A Counterfeit Paper Currency Recognition System Using LVQ based on UV Light

Dewanto Harjunowibowo  
Physics Education Department  
Sebelas Maret University  
Surakarta, Indonesia  
dewanto_h@yahoo.com

Sri Hartati  
Electronics and Computer Science Department  
Gadjah Mada University  
Jogjakarta, Indonesia  
shartati@ugm.ac.id

Aris Budianto  
Electronics Engineering Department  
Gadjah Mada University  
Jogjakarta, Indonesia

Abstract—This research is aimed to test a paper currency counterfeit detection system based on Linear Vector Quantization (LVQ) Neural Network. The input image of the system is the dancer object image of paper currency Rp. 50,000,- fluorescent by ultraviolet light. The image of paper currency data was taken from conventional banks. The LVQ method is used to recognize whether the paper currency being tested is counterfeit or not. The coding was carried out using visual programming language. The feature size of the dancer tested object is 114x90 px and the RGBHSI was extracted as the input for LVQ. The experimental results show that the system has an accuracy 100% of detecting 20 real test case data, and 96% of detecting 22 simulated test case data. The simulated case data was generated by varying the brightness of the image data. The real test case data contains of 10 counterfeit paper currency and 10 original paper currency. The simulated case data contains of 11 original paper currency and 11 counterfeit paper currency. The best setting for the system is Learning Rate = 0.01 and MaxEpoch = 10.

Keywords—CRM 2.0; detection system, counterfeit paper currency, neural network, LVQ, digital image processing

I. INTRODUCTION

That the RGB values from fluorescence invisible ink image by UV light, can be used as input for LVQ neural network to detect counterfeit paper currency has been proven with 100% accuracy [1]. In this paper, the accuracy of the system using RGBHSI as the input will be revealed.

On preliminary experiment, a detection system has been built based on Linier Vector Quantization (LVQ) neural network using UV’s lamp to show up the original feature of original paper currency. It has been proved that this technique has 100% accuracy using cropping 90x114 pixels feature [2]. On the next experiment the cropping 114x90 pixels feature was used [1], which means, only part of original feature was used.

In this paper, the feature was taken from an image appear under an UV lamp. The LVQ will then recognize the pattern, thus it can be defined whether it is the original paper currency or the counterfeit.

II. THEORY

A. Neural Network (LVQ)

Neural network is adopted from biologic neural network of human and can be trained to recognize an object with specific pattern[3]. LVQ is one of supervised training methods to its competitive layers [4, 5, 6, 7, 8, 9]. A competitive layer automatically learn to classify input vectors. The classification result of competitive layer only depend on the distance between input vectors and weight vectors [10]. If there are two vectors where the distance is almost the same and nearest than the other, therefore, competitive layers will classify both of them into the same class.

LVQ's network has two layers such as competitive and linear layers (Fig. 1). Neurons on competitive layers compete each other and produce the winning neuron [8]. The competitive layer classify input vector into the amount of clusters based on distances in each input vectors. On the second layer, linear layer mapped the clusters classified by the competitive layer into classes which has been defined by the user [11].

B. Digital Image Processing

A visual system has the ability to fix useful information from an image and use it for many things. The information will be used after several times of image processing [12].

Three basic quantities are used to describe the quality of a chromatic light source are: radiance, luminance, and brightness. Radiance is the total amount of energy that flows from the light source and is measured in watts (W). Luminance, measured in lumens (lm), gives a measure of the total amount energy an observer perceives from a light source. Brightness is a
subjective descriptor that is practically impossible to measure [13].

Owing to the structure of the human eye, all colors are seen as variable combinations of the three so-called primary colors: red (R), green (G), and blue (B). For the purpose of standardization, the CIE (Commission Internationale de l’Eclairage-the International Commission on Illumination) designated in 1931 the following specific wavelength values to the three primary colors: blue=435.8 nm, green=546.1 nm, and red=700 nm [13].

