THAI COINS ANALYSIS AND CLASSIFICATION USING X-RAY FLUORESCENCE TECHNIQUE

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ABSTRACT

This research developed the machine tool to measure a compositional of Thai coins using X-ray Fluorescence techniques. The methods used to determine the elemental composition of materials by measuring the energy of characteristic secondary X-rays that emitted after atoms have been excited by high-energy X-rays. In order to identify elements from the energy, an expert system for data analysis and classification is required .Expert systems can operate machine learning for computers to make pattern recognition by exploring the studies and constructions of algorithms that are able to learn and make predictions on data. Also, the analyze procedures are non-destructive testing and focused on evaluating the use of this technique as a screening tool for elemental composition of the coins. The learning 80 Thai coins in different Types data are mainly constituted by Cu, Ni, Al and Fe, respectively. The measuring results have revealed Cu, Ni contents in the old 1 Baht type and 5 Baht type, Cu, Al, and Ni contents in the 2 Baht type and Fe, Ni contents in the new 1 Baht type. Thus, Micro-X-ray fluorescence machine in this research has been chosen as a suitable non-destructive method to identify present the type elements in investigated artifacts.

KEYWORDS: Thai Coins, X-Ray Fluorescence, machine learning, pattern recognition, non-destructive testing

1. Introduction

Nowadays, the coins are a format of currency widely used in many countries. There may be real coins and fake coins that cannot be identified and difficult to verification just the appearance. Thus, composition of coin is very important for verification and coin production. There are many methods to analyze the element of coins. X-ray fluorescence technique (XRF) is a method uses to be substitute for conventional destructive analytical methods. This method has various advantages:

- Non-destructive, there is no modification of sample or sample surface,
- Fast and it allows determination of a large number of elements,
- Qualitative and quantitative multi-elemental analysis.

X-ray fluorescence (XRF) is an analytical technique used to determine the elemental composition of materials by measuring the energy of characteristic secondary X-rays that emitted after atoms have been excited by high-energy X-rays. In order to identify elements from the energy, the knowledge of data analysis and classification use to build an expert system. Expert systems can operate machine learning for computers to make decision by exploring the studies and constructions of algorithms that are able to learn and make predictions on data as detail in section 3.

2. Related Works

Elemental analysis is analysed for material compositions. The Elemental analysis method can be qualitative (determining what elements are present), and it can be quantitative (determining how much of each are present). But the most common form of elemental analysis is accomplished by destructive technique like combustion analysis, that can't be used for valuables object like coin. Many archaeology researches preferred XRF technique for study the ancient coins due to its non-invasive and non-destructive nature. [1] They used XRF collected data from ancient roman imperial coins to create database for identification and verification the roman ancient coins in many eras which are different qualitative and quantitative, but the process to compare the test object and the database still use expertise to analyses.

For developing computer classification model in [2] proposed a new technique to classify the coins using image processing. There are the steps as follows: firstly, segmentation the

coin images. Secondly, feature extraction to extract coin-specific features from coin images. The resulting features can be used to train a classifier. Thirdly, the data is classified by machine learning algorithm to create classification model. And finally, verify the model using the test sets. However, the limitation of image processing is the method can't be determining elemental composition that can't classify real or fake coin. In [3] has developed XRF algorithm named PyMCA (Python multichannel analyzer), for processing the data from XRF Spectrometer by step.

1. Fitting curve.
2. Peak shape model using Gaussian filter to eliminate noise.
3. Find peaks and count.
4. Element line groups by calibrate energy of any peaks.
5. Sum and escape peaks are the method to divide the energy to any electron shell from test objects.
6. Polychromatic sources are the step to compare the data from test objects and the database.

This research applies the PyMCA algorithm in step 1-3. Besides, the system adds more features for processing to create the classification models.

To develop the XRF techniques for computer classification, we need to add more features. For many research used the statistical approach features for classification. [4] This paper proposed means of wavelength-dispersive X-ray florescence (WD-XRF) for determination of the quantitative composition of the coins, which can use in ED-XRF by use means to identification [5]. This research has preferred to add standard deviation (SD) and used means for the feature to develop the classification model as details in section 5.

