Fuzzy Set Analysis of Thai Coins Using X-Ray Fluorescence Technique

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Abstract

This research developed the fuzzy set tool to analyze a type of Thai coin using X-ray fluorescence technique. The elemental compositions of Thai coins produce a set of secondary X-ray. The count and energy of secondary X-ray are used to identify the type of Thai coins by fuzzy expert system. The rectangular fuzzy rules in this system are built using the characteristic X-ray data for prediction. The analyze procedures are non-destructive testing and able to learn on X-ray energy data for analyzing the type of Thai coins. The learning 80 Thai coins in different Types data are mainly constitute Cu, Ni, Fe 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, Fuzzy set analysis Micro-X-ray fluorescence system has been chosen as a non-destructive method to identify present the type Thai coins.

Keywords: fuzzy set analysis, fuzzy expert system, Thai coins, X-ray fluorescence, non-destructive testing

1. Introduction

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. The advantages of this method are non-destructive, rapid, and find the content of the element in the samples. The principle of 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. From the energy of secondary X-rays, the expert can to identify the elements of coins. Astrik Gorghinian and et al. [1] preferred XRF technique for study the ancient coins due to its non-invasive and non-destructive nature. They used XRF to collected data from ancient roman imperial coins to create database for identification and verification the roman ancient coin in many eras which different qualitative and quantitative, but the process compares the test object and the database still use expertise to analyses. L.J.P. van der Maaten and P.J. Boon proposed [2] a new technique to classify the coins using image processing by first, Segmentation the coin images. V.A. Solé et al. developed XRF algorithm named PyMCA (Python multichannel analyzer), for processing the data from XRF Spectrometer by step: fitting curve, peak shape model, find peaks and count, element line groups by calibrate energy of any peaks, sum and escape peaks, and polychromatic sources, respectively. The XRF technique classification needs to add more features. Ivan Grz˙etic et al. [4] used the statistical approach features for classification. M. Hložek and T. Trojek [5] proposed means of wavelength-dispersive X-ray florescence (WD-XRF) for the determination of quantitative composition of the coins, which can use in ED-XRF due to use the means for identification. In this research, the selection of 80 Thai coins were analyzed by rectangular fuzzy rules using the peak count of secondary X-ray and the energy channels of element to develop the classification model as details in section 2 - 4.

2. Theory

2.1 X-Ray Fluorescence

Generally, atoms have several electron orbitals (such as: K shell, L shell, M shell). A primary X-ray energy causes electrons to transfer out of shell levels and electrons in higher orbitals fall into the lower orbital to fill the hole left behind. In this situation, the falling electron is emitted a characteristic X-ray, as shown in Figure 1. This energy is equal to the energy difference of the two orbitals involved. Thus, the emitted radiation will present a characteristic of the material.

The application of X-ray fluorescence is a non-destructive analytical technique used to determine the elemental composition of materials. This method measures the fluorescent X-ray emitted from a sample when it is excited by a primary X-ray source.

Each of the elements present in a sample produces a set of characteristic fluorescent X-rays.

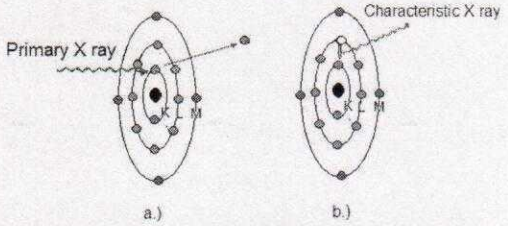

Figure 1 a.) Primary energy X-ray causes electrons to transfer out of shell levels
b.) Electron in higher orbital transfers in to lower orbital and emitted characteristic X-ray.

2.2 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 detector to detect a secondary X-ray (X-ray florescence) and convert X-ray energy into voltage signals corresponding with the energy of X-ray. The signal depends on the energy of 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 signals are actually amplified. In EDXRF spectrometers, all of the elements in the sample are excited simultaneously, and an energy dispersive detector in combination with a multi-channel analyzer and use to simultaneously collect the fluorescence radiation emitted from the samples. The analyzer separates 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 and fast operation.

