. The most prominent color spaces examined during the literature review were: (1) red, green, and blue (RGB); (2) hue, saturation and intensity (HSI); and (3) Lab, Lightness, 'a' color opponent value, and 'b' color-opponent value. Each color space has intrinsic characteristics making it more suitable for use in certain scenarios, the color space used for the feature extraction is a fundamental determining factor to the overall accuracy of classification, and therefore must be tested and compared to find the most suitable one for use in this application.

A comparison between shortlisted candidate classifier, and pattern recognition methods must be made in order to verify suitable candidate classification, feature vector, and color space combination. The four shortlisted candidate classifiers are compared by direct side-by-side performance evaluation. Direct performance evaluation is conducted on the classifiers using identified key characteristics combination in section 3.4.1, the highest performing combination of characteristics is selected as the final shortlist, this will comprise the final feature vector used to train the four aforementioned classification algorithms, and then evaluation is performed by side-by-side comparison.

TEMPLATE MATCHING

A similarity measure is output to the user of the system, the similarity measure is obtained by a direct comparison of a representative preselected known good example template image for each denomination. A direct comparison is made between the template and suspect input banknote image, in performing the comparison a calculation is made between the input

vector, and the template note vector. The calculation performed between the suspect note vector, and the template note vector is performed by usage of the inner product.

THE RESEARCH DESIGN

As indicated in previous section , the primary objective of this research project is to produce a prototype system to demonstrate with sufficient capability for banknote recognition, classification, and authentication; it is intended that this functionality primarily assist forensic investigations, and potentiality, currency security applications. The DSRM paradigm loosely defines the overall structure which a project will follow, we may enter the process at any point within the life cycle, and iterate accordingly, as needed. Initially, in this thesis, we begin with DSRM 1.0 Problem Identification & Motivation. Clearly, during initiation of this project we have demonstrated motivation to investigate the topic of digital currency forensics, and to provide a solution, through a preliminary literature review various enduring problems have surfaced primarily relating to the on-going arms race between, the currency issuing authorities, and counterfeiters, fueled by continual technological advancements available to both parties.

Consequently, the primary problem has been defined, from a forensic investigation point of view, there is a gap in knowledge; binding knowledge of the top secret security printing industry, counterfeiters, and specialist trained sought after Questioned Document Examiners (QDEs), to formulate systematic, and methodological investigative methods. From this, a tentative solution shown in figure Figure 3.1, has been formulated in which color descriptor features, and texture descriptor features are concatenated to one single feature vector for classification, followed by similarity comparison measurement.

During the experimental phase, a collection of banknote images was compiled, Predefined characteristics were identified as color histogram shape descriptors: *mean*, *skew*, *variance*, *standard deviation*, *kurtosis* and *central moment*. The texture features *entropy*, and GLCM statistics *homogeneity*, *energy*, *contrast*, and *correlation* were extracted, and concatenated with the color feature vector. The three most prominent color spaces observed in the literature will be examined, and compared for classification accuracy; it has been observed in the literature, using specific channels of each color space can provide significant improvement or reduction in classification accuracy depending on the application, and thus the channels within the color space will be compared also.

To perform a comparison of the color spaces observed in the literature, three have been shortlisted as the most prominent used throughout the literature, in similar applications. In particular the RGB, HSI and Lab color spaces appear to be the most prominently used, and thus investigation of these color spaces will be undertaken. For this, an experiment will be initiated where all eleven of the original color, and texture features will be extracted from

the banknotes; during each iteration of the experiment the variable color space will be changed. Through the characteristic color, and texture extraction phase, the characteristics will be extracted as R, G, B, $((R + B + G)/3)$, HSI(I), L , a , b . Secondly, classifiers will be trained to classify based on the respective color spaces; hence, an observation will take place whereby the only variable changed is the color space used during each scenario, and results will be compared to find the scenario with the highest accuracy.

As mentioned in previous section, a primary objective of this thesis is the selection of optimal descriptive features, in order to select the optimal features: experiments will be conducted to identify the key features. Initially, four supervised learning algorithms were trained for the task of pattern recognition; firstly, an AdaBoost with 100 weak classifiers, then FNN, CNN, and PRFNN using Bayesian back propagation regulation learning.

Experiments are undertaken in three primary phases:

1) where the accuracy of classification is recorded with removal of texture feature vector, and then removal of the color feature vector for comparison of texture features compared against color features; 2) removal of individual characteristics whilst recording the accuracy, the accuracy with individual feature removed determines how much the individual feature contributes to the overall performance; 3) once the suitable combination of features has been determined the classifier accuracy is compared, whereby all feature elements are considered, the only variable changed is the classifier used.

DATA REQUIREMENTS

A selection of descriptive measures regarding the shape of the aforementioned intensity histogram shape have been shortlisted using the literature and initial pilot tests; as this thesis is considering the banknote image as a whole, a classifier must perform recognition purely on the captured image. The literature, and initial pilot tests have demonstrated that texture and colour features must be used for computational description of images such as banknotes.

The primary data requirements are those descriptive statistics which make up the two-part color, and texture feature vector. Here, a sample set of banknote images within a specific currency series must be compiled, in this case we are using the current currency series of the Bangladesh Bank. being that this is the current country this thesis is being undertaken within, however, it must be noted as in this same approach can be used for any currency series where color is used to differentiate the individual denominations from one another.