3. Theory

3.1 X-ray fluorescence

Most atoms have several electron orbitals (K shell, L shell, M shell). If a primary X-ray energy causes electron to transfer out of shell levels and electrons in higher orbitals fall into the lower orbitals to fill the hole left behind. In falling, energy is emitted in the form of a characteristic X-ray, as shown in Figure 1. The energy of which is equal to the energy difference of the two orbitals involved. Thus, the material emits radiation, which has energy

characteristic of the atoms present. The term fluorescence is applied to phenomena in which the absorption of radiation of a specific energy results in the re-emission of radiation of a different energy.

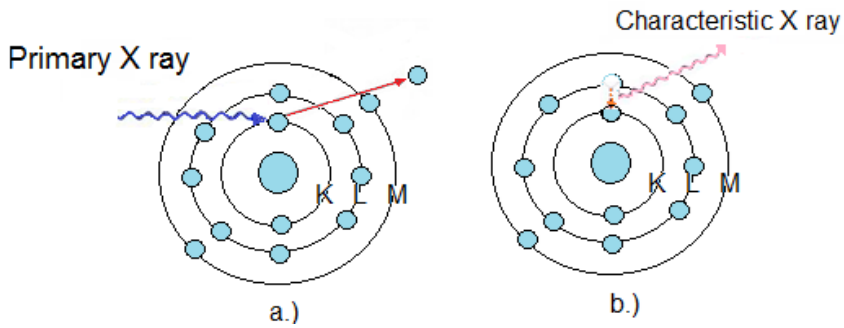


Figure 1 **a.) High energy X-ray causes electrons to transfer out of shell levels b.) Electron in higher orbitals transfers in to lower orbitals and emitted characteristic X-ray**

3.2 Energy Dispersive X-ray Fluorescence (EDXRF)

Energy Dispersive X-ray Fluorescence (EDXRF) is an analytical technique used for the elemental analysis or chemical characterization of a sample. After the examples are excited by primary X-ray, a secondary x-ray (X-ray florescence) is directed to a detector. This detector is used to convert X-ray energy into voltage signals corresponding with the energy of X-ray. The signals are sent to a pulse processor, which measures the energy of the signals and passes them onto an analyzer. The analyzer converts an analog signal into a digital signal which is proportional to the energy of the incoming pulse. Received pulses are actually amplified, converted into digital signals. In EDXRF spectrometers, all of the elements in the sample are excited simultaneously, and an energy dispersive detector in combination with a multi-channel analyser is used to simultaneously collect the fluorescence radiation emitted from the sample and then separate the different energies of the characteristic radiation from each of the different sample elements. Resolution of EDXRF systems is dependent upon the detector, and typically ranges from 150 eV – 600 eV. The principal advantages of EDXRF systems are their simplicity, fast operation, lack of moving parts, and high source efficiency.

3.3 Identification Theory

This research used a decision tree for identifying to analyse the spectrums from EDXRF systems. Decision tree is a flow chart like a tree structure that classifies instances by sorting them based on the feature (attribute) values. Each node in a decision tree represents a feature in an instance to be classified. All branches denote an outcome of the test, each leaf node hold the class label. The instances are classified from starting based on their feature value. Decision tree generates the rule for the classification of the data set.

4. Methodology

The researchers use an efficient identifying to determine the element compositions of Thai coins. All Thai coins selected in this research were measured by X-ray Fluorescence techniques. These Thai coins are divided into groups: training group and testing group. The training process was applied to 80 Thai coins and divide into 20 coins of each type for old one Baht, new one Baht, two Baht, and five Baht, respectively. The testing process uses 5 coins of each type similar as the training process. The Thai coins analysis and classification system consists of the following steps as shown in Figure 2.

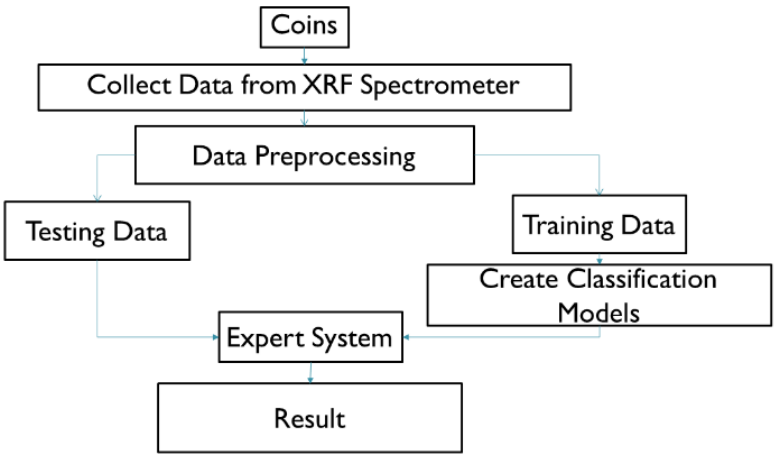


Figure 2 Flowchart of the identifying process to analyse the element composition of Thai Baht coins

Furthermore, the researchers would compare the decision tree with the Naïve Bayes, and Neural Network as details in experimental results of section 5.