2.3 Fuzzy Sets

Fuzzy sets [6, 7] extend crisp sets using membership scores in the interval between [0] and [1]. Fuzzy membership scores address the varying degree to which difference cases belong to a set. For instance if X is a collection of objects denoted by x then a fuzzy set $\vec{B}$ in X is an ordered pair ($\vec{B} = \{(x, \mu_{\vec{B}}(x))|x \in X\}$). $\mu_{\vec{B}}(x)$ is called the membership function of object x in $\vec{B}$. Fuzzy sets and linguistic variables can be used to quantify concepts in membership function. A linguistic variable need has a valid syntax and semantic, which can be specified by fuzzy rules. The rule-based systems have been applied to various problems: identification/classification, pattern recognition, control systems etc. In processing, fuzzy-rule-based is built in the following structure:

$$R_k: If\ x_1\ is\ B_1^k\ and \ldots and\ x_n\ is\ B_n^k\ then\ Y\ is\ C_j$$

,

where x_1, x_2, ..., x_n are the outstanding selected features for the classification problem,

B_1^k, B_2^k, ..., B_n^k are linguistic variables used to discretize the continuous domain of the variables, and

Y is the class C_j to which the pattern belongs.

The terms between If and then are antecedents and after then are consequents of fuzzy sets. This research uses the rectangular fuzzy rules from fuzzy partition as shown in Figure 2.

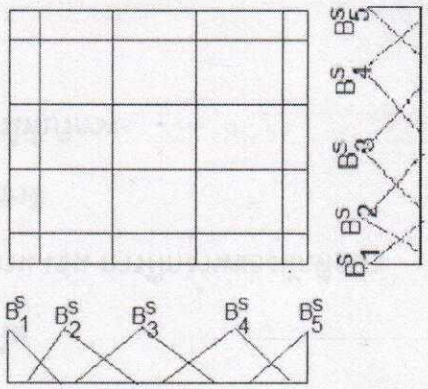

Figure 2 Fuzzy partitions of two dimensional pattern space.

2.4. Identification Theory

This research used a rectangular fuzzy rule based model for identifying to analyze the spectrums from XRF systems. Fuzzy rule based is a linguistic computation classifies instances in the form of linguistic rules of the feature (attribute) values. Each linguistic variable represents a feature in an instance to be classified. The instances are classified from starting based on their feature value. The expert generates the fuzzy rule based for the classification of the data set.

3. Methodology

The researchers use an efficient identifying to determine the type 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 10 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 3. Furthermore, the researchers would compare the Fuzzy set analysis with the Naïve Bayes, and Neural Network as details in the experimental results of section 4.

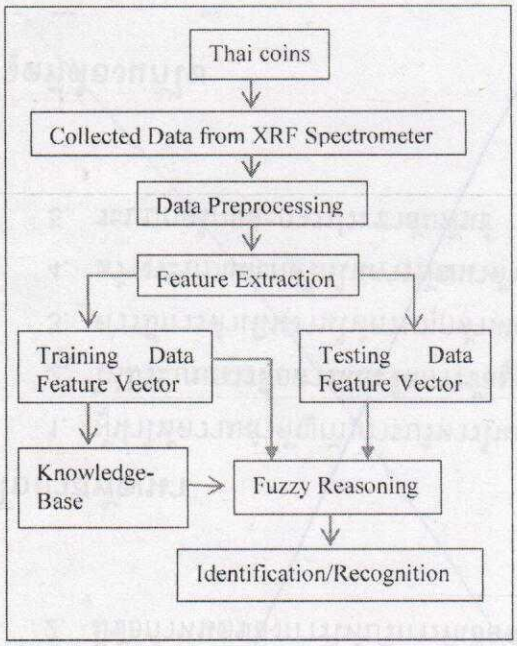

Figure 3 Flowchart of the identifying process to analyze the type of Thai Baht coins.

4. 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 4) to get the data from coins.

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 5) and divided into 2 sets: training data and testing data. In measuring, energy of secondary X-ray related with 4096 channels for 3 keV to 30 keV as in the x axis. The y axis represents the count of measuring at 60 seconds, 15 kV, and 15 mA setting. Next step normalized the energy and count of measuring as shown in Figure 6. The expert uses the vertex of graph (peak) and channel position to build the fuzzy rule based system for coin identification as follow:

Rule 1: If x = S and y = VL then output = k_1
Rule 2: If x = L and y = L then output = k_2
Rule 3: If x = L and y = M then output = k_3
Rule 4: If x = L and y = S then output = k_4
: :
: :

where S = small fuzzy set,
M = medium fuzzy set,
L = large fuzzy set,
VL = very large fuzzy set,
x = normalized energy,
y = normalized count,