Subsequently, as mentioned, the three most prominent colour spaces, and their channels will be examined to determine the most suitable colour space and channel for use in the application of recognition, for currency, where colour is a key discriminating factor.

Primarily, we will obtain the RGB channels individually for comparison between individual

channels, obtain an average value across all channels defining an intensity image data set, the *I* intensity channel from the HSI colour space will be used providing a data set of the *I* channel, the lightness, and ‘a’ color-opponent, and ‘b’ color-opponent channels of the Lab colour space will make up the rest of the color space dataset.

To determine the overall accuracy, it has previously been indicated that the primary data or feature vectors will define the variables within the experimental phase, the feature vectors are modified in each scenario in order to perform comparisons between experiments.

Resulting from the aforementioned experimental phase data will be collected, indicating the according performance level, a percentage level will be the primary indicating factor stating the observed accuracy, whence, each individual variable is removed from the feature vector thus indicating contributions to overall effectiveness..

LIMITATIONS OF RESEARCH

The primary limitation on this research project is that of the total amount of banknotes comprising the sample dataset, during a narrow window of time banknote images are to be collected from each of the five denominations on the RBNZ denominations \$5, \$10, \$20, \$50 and \$100. The lower denominations from \$5, \$10 and \$20 are the most commonly used denominations in every day transactions within New Zealand. The denominations \$20, \$50 and \$100 are the most commonly to be issued by ATMs, a small proportion do however dispense the \$10. The lower denominations \$5 and \$10 move around more frequently than the larger denominations, as the value of the denomination increases it is typically used less. These factors limit this research in such a way that the variability of banknote wear and tear is not uniform across the denominations, meaning, in the lower denominations we will expect to observe a wider variability in captured image quality; whereas, in the higher denominations we will expect to observe quite uniform results, thus minimum variability. However, it could be argued: as this is data that is collected from real-world examples of banknotes in circulation that this limitation could in actuality be seen as a necessary factor to ensure that the digital currency forensics system is trained for typical real-world data, and thus trained for realistic events.

The fact that the circulation of currency decreases as the denomination value increases, there will clearly be less samples to work with as, thus, being that there are less samples to work with as the denominations increase there is consequently less data in which to train the classifiers, and to test later perform experiments to assess accuracy. Similarly, as it is expected that there will be less variation in observed descriptive statistics as the denominations increase, we may argue that any difference in individual denomination sample size may be inconsequential due to the fact that this is also pertinent to the real-world, and thus any concern of discrepancy maybe seen as redundant as a result.

The solution proposed in this research is to evaluate the similarity of the suspect note in relation to the template note based on an inner product comparison, this comparison considers the image fidelity of the suspect compared to the template. The template image is a pre-selected image, based on the choice of the system designers, the template image for each denomination is a randomly chosen sample out of a given set of known good samples. This sample is subjective, and representative of the entire database, however if an average were to be taken across the entire database of known good templates, it could be said that we are taking the average rather than specific comparison to one banknote image in particular. Clearly, the comparison made is subjective to the choice of template banknote, it could be argued that we know in advance that the randomly selected template image is known to be authentic and therefore is a good candidate, however it could also be argued that we must take an average across the entire data set of known good templates for each vector comparison. Therefore, it may be seen as a limitation in that we have decided to select a known good sample rather than using the average across the template dataset as the comparison values.

The primary issue noted is that the process of analysis is based on human evaluation, and is therefore subject to human error, it was also identified that to be fully robust, any forensic analysis process must be both methodological and systematic meaning that it must be repeatable and verifiable. Clearly, a process which is entirely reliant on manual labor is subject to human error, and dispute between potential opposing experts, therefore, it has been identified that an automated digital currency forensics system would satisfy the aforementioned requirements.

Primarily, as such a system is automated we can ensure that the process will be systematic and repeatable, therefore, if an investigation required forensic analysis of currency, we could ensure similarity between results from both opposing sides with any discrepancy being due to the prior acquisition process. Secondly, as this is an automated system we can verify its methodological approach to analysis, the analysis process is as such performed computationally by an algorithm thus repeating the same process for each banknote in question. Therefore, this process follows a tested method throughout the study of this thesis and is open to peer review for future improvement.

In particular, the aforementioned process can be loosely summarised as such: a pre-acquired banknote of an arbitrary size is input to the system. The banknote is converted from the raw RGB color space to an equally weighted average of the RGB contribution to the overall system.

Similarly, the most prominent classifiers throughout the literature will be evaluated, it was noted in the literature that the *AdaBoost*, *PNN*, *CNN*, *SVM*, *FNN*, *PRFNN* classifiers were the most commonly used and therefore are the shortlisted candidates. The classification step is a necessary step in the forensic analysis process, as to make a fully automated system we

need a system which is capable of identifying the denomination its self without human intervention. This is because the end implementation, is, at this point unknown, for best performance no human intervention must take place, and therefore classification is necessary. It is widely known that certain classifiers will perform differently under different circumstances, and thus, it is imperative to select the most suitable one for any application where such is required.

Finally, after the template database has been established, feature vectors have been extracted and defined, and template known good banknotes have been selected, a direct comparison will take place. The direct comparison is performed by the pre-selection of the known good value for the banknote denominations, a feature vector is extracted, and defined, a direct comparison takes place by calculating an inner product calculation for comparison.