Generally, the characteristic used to distinguish one color to another are brightness, hue, and saturation [13]. Brightness embodies the chromatic notion of intensity. Hue is associated with the dominant wavelength in a mixture of light waves, thus it represents dominant color as perceived by an observer, e.g. red, orange or yellow according to observer actually each of those are specification of a hue. Saturation is relative purity or the amount of white light mixed with a hue.

The HSI space is obtained by non-linear transformation of the RGB space. The HSI representation uses the brightness (or intensity) value, I (intensity) as the main axis orthogonal to the chrominance plane. The saturation S and the hue H are the radius and the angle, respectively, of the polar coordinates in the chrominance plane with the origin in the trace of the value axis (with R corresponding to 0°) (Fig. 2):

This representation is approximately perceptually uniform and is closely related to the way the human vision perceives color images. Because of invariance to the object orientation with respect to illumination and camera viewing direction, the hue is more suitable for object retrieval. But the conversion from the RGB to HSI color coordinates is a bit complicated. Colors in HSI model are defined with respect to normalized red, green, and blue values:

\[
I = \frac{1}{3 \times 255} (R + G + B), \quad [0,1]
\]

\[
S = 1 - 3 \min (r, b, g), \quad [0,1]
\]

\[
H = \begin{cases} 
\delta & \text{if } b < g, \\
2\pi - \delta & \text{otherwise,}
\end{cases} \quad [0, \pi]
\]

\[
\delta = \cos^{-1} \left( \frac{\frac{1}{2}([r-g] + (r-b))}{(r-g)^2 + (r-b)(g-b)} \right)^{\frac{1}{2}}
\]

where \( b = \min (r, g, b) \) in the RG sector.

For convenience, H, S and I values are converted in the ranges of [0,360], [0,100], [0,255] respectively by:

\[
H = H \times 180 / \pi; \quad S = S \times 100; \quad I = I \times 255
\]

C. Ultraviolet

UV is an electromagnetic radiation with shorter wavelength than visible light but longer than X-ray. Therefore, the energy of UV is bigger than visible light as in (9).

\[
E = h\nu = \frac{hc}{\lambda}
\]

where energy (E), h is Planck constant \((6,626 \times 10^{-34})\) Js, frequency (\(\nu\)), light velocity (c) = \(3 \times 10^8\) m/s, and wavelength (\(\lambda\)).

Moreover, UV has a lot of functions, e.g. to produce D vitamin and to detect counterfeiting of paper currency and credit card [14]. Invisible Ink and safety line in paper currency are used as security from counterfeiting and it is usually fluoresced by UV [15].

III. METHODS

Methods of the research (Fig. 3):

A. Data Acquisition

Data acquisition process is needed to take a picture of the paper currency using these tools and setting:

1) Digital Camera ; setting ISO 800; Focus 3.1; Speed 1/15; no blitz, camera to object distance 21 cm.
2) LuxMeter Digital LX-100 Merk Lutron, Setting Scale: 0-1999 x 1 Lux
3) UV Lamp 10 Watt Sin Sen brands.
4) White lamp T5 8 Watt Sin Sen brands.
5) Power Regulator 220V

B. Preprocessing

It was done to extract the image feature from its background in order to make the next process easier. The image was cropped into the size of the paper currency and normalized to be 550x240px.
C. Feature Extraction

It is undertaken to take the value of RGB and HSI from the feature so that LVQ can use it as the input and to classify the paper currency. The feature was taken from fluorescent image with size of 114x90 pixels then the RGBHSI values are extracted as input for LVQ.

First of all, the values of RGB were extracted then normalized as in (1) to (3), the RGB values were then converted into HSI as in (4) to (8). Finally, both RGBHSI were used as input for LVQ neural network.

D. Paper currency Detection

Detection by LVQ is based on the closest distance between test vector (testing image) with reference (weight) vector (training).