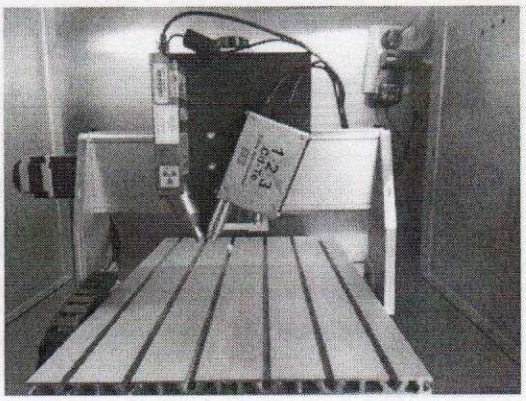

Figure 4 XRF-Spectrometer Model X-123 CDTE.

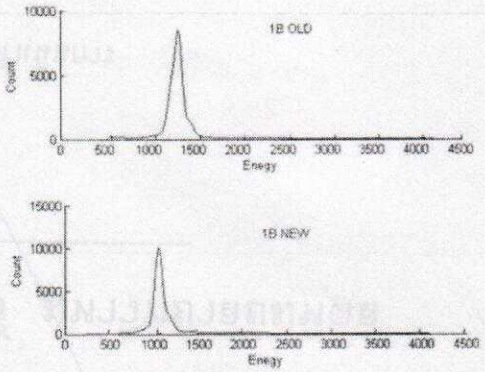

Figure 5 Sample Coins Data from XRF spectrometer.

k_i is a constant: k_1, k_2, k_3, k_4 represent new 1 Baht coins, 2 Baht coins, 5 Baht coins, and old 1 Baht coins, respectively.

In decision making, fuzzy system selected the maximum output value from fuzzy rule based results. Since, there are 4 different types of coins. There are 4 different conditions. For example, it has 4 output results from the alternative evaluation results as follow: $k_1 = 0.98$, $k_2 = 0.21$, $k_3 = 0$, and $k_4 = 0$, respectively. The best result is k_1 which represents new 1 Baht coin. Thus, a maximum output value is chosen which represents the each type k_i.

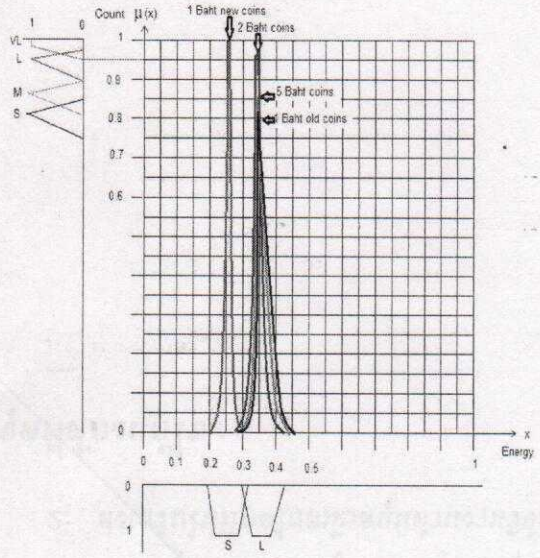

Figure 6 Fuzzy rule based system for coin identification.

The element composition of coin is very important for identification/verification, which fuzzy set analysis model uses their composition to detect the real coins or fake coins. This system creates fuzzy set analysis model from training data. Next step, a fuzzy set analysis model is measured Thai coins using testing data and compares the results to the other models as shown in Table 1.

Table 1: Accuracy testing

Identification Methods	% Accuracy Results				
	Old 1 Baht	New 1 Baht	2 Baht	5 Baht	Average results
Fuzzy Analysis	100	100	100	100	100
Naïve Bayes	90	90	90	80	87.5
Neural Network	100	100	100	90	97.5

From the experimental results, fuzzy set analysis model has the highest efficiency and accuracy due to correctly classify the instances both training data and testing data are the best. The efficiency of neural network model is higher than Naïve Bayes model.

5. Conclusions

In this paper, a method proposed to estimate membership value of the fuzzy sets using the count of X-ray pulses and energy channel positions at peaks. The fuzzy set analysis model is created by expert. It can be used as the expert system for XRF analysis and identification of Thai Baht coins. From the experimental results, the fuzzy analysis system gave the high efficiency and accuracy. Thus, the expert system can further apply to computer application for analyze XRF data.

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