DISCRIMINATION OF COUNTERFEIT FIFTY RINGGIT MALAYSIA BANKNOTES USING ATTENUATED TOTAL REFLECTANCE-FOURIER TRANSFORM INFRARED SPECTROSCOPY AND CHEMOMETRIC METHODS

FOO KEAT HOW

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DEDICATION

This thesis is dedicated to my beloved parents and wife, who taught me that the best kind of knowledge to have is that which is learned for its own sake and the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Counterfeiting of banknotes is one of the oldest criminal activities since 5th century AD and it still a constant concern to various countries including Malaysia because of its effects on the economy. With the continuous improvement and advanced printing technology nowadays, the task of identifying counterfeit banknote is getting more formidable. This study presents the Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy in combination with chemometric tools as an analytical method to discriminate authentic and counterfeit RM50 banknotes. The counterfeit RM50 banknotes were obtained on loan from Commercial Crime Investigation Department (CCID), Royal Malaysia Police (RMP). The RM50 banknotes samples were first examined under video spectral comparator (VSC) followed by the characterization of the genuine and counterfeit RM50 banknotes in the IR fingerprint region (1800-650 cm^{-1}) using ATR-FTIR. Fifteen areas of the RM50 banknotes samples were scanned for examining its functional groups in the IR fingerprint region and five areas of the RM50 banknotes samples were then selected into chemometric study. These parameters were computed using Solo 8.6 software to determine the organization of dataset and the main contributing factors for grouping using the unsupervised PCA. Supervised PLS-DA models were developed for predicting the unknown samples. PCA scores with more than 90% of variances was attained illustrating it as the main factors contributing for grouping. Although ATR-FTIR spectra was adequate for differentiating the genuine and counterfeit RM50 banknotes samples, PCA was applied for better separation in view of its practical values in forensic investigations, resulting few distinct clusters differentiating the genuine and counterfeit RM50 banknotes samples and within the counterfeit RM50 banknotes samples. The reliability of the PLS-DA results were examined based on its RMSEC, RMSECV and RMSEP values, and were acceptable for discrimination of genuine and counterfeit RM50 banknotes samples. Hence, the method of ATR-FTIR spectral data coupled with PCA and PLS-DA can be adopted as a useful complementary tool in RMP investigation for discriminating the genuine and counterfeit RM50 banknotes samples.

ABSTRAK

Pemalsuan matawang adalah antara aktiviti jenayah tertua sejak abad ke-5 AD dan ia masih menjadi kebimbangan berterusan kepada pelbagai negara termasuk Malaysia kerana kesannya tarhadap ekonomi. Dengan penambahbaikan teknologi pencetakan canggih sekarang secara berterusan, usaha untuk mengenalpasti matawang palsu adalah semakin menyukarkan. Kajian ini menunjukkan keupayaan gabungan spektroskopi Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) dengan kaedah kemometrik sebagai kaedah analisis dalam mendiskriminasikan matawang RM50 tulen dan palsu. Sampel matawang RM50 palsu telah dipinjam daripada Jabatan Siasatan Jenayah Komersil (JSJK), Polis Diraja Malaysia (PDRM). Sampel matawang RM50 berkenaan pada mulanya telah diperiksa dibawah video spectral comparator (VSC) kemudian diikuti dengan pembandingan ciri-cirinya di dalam lingkungan cap jari IR (1800-650 cm^{-1}) dengan menggunakan ATR-FTIR. 15 titik daripada setiap sampel matawang RM50 tersebut telah diimbas untuk memeriksa kumpulan fungsi kimianya di dalam lingkungan cap jari IR dan lima tempat daripada setiap sampel matawang RM50 tersebut kemudiannya telah dipilih untuk kajian kemometrik. Kedua-dua parameter tersebut disimulasi menggunakan perisian Solo 8.6 untuk menentukan organisasi set data dan faktor penyumbang utama bagi pengelompokan dengan menggunakan PCA yang tidak terselia. Model ramalan PLS-DA yang diselia telah dibina untuk meramalkan sampel anu. Pencapaian skor PCA yang melebihi variasi 90% menggambarkan ia sebagai faktor utama menyumbang kepada pengelompokan. Walaupun spektrum ATR-FTIR adalah mencukupi dalam membezakan antara sampel matawang RM50 tulen dan palsu. Namun, PCA dapat digunakan sebagai teknik klasifikasi yang lebih baik memandangkan nilai-nilai praktikalnya dalam penyelidikan forensik, dimana ia dapat menghasilkan kelompok yang dapat membezakan antara matawang RM50 palsu selain membezakan antara matawang RM50 tulen dan palsu. Nilai RMSEC, RMSECV dan RMSEP model PLS-DA tersebut telah diteliti dan didapati boleh diterima dalam membezakan antara sampel matawang RM50 tulen dan palsu. Justeru, kombinasi ATR-FTIR bersama PCA dan PLS-DA wajar dilihat berguna kepada pihak PDRM dalam membantu siasatan ke atas kes matawang RM50 palsu.