Chapter4

Findings

APPROACH

The approach in this thesis is to use a combination of image processing, and classification techniques to identify banknote denomination by colour, and texture features. Banknote recognition, and denomination identification is made possible by extracting computable features for describing colour, and the texture of acquired banknotes, then, classifying against a database of learned known good template images. Once the banknote has been identified, and classified, a similarity measurement is calculated and output for side-by-side comparison.

To test the algorithm proposed by this thesis, a number of comparisons were undertaken to identify the most suitable feature vector, classifier, and colorspace combination. From this point forward, various tables are presented demonstrating the accuracy of each scenario in percentage values, collected during the data collection phase. Please note, for presentation purposes, some key information has been truncated, and where information has been truncated, an explanation is present. For example, experiments were conducted, comparing the direct accuracy from one scenario versus another, identical samples were used for comparison; in representing the front and back sides of the note, and thus all samples of that type within the respective class.

PRE PROCESSING

Initially, pilot tests were conducted to investigate the potential accuracy of the most prominent colour spaces observed throughout the literature, following this: RGB, HSI, and Lab colour spaces were shortlisted as final candidates. As shown in table Table 4.1, the intensity or grey-level, which in this thesis is the combined average of the *R*, *G*, and *B* channels, weighted equally, is found to provide the highest level of accuracy. It was observed, that when performing the classification task across all possible denominations combined, an accuracy totaling 97.66% occurs under the conditions of this experiment; as expected, the variability primarily appears to occur within the lower denominations. Interestingly, the *R*, and *G* channels provide the next best performance, at 28.65%, and 27.49% respectively. Clearly, the combined grey-level of the RGB colour space is the most suitable candidate, and in conclusion, the digital currency forensics system will use the the grey-level, or grey-world algorithm.

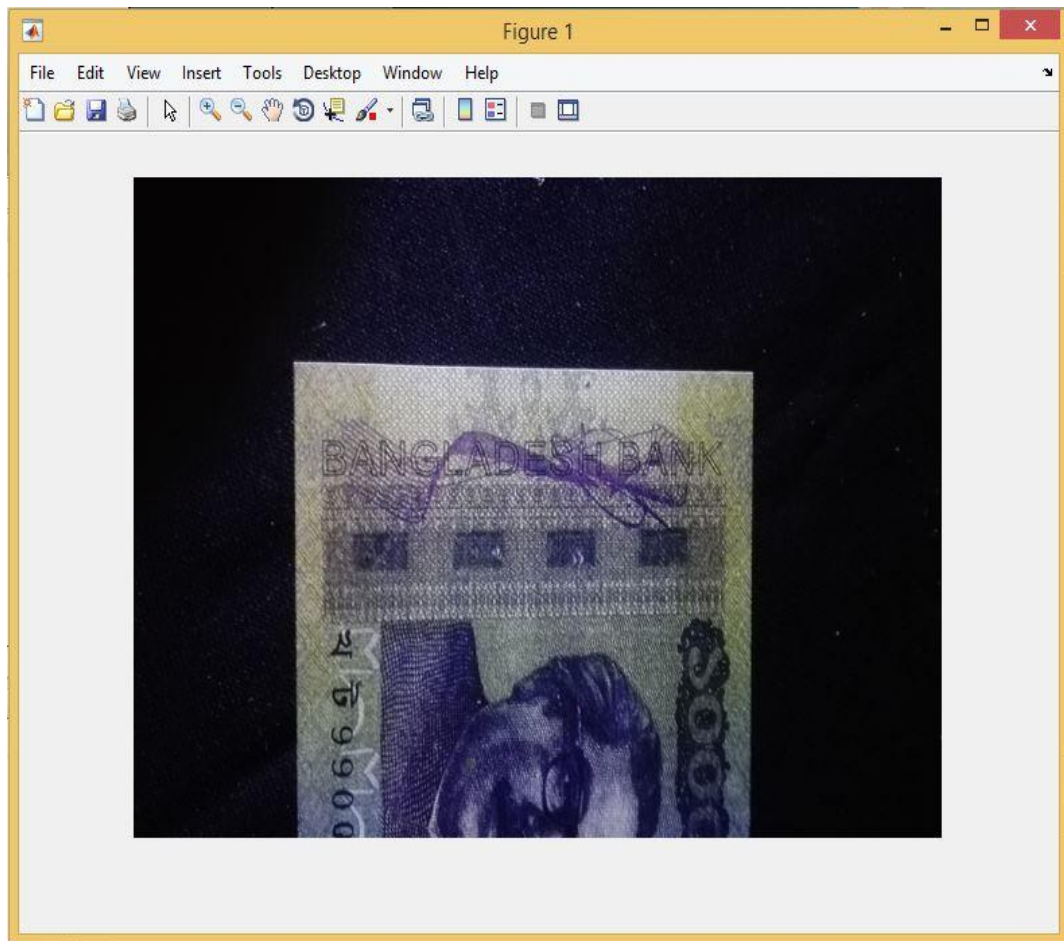


Figure1:Pre processed captured image

Image Acquisition:

The first stage of any vision system is the image acquisition stage. After the image has been obtained, various methods of processing can be applied to the image to perform the many different vision tasks. Performing image acquisition in image processing is always the first step in the workflow sequence because, without an image, no processing is possible. There are various ways to acquire image such as with the help of camera or scanner. Acquired image should retain all the features.