5. Experimental Results

This research used XRF-spectrometer model X-123 CDTE at Engineering division, Thailand institute of Scientific and Technological Research (as shown in Figure 3) to get the data from coins.

Figure 3 XRF-Spectrometer Model X-123 CDTE outside and inside

The Data generated by XRF-spectrometer that pre-processed by Gaussian filter to eliminate the noise and find peak algorithm is curve fitting graph (as shown in Figure 4) which 4 features (peak, count/minute, Mean, SD.) and divided into 2 sets: training data and testing data.

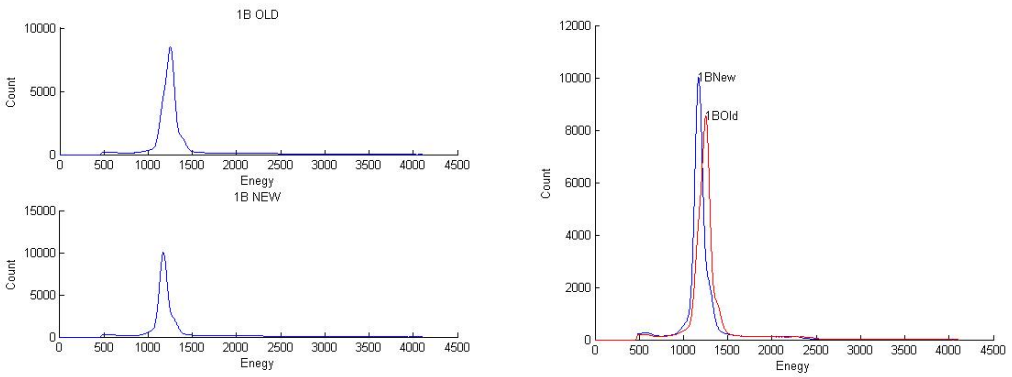
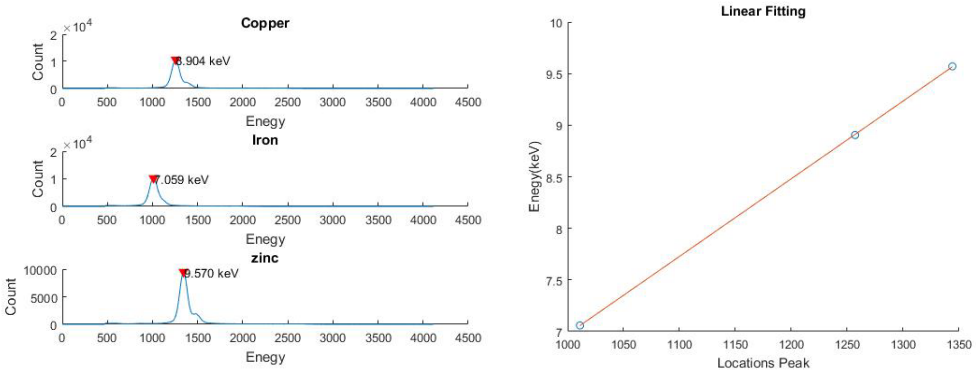


Figure 4 Sample Coins Data from XRF spectrometer

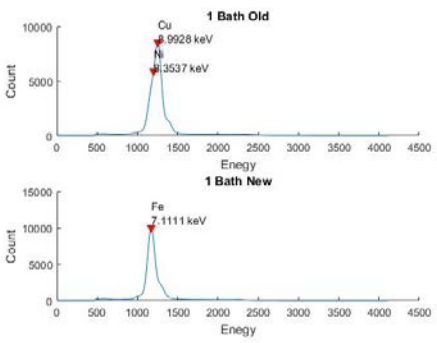
The curve fitting graph can be used to identify the elemental composition of coins by calibrated the peak value using standard elementals. Linear regression method is used to create calibration line, as shown in figure 5. The calibration line defines weight value for linear predictor functions to calculate peak energy from graph and identify elemental composition.



a.) b.)