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LIST OF ABBREVIATIONS

IR	-	Infrared
HPLC	-	High Performance Liquid Chromatography
MS	-	Mass Spectrometry
RM	-	Ringgit Malaysia
ATR-FTIR	-	Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy
PCA	-	Principal Component Analysis
2D	-	2 Dimensional
3D	-	3 Dimensional
PLS-DA	-	Partial Least Square Discriminant Analysis
GA	-	Genetic Algorithm
SW	-	Stepwise Formulation
SPA	-	Successive Projections Algorithm
RMP	-	Royal Malaysia Police
BNM	-	Central bank of Malaysia
CCID	-	Commercial Crime Investigation Department
IP	-	Investigation Paper
UV	-	Ultraviolet
VSC	-	Video Spectral Comparator
ATM	-	Automated Teller Machine
UTM	-	Universiti Teknologi Malaysia
CDM	-	Cash Deposit Machine
RBI	-	Reserve Bank of India
LDA	-	Linear Discriminant Analysis
PC	-	Principal Component
LV	-	Latent Variable
Vis	-	Visible
ZnSe	-	Zinc Selenide
DTGS	-	Deuterated Triglycine Sulfate
SNV	-	Standard Normal Variate

FD	-	First Derivative
SD	-	Second Derivative
RMSEC	-	Root Mean Squared Error
RMSECV	-	Root Mean Squared Error of Cross-Validation
RMSEP	-	Root Mean Squared Error Prediction
R^2	-	Predicted Coefficient of Determination

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Counterfeiting of banknotes is one of the oldest criminal activities since 5th century AD and it still a constant concern to various countries because of its effects on the economy (Almeida *et al.*, 2013; Itrić & Modrić, 2017). Malaysia is among the countries that cannot spare of the counterfeiting banknotes criminal activities.

In addressing the counterfeiting banknotes criminal activities, some non-destructive and destructive forensic analysis have been reported done on the counterfeit banknotes such as identification of counterfeit England £20 banknotes using infrared (IR) spectroscopy (Sonnex *et al.*, 2014) and identification of counterfeit Brazil Real banknotes using Raman spectroscopy (Almeida *et al.*, 2013). For destructive analysis, Xu *et al.*, 2016 have been reported to used high performance liquid chromatography (HPLC) and HPLC/mass spectrometry (HPLC/MS) to analyse the red ink used on the seized counterfeit 100-yuan banknotes.

However, no similar study has been done on counterfeit Ringgit Malaysia (RM) banknotes. Herein, for the first time this study will focus on discriminating the counterfeit RM banknotes using non-destructive attenuated total reflectance-fourier transform infrared spectroscopy (ATR-FTIR) technique and video spectral comparator (VSC). The IR spectrum data will be further explored with chemometric techniques, unsupervised Principal Component Analysis (PCA) and supervised partial least square discriminant analysis (PLS-DA) for classification and discriminating the RM50 banknotes from forensic point of view.

1.2 Problem Statement

Continuing efforts have been put by the Royal Malaysia Police (RMP) who have been cooperates with the Central Bank of Malaysia (BNM) to track and curb the counterfeiting of banknotes activities in Malaysia. The operation and investigation works on the counterfeiting banknotes activities in Malaysia is carry out by the Commercial Crime Investigation Department (CCID) of RMP and the seized questioned banknotes is analyse and certify by BNM for its authenticity. Meanwhile, the prosecution on the counterfeit banknotes syndicates and its members is carry out by the public prosecutor after receiving the investigation paper (IP) from RMP attached with the certified counterfeit banknotes document issued by BNM.