Gray Scale Conversion:

The image acquired is in RGB color. It is converted into gray scale because it carries only the intensity information which is

easy to process instead of processing three components R (Red), G(Green), B(Blue). to take the RGB values for each pixel and make as output a single value reflecting the brightness of that pixel. One such approach is to take the average of the contribution from each channel: $(R+B+G)/3$.

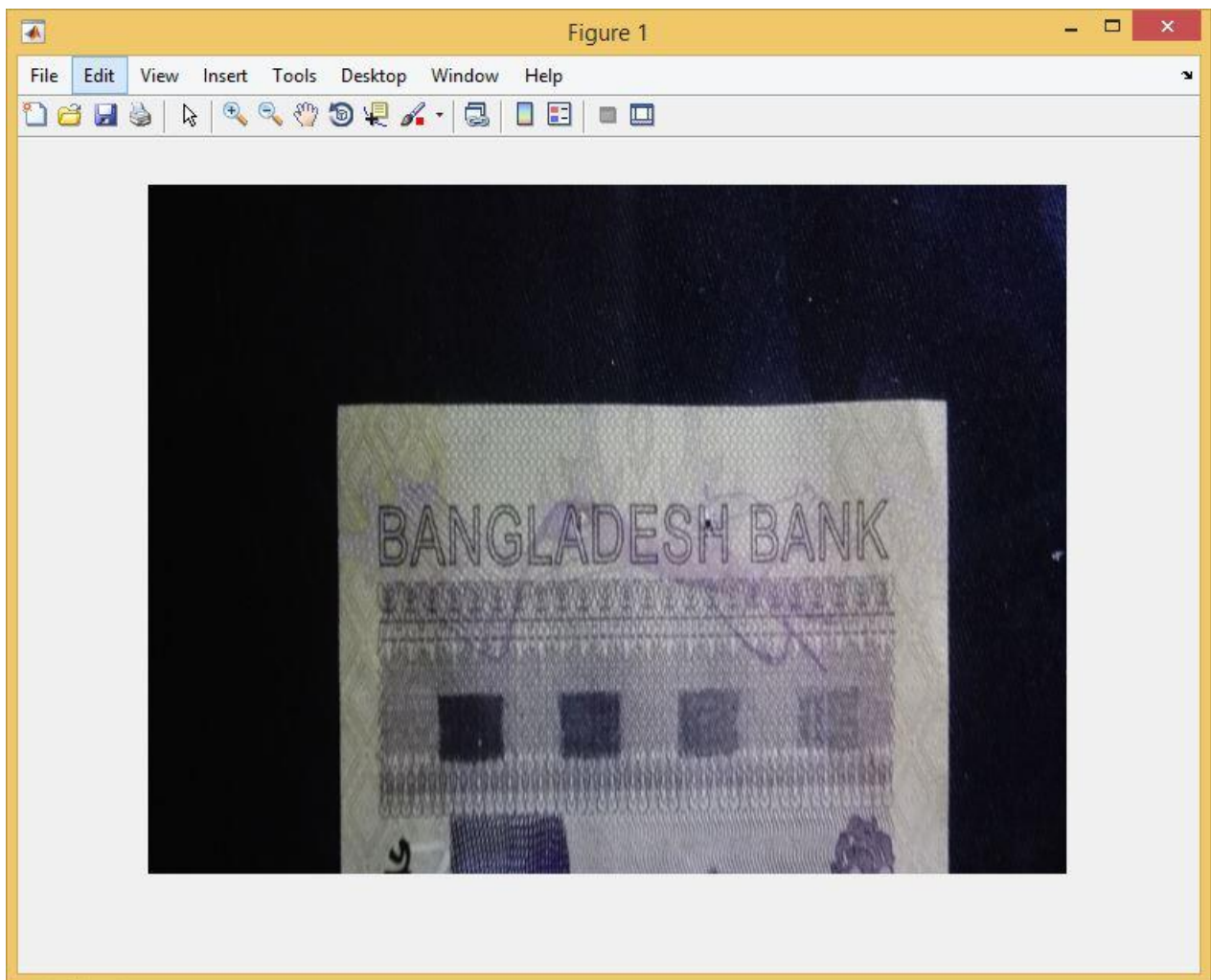


Figure 2: Grayscale converted image.

Edge Detection:

Edge detection is the name for a set of mathematical methods which aim at identifying points in a digital image at which the image brightness changes sharply or, more formally, has discontinuities. The points at which image brightness changes sharply are typically organized into a set of curved line segments termed edges. The same problem of finding discontinuities in 1D signals is known as step detection and the problem of finding signal discontinuities over time is known as change detection. Edge detection is a fundamental tool in image processing, machine vision and computer vision, particularly in the areas of feature detection and feature extraction. Edge detection is an image processing technique for finding the boundaries of objects within images. It works by detecting discontinuities in brightness. Edge detection is used for image segmentation and data extraction in areas such as image processing, computer vision, and machine vision. Based on this one dimensional analysis, the theory can be carried over to two dimensions as long as there is an accurate approximation to calculate the derivative. Image segmentation is typically used to locate objects and boundaries (lines, curves, etc).