Figure 5 a.) Standard elemental measured by XRF spectrometer, b.) Calibration line created by linear regression method using Standard elemental data.

Calibration line can be used to calculate energy from coin fitting graph for identifying elemental composition of coins. Then, the calibrated peak is mapped with the X-Ray energies database, illustrated in figure 6.



a.)

X-ray adsorption edges and characteristic X-ray line energies (keV)

Atomic number and element	*K-series*					
	K edge	KN_{III}	KM_{III}	KM_{II}	KL_{III}	KL_{II}
		$K\beta_2$	$K\beta_1$	$K\beta_3$	$K\alpha_1$	$K\alpha_2$
Intensity	–	2–5	~20	~10	100	50–53
26 Fe	7.112		7.058		6.404	6.391
27 Co	7.712		7.649		6.930	6.915
28 Ni	8.339		8.265		7.478	7.461
29 Cu	8.993		8.905	8.903	8.048	8.028
30 Zn	9.673	9.658[1]	9.572	9.567	8.639	8.616

b.)

Figure 6 a.) Elemental composition energies of coin, b.) X-Ray energies table from X-Ray energies database

This research used the Weka data mining software to create classification models from training data by 3 classification algorithms: Naïve Bayes, Neural Network, and J48 Decision tree, respectively. Next step, the model efficiency is measured by cross-validation the training data into 10 folds as shown in Table 1.

Table 1 Models Efficiency Result by Cross-validation from Training Data

Classification Summary	***Naïve Bayes***	***Neural Network***	***J48 Decision Tree***
Correctly Classified Instances	87.5 %	93.75%	100%
Kappa statistic	0.8333	0.9167	1
Mean absolute error	0.0817	0.0661	0
Root mean squared error	0.2381	0.1725	0
Relative absolute error	21.7925 %	17.6316 %	0
Root relative squared error	54.9828 %	39.838 %	0
Total Number of Instances	80	80	80

Table 1 showed the models efficiency where the J48 Decision tree model is the highest efficiency with 100% correctly classified instance and 0 all error stats. The neural network model efficiency is lower than J48 Decision tree model with 93.75% correctly classified instance and more error stat than J48 Decision tree model. The Naïve Bayes model is the lowest efficiency with 87.5% correctly classified instance and most error stats. All errors from the neural network model and the Naïve Bayes model are caused by classification between 1 Baht old type coin and 5 Baht coin.

After that, an accuracy of the classification model is measured by re-evaluation the models using testing data and compare the results to the other models, shown in Table 2.

Table 2 Accuracy testing by re-evaluation the model uses testing data

Classification Summary	*Naïve Bayes*	*Neural Network*	*J48 Decision Tree*
Correctly Classified Instances	95 %	95 %	100 %
Kappa statistic	0.9333	0.9333	1
Mean absolute error	0.0438	0.0544	0
Root mean squared error	0.1555	0.1579	0
Total Number of Instances	20	20	20

In summary, the classification model creates by J48 decision tree has the highest efficiency and accuracy due to correctly classify the instances and mean absolute error both training data and testing data are the best. The efficiency of neural network model is higher than Naïve Bayes model, but in testing stage the accuracy of Naïve Bayes model is nearly the neural networks model on testing data, while mean absolute error of Naïve Bayes network model are better than neural network model. Furthermore, Naïve Bayes model and neural network model have an error because 1 Baht old type coin and 5 Baht coin have the same qualitative elemental composition but different quantitative elemental composition that the Naïve Bayes model and the neural network model can't classify with 100% accuracy.

6. Conclusions

Coin is the precious object that is difficult to identify and verify. This paper proposed the new method for coin analysis and classification by using X-Ray Fluorescence technique. XRF-spectrometer was used to get the data. This paper also introduced expert system that can identify the elemental composition and classify Thai coin. Machine learning and pattern recognition were applied in the proposed expert system for classification Thai coins. The results showed the high efficiency and accuracy in classifying different type of Thai coins.

For the future work, the expert system can further apply to computer application for analyse XRF data without human expertise.

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