If classification is appropriate with the class target then use formula (10):
\[
w_i(\text{new}) = w_i(\text{last}) + \alpha (x-w_i(\text{last}))
\]
(10)

If classification is inappropriate with the class target then use formula (11):
\[
w_i(\text{new}) = w_i(\text{last}) - \alpha (x-w_i(\text{last}))
\]
(11)

Classification based on closest distance use formula (12):
\[
\|X-W_i\| \leq \|X-W_{j}\| \text{ or } \|X-W_{i}\| > \|X-W_{j}\|
\]
(12)

where
\[
\|X-W_i\| = \sqrt{(x_1-w_{i1})^2 + (x_2-w_{i2})^2 + (x_3-w_{i3})^2},
\]
i notation shows the total amount of input variables (six variables), and j shows the total amount of class target (two classes) [1, 2].

The system will do some tests i.e. Validation, Accuracy test with variation of Learning rate and Epoch, and tried to find the best setting to be applied.

IV. RESULT

A. Validation System

Validation is conducted by detecting the training images one by one so that the quality of system can be known. The testing images consist of seven counterfeit paper currencies and five original paper currencies. The neural network setting are MaxEpoch = 1000 and Learning Rate = 0.01. The result is shown in Table I.

<table>
<thead>
<tr>
<th>No</th>
<th>Paper currency</th>
<th>Brightness (%)</th>
<th>Distance Class 1</th>
<th>Distance Class 2</th>
<th>Category class</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50th data asli2</td>
<td>262.8874</td>
<td>314.7337</td>
<td>1</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>50th data palsu-2</td>
<td>317.2408</td>
<td>263.9294</td>
<td>2</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>asli utuh1</td>
<td>149.3534</td>
<td>194.5605</td>
<td>1</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>asli utuh2</td>
<td>169.7315</td>
<td>204.0747</td>
<td>1</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>asli utuh3</td>
<td>191.2581</td>
<td>215.1399</td>
<td>1</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>asli utuh4</td>
<td>210.0506</td>
<td>227.4419</td>
<td>1</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>palsu utuh1</td>
<td>202.8637</td>
<td>141.2639</td>
<td>2</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>palsu utuh3</td>
<td>245.7379</td>
<td>215.5518</td>
<td>2</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>palsu utuh4</td>
<td>267.9559</td>
<td>250.7049</td>
<td>2</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>palsu utuh5</td>
<td>293.5544</td>
<td>286.9850</td>
<td>2</td>
<td>True</td>
<td></td>
</tr>
</tbody>
</table>

Categories: 1 = original; 2 = counterfeit

Each file has its own brightness level, they are respectively: 0% for data number 1 and 2, then 5%, 10%, 15%, 20% for the original paper currency, and 15%, 30%, 45%, 60%, 75%, 100% for counterfeit paper currency. The validation result is 91.7% worst than RGB input 100% correct in recognizing [1].

B. Testing

The system is tested using two types of data. First, the brightness level of data were varied from 0-100% using image external software. The image was taken from Rupiah currency with nominal 50.000 rupiahs. The system can detect to 96% accuracy. It was falsely detect one datum on counterfeit paper currency with 100% brightness level (Table II), similar with RGB input [1].

<table>
<thead>
<tr>
<th>No</th>
<th>Paper currency</th>
<th>Intensity (…±1) Lux</th>
<th>Distance Class 1</th>
<th>Distance Class 2</th>
<th>Category class</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Original</td>
<td>28</td>
<td>33.0533</td>
<td>179.5724</td>
<td>1</td>
<td>True</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>40</td>
<td>75.4598</td>
<td>158.135</td>
<td>1</td>
<td>True</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>51</td>
<td>72.2703</td>
<td>156.1656</td>
<td>1</td>
<td>True</td>
</tr>
</tbody>
</table>

Categories: 1 = original; 2 = counterfeit

The image where the brightness level is 100% has no histogram (like white paper), therefore the LVQ found the same vector distance. Thus, it was classified as class 1 (original) which has been programmed for anticipation.

Second, the test used the data which has been varied using external light consist of 10 counterfeit paper currency and 10 original paper currency images. The test result of original paper currency (lux): 28, 40, 51, 60, 70, 80, 91, 101, 110, 111, and for counterfeit paper currency