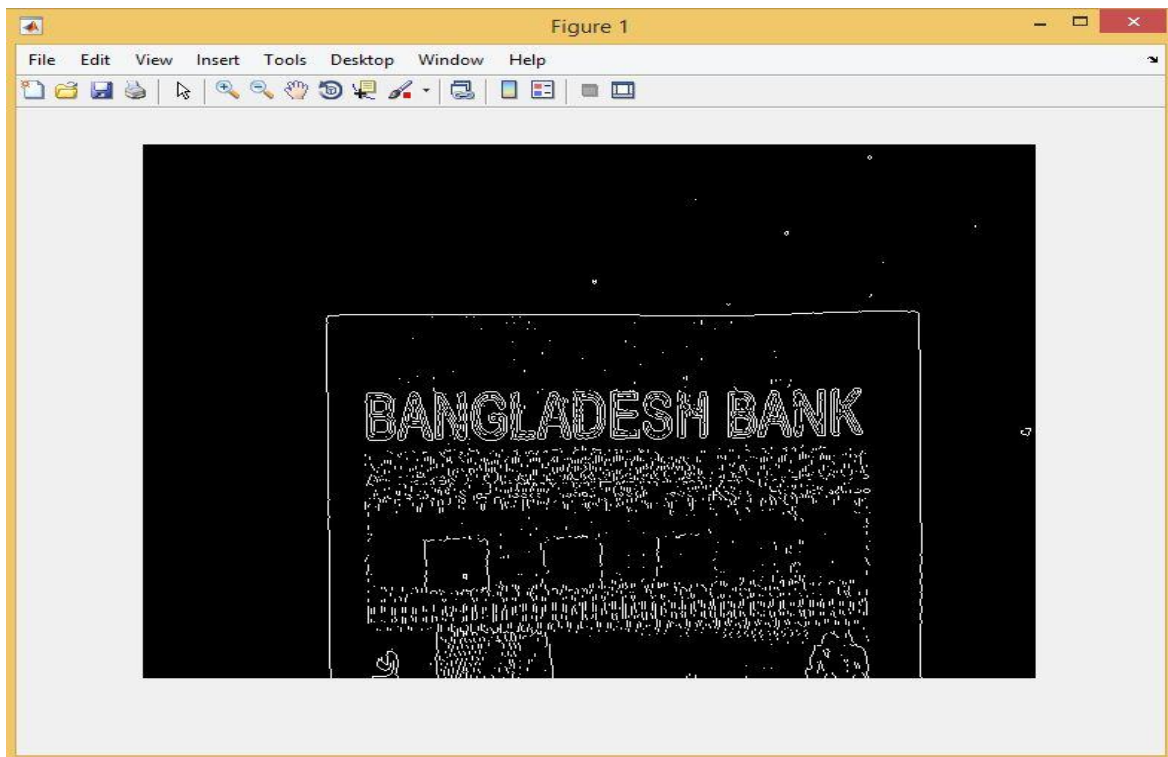


Figure 3 : Edge detected image output of 1000 taka

EXPERIMENT RESULTS

The currency forensics system has been prototyped in the MATLAB environment running under the platform. A second experiment was performed, networks were trained, each using the feature vector minus one characteristic. The intention was to determine the level of accuracy upon removing a particular characteristic, therefore, determining each characteristic's contributing effectiveness. The subcategories are used as the training set, with a total of 30 number of notes.

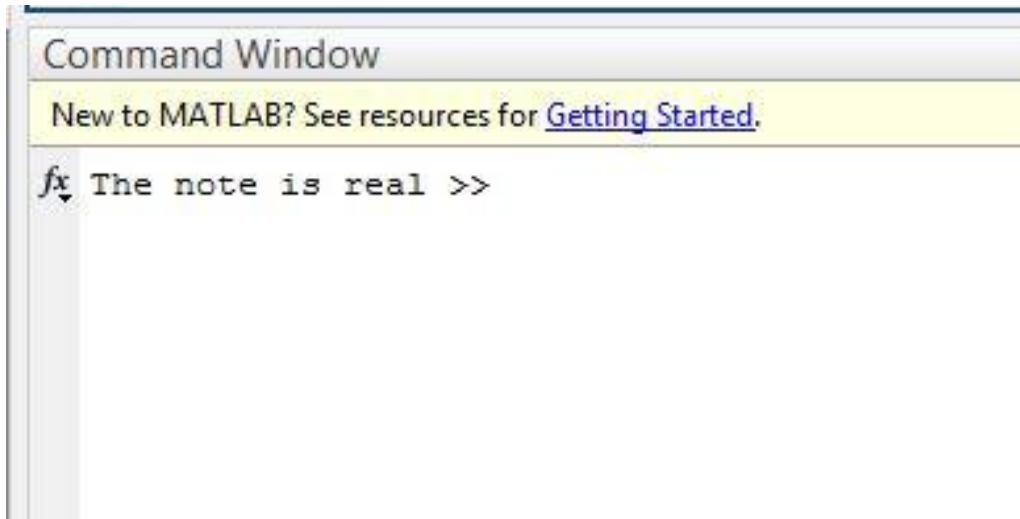


Figure 4: Result of real currency

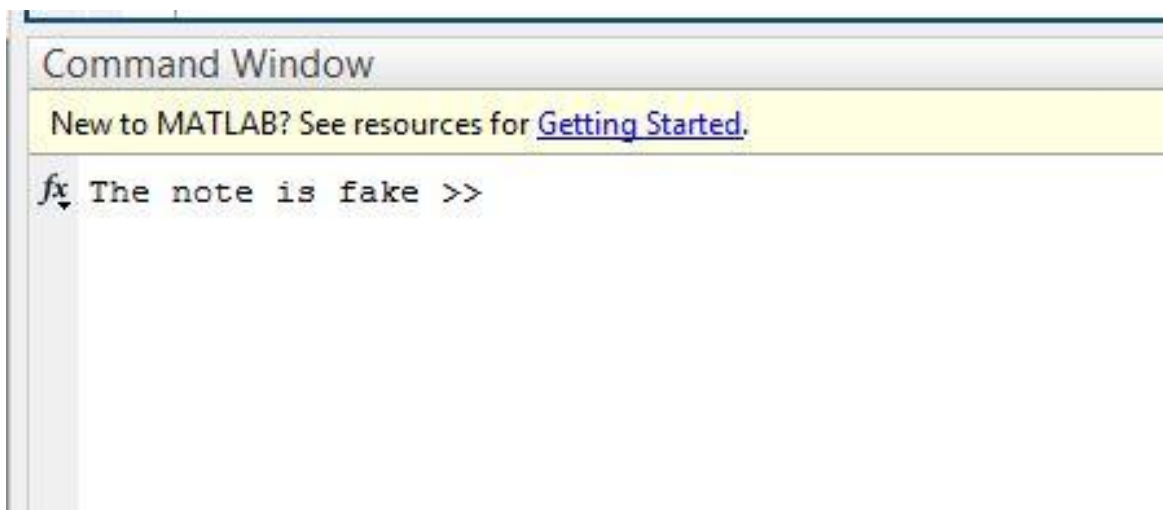


Figure 5 : Result of fake currency

Test Instances	Test results
1	Correct
2	Correct
3	Correct
4	Incorrect
5	Correct
6	Incorrect
7	Incorrect
8	Correct
9	Correct
10	Incorrect
11	Correct
12	Correct
13	Correct
14	Correct
15	Incorrect
16	Incorrect
17	Correct
18	Incorrect
19	Correct
20	Correct
21	Incorrect
22	Correct
23	Incorrect
24	Incorrect
25	Correct
26	Correct
27	Correct
28	Incorrect
29	Correct
30	Correct

Table 2 : Table of experimented results

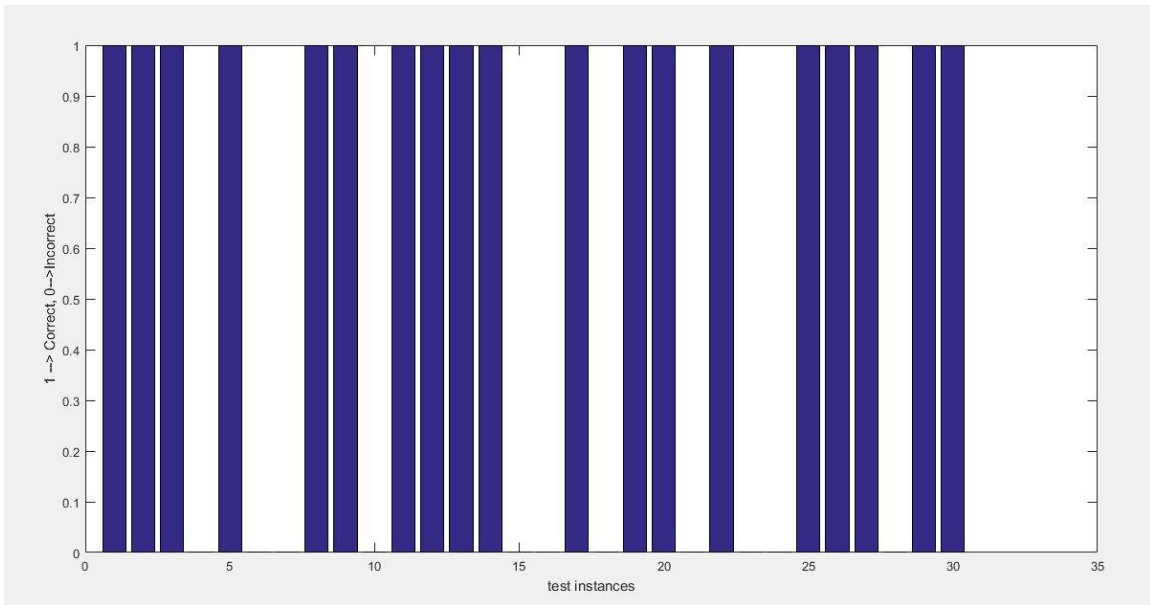


Figure 6: Graph of results

Accuracy rate = (No. of Correct readings/Total No. of readings)*100

$$= (19/30)*100 = 63.34\%$$

Chapter5 Discussion

REFLECTION

A digital currency forensic method has been defined, an authentication method has been formulated based on classification of currency notes using intrinsic colour, and texture features, followed by template matching. Template matching is conducted using the inner product of the suspect banknote, and a known good template banknote image. This gives the forensic investigator a level of confidence, indicating the measure of similarity as a percentage for suspect banknote images, against known good images within a template database. Experiments have been conducted to assess the accuracy of candidate features, and classifiers, the results suggest that a suitable framework has been constructed.

There are remaining areas of interest to be explored, currently we have explored the relationships between colour, and texture features when applied to classification of Bangladesh banknotes; final tests show that the classification accuracy has been able to be increased from 82.46%, to, 92.40%, and then, 98.60%. The first increase was observed during an experimental phase, whereby individual characteristics were removed from the feature vectors to observe the accuracy of each. It was found that both the central moment, and the contrast contribute the least to the overall discriminability, and the final increase was achieved with the removal of unusual outliers.

Therefore, the central moment within the feature vector is removed, and we are left with a feature vector containing five colour descriptors, and five texture descriptors. Therefore, the final feature vector is comprised of the colour features: *mean*, *skew*, *standard deviation*, *variance*, and *kurtosis*; and texture features: *homogeneity*, *correlation*, *contrast*, *energy*, and *entropy*. Based on the findings shown in table Table 2, this two part feature vector appears to be sufficient in providing approximately 63.36% accuracy.

EVALUATION

Evaluation of this proposed method is primarily based on classifier accuracy, and the similarity measurement of suspect banknote when compared against the template banknote. Consequently, in section 3, specific hypotheses were defined stating determining factors relating to the final selection of characteristic descriptors, the key descriptors are fundamental to classification accuracy. Therefore, the hypotheses of this thesis focus primarily on key characteristic feature selection.

In the following, an analysis of the accuracy of each characteristic will be evaluated, and related back to the initial hypotheses defined in section 3:

1. **Hypothesis 1.0:** A feature vector comprised of both colour features, and texture features significantly improves the classification accuracy when applied to

currency, where colour is used as a major differentiating feature between denominations .

2. **Alternative hypothesis 1.0:** A feature vector comprised of both colour features, and texture features does not show significant improvement of the classification accuracy when applied to currency, where colour is used as a major differentiating feature between denominations.
3. **Hypothesis 2.0:** Redundant, and non-ideal characteristic features exist in the feature vector, removal of redundant characteristics will improve overall accuracy.
4. **Alternative hypothesis 2.0:** Redundant, and non-ideal characteristic features exist in the feature vector, removal of redundant characteristics will not result in sufficient improvement in overall accuracy.
5. **Hypothesis 3.0:** The colour space used to extract the features influences the overall accuracy of the classification component of the system.
6. **Alternative hypothesis 3.0:** The colour space used to extract the features has no noticeable influence on the overall accuracy of the classification component of the system.

Hypothesis from the previous, regard the outcome of classifier accuracy when using either colour, or texture features, from the results in table Table 4.5, and table Table 4.4, considerably similar accuracy is contributed to the overall accuracy. Consequently, it is interesting to note, classification accuracy during the experimental phase concluded that we can obtain more, or less, the same results when using either colour, or texture. Similarly, when concatenating colour, and feature vectors together, we observe a slight increase in accuracy, from 86.55%, to, 87.72% when the order of concatenation is texture and colour, compared against colour and texture, respectively. Therefore, we can conclude; when considering all variables present in this thesis, the order of the characteristics in the feature vector does influence the accuracy of the digital currency forensics system.

JUSTIFICATION

To justify the proposed solution for digital currency forensics, a prototype has been formulated, and developed in the MATLAB programming environment using the image processing, and neural network toolboxes to demonstrate the applicability of this solution. Providing the forensic investigator with a calculated percentage level of similarity between suspect note and template note simplifies the process of analysis, when compared to performing manual analysis, this increases the applicability of using the same methods

across multiple currencies of similar types. Thus, this process can be made more streamlined, as this is a repeatable process it satisfies the requirement of forensic analysis to be systematic, and methodological in nature.

Chapter6

CONCLUSION

The following section concludes this thesis by firstly summarizing the previous chapters, and then by identifying future research directions.

SUMMARY

In conclusion, currency is a formal medium for exchange used to facilitate the transfer of property or ownership from one party to another, the current currency systems are composed of a complex combination of coins, banknotes, and electronic currency variants. Throughout history, issuing authorities have faced one common threat, the threat of counterfeiting, today it appears that counterfeiting remains an on-going arms race, fuelled by the continual technological advancements in reprographic equipment available to both the currency designers, and the general public. The currency forensics analysis process is hindered by the fact that the banknote manufacturing industry is extremely secretive, the fundamental mechanics of security components are often closely guarded trade secrets, where much of the security.

FUTURE WORK

To date, there is little research in the area of forensic science focusing strictly on currency when compared to other areas of dedicated forensic science specialties. Other areas of discipline were examined to build a foundation through a literature review, and survey paper; the survey was conducted with the primary focus in mind that we as forensic investigators must understand the fundamental mechanics of banknotes including the process of security printing, and banknote manufacturing, the ingredients, and characteristics of substrates, inks, and complexities of integrated security components.

Extensive research exists for computer vision, and machine learning for application in ATMs, banknote sorting machines, self-service payment kiosks, and visual impairment assistance, the primary focus in these applications is to ensure security, by determining the correct denomination at time of transaction. Research in this area looks at the texture of the substrate surface, pixel distribution patterns, pigments in ink, fluorescence levels emitted from specific parts of the note, and strict analysis of specific regions of interest.

Ultimately, a robust form of currency to both forgery and fatigue is desired, polymer the latest in banknote substrate. Even polymer is not immune to counterfeiting, and appears that the level of sophistication is on the rise.

Analyzing how ink reacts to polymer may eventually enable for the determination of ink age on polymer substrates. Evidence to determine the date for the actual forgery, supposing the ink was bought commercially, the raw material makeup of the ink should lead us to possibilities of determination of location to begin a trail to follow for investigation.

There are many aspects of physical currency yet to explore, the watermark, security threads, and fibers are some of the oldest, and simplest yet most effective techniques in securing documents. These methods are incredibly difficult to replicate, crude attempts have been seen, yet these are not evidently not always used in banknote authentication devices.

The governance of electronic currency systems is lacking, and therefore needs to be reviewed. Proposals have been put forth suggesting models to integrate virtual currency, and physical currency, thus bridging the gap. Not only do systems need to be reviewed for integration models, the jurisdictional issues defining the rules and regulations within these systems collaborating with other systems, need to be specified in consideration of this ubiquitous paradigm.

Future work will see in-depth analysis of the current methodology employed by this proposed solution, it is required that a 99% accuracy rate be achieved, such analysis will focus on the training, and testing size of the sample set, this will be made possible whereby over a longer duration of time, a wider array of banknote images will be acquired for testing purposes. Consequently, the characteristics used to computationally describe the acquired banknote images will be refined, further analysis of the color descriptors, and texture descriptors will be explored.

Through the experiments conducted during the process of this thesis, it was observed that the RGB color space is the most suitable for the application of digital currency forensics. In particular, the equally weighted grey-level, intensity level, provided the most accurate results, and thus is selected as the final candidate. The equal weighting between the *R*, *G*, and *B*, channels was used purely to perform a direct comparison between the shortlisted color spaces observed in Section 2, namely: *HSI*, *Lab*, and *RGB*. In addition, it would be beneficial to adjust the scope to expand the current research with the intention to explore the relationship of the individual *R*, *G*, and *B*, channels, with such exploration it is envisaged that the accuracy will be improved and fine tuned to bring the digital currency forensics system accuracy closer to the 64% goal.

On a final note, it is interesting to note that the technique of describing banknote images by their color, and texture features can be employed on any currency, world wide, where the use of color is one of the key points determining which denomination is currently being analyzed.

References

- Adams, G., Pollard, S., & Simske, S. (2011). A study of the interaction of paper substrates on printed forensic imaging. *Proceedings of the 11th ACM symposium on Document engineering (DocEng '11)*, 263-266.
- Beekhof, F. P., Voloshynovskiy, S., Koval, O., Villan, R., & Topak, E. (2008). Document forensics based on steganographic anti-counterfeiting markings and mobile architectures. *Proceedings of the 1st international conference on forensic applications and techniques in telecommunications, information, and multimedia and workshop (e-Forensics '08)*, 1-5.
- Bender, K. (2006). *Moneymakers*. Berlin: John Wiley and Sons.
- Berthier, S., Boulenguez, J., & Bálint, Z. (2007). Multiscaled polarization effects in *Suneve coronata* (Lepidoptera) and other insects: application to anti-counterfeiting of banknotes. *Applied Physics A: Materials Science and Processing*, 86(1), 123-130.
- Bulan, O., Mao, J., & Sharma, G. (2009). Geometric distortion signatures for printer identification. *Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP'09)*, 1401-1404.
- Burger, A. (2009). *The Devil's workshop: a memoir of the nazi counterfeiting operation*. Barnsley: Frontline Books.
- Chang, C. C., Yu, T. X., & Yen, H. Y. (2007). Paper currency verification with Support Vector Machines. *3rd International IEEE Conference on Signal-Image Technologies and Internet-Based System (SITIS '07)*, 860-865.
- Chia, T. H., & Levene, M. J. (2009). Detection of counterfeit U.S. paper money using intrinsic fluorescence lifetime. *Optics Express*, 17(24), 22054-22061.
- Clarkson, W., Weyrich, T., Finkelstein, A., Heninger, N., Halderman, J. A., & Felten, E. W. (2009). Fingerprinting blank paper using commodity scanners. *30th IEEE Symposium on Security and Privacy*, 301-314.
- Daraee, F., & Mozaffari, S. (2010). Eroded money notes recognition using wavelet transform. *6th Iranian Machine Vision and Image Processing (MVIP)*, 1-5.
- Dasari, H., & Bhagvati, C. (2007). Identification of non-black inks using HSV colour space. *9th International Conference on Document Analysis and Recognition (ICDAR '07)*, 1, 486-490.

Debnath, K., Ahmed, S., Shahjahan, M., & Murase, K. (2010). A paper currency recognition system using negatively correlated neural network ensemble. *Journal of Multimedia*, 5(6), 560-567.

Debnath, K. K., Ahdikary, J. K., & Shahjahan, M. (2009). A currency recognition system using negatively correlated neural network ensemble. *12th International Conference on Computers and Information Technology, 2009.*, 367- 372.

García-Lamont, F., Cervantes, J., & López, A. (2012). Recognition of Mexican banknotes via their color and texture features. *Expert Systems with Applications*, 39(10), 9651-9660.

Gaubatz, M. D., & Simske, S. J. (2009). Printer-scanner identification via analysis of structured security deterrents. *1st IEEE International Workshop on Information Forensics and Security (WIFS'09)*, 151-155.

Gaubatz, M. D., Simske, S. J., & Gibson, S. (2009). Distortion metrics for predicting authentication functionality of printed security deterrents. *16th IEEE*