With the continuous improvement and advanced printing technology nowadays, the task of identifying counterfeit banknote is getting more formidable. The same goes to the syndicates behind the counterfeit banknotes activities, who has been getting smarter and better organized in order to hide from the authorities. Hence, a more reliable and robust technique to address the counterfeiting issue is needed, which could assist the RMP in tracking down the source of origin of the counterfeit banknotes if it could be associated to the syndicate and counterfeiter. Moreover, the detailed analysis of the composition of the counterfeit RM50 banknotes in the fingerprint region could serve as a centralized database to facilitate the police investigation and to narrow down the field of possible suspects.

1.3 Objectives

The objectives of the studies are as follows:

(a) To examine the security features of the counterfeit RM50 banknotes using magnification function and ultraviolet (UV) light of various wavelengths of video spectral comparator (VSC) and compare it with the genuine RM50 banknotes according to the guidelines by BNM.

(b) To analyse fingerprint region characteristic of the counterfeit RM banknotes and genuine RM50 banknotes using ATR-FTIR spectroscopy.

(c) To determine the classification of RM50 banknotes ATR-FTIR dataset using unsupervised PCA and prediction of unknown banknotes samples ATR-FTIR dataset using supervised PLS-DA.

1.4 Scope of Study

Sample of counterfeit RM banknotes (RM50 x 33 pieces) was obtained on loan from the CCID, RMP which were seized in 2017. From the obtained samples, only 28 pieces of the counterfeit RM50 banknotes samples featuring RM50 (fourth series) introduced into circulation in July 2009 were selected into study. The RM50 genuine banknotes denomination featuring the same series were obtained from automated teller machine (ATM) in Universiti Teknologi Malaysia (UTM), Taman Sri Pulai and Taman Universiti, Skudai, Johor Bahru. The 5 pieces of the counterfeit RM50 banknotes others than the said series were excluded from the study.

For physical examination, the counterfeit RM50 banknotes was first observed under digital magnification of VSC for its security features compared to genuine RM50 banknotes according to the guidelines by BNM. The study on the counterfeit RM50 banknotes were followed by optical examination using VSC for its security features when exposed to UV light of various wavelengths compared to the genuine RM50 banknotes according to the guidelines by BNM.

For discriminating the counterfeit RM50 banknotes from that of genuine RM banknotes, triplicates scan using non-destructive ATR-FTIR spectroscopy was done on fifteen areas of the banknotes sample to examined its variations in chemical functional groups, their wavenumbers and intensities in the fingerprint region (1800-650 cm^{-1}). For chemometric analysis, the data obtained were computed using *Solo 8.6* stand alone chemometrics software for determining the organization of the datasets

and its main contributing factor for grouping using PCA. Next, the PCA exploratory results were used in the supervised PLS-DA to build a predictive model for the prediction of unknown samples.

1.5 Significance of Study

With the continuous advancement of digital printing technologies and sharing of the counterfeiting knowledge over the internet, it is unavoidable that the counterfeit banknotes syndicates are expanding and may produce more large-scale counterfeiters. A big amount of counterfeit RM banknotes could have been circulated in the market for some times until the counterfeit banknotes factories or syndicates were cracked down by the RMP. The analysis on the seized counterfeit RM50 banknotes with the use of non-destructive examinations such as VSC and spectroscopy especially ATR-FTIR coupled with chemometric techniques like PCA and PLS-DA have yet to be reported so far.

Thus, the present research results have indicated the feasibility of this analytical techniques system for discriminating the counterfeit RM50 banknotes from the genuine banknotes and possible linking the counterfeit RM50 banknotes to its source of production origin based on IR spectrum generated. With this, the authority could possible linking the counterfeit RM50 banknotes to the counterfeiters based on the results which could be used as an information to create future database.

This analytical approach is non-destructive in nature, rapid, relatively cheap and manageable by the authorities i.e. RMP and BNM. This study may provide an effective forensic intelligence solution for law enforcement parties to address the counterfeiting issue and aid their investigation based on the chemical fingerprint of the material used in the counterfeit banknotes.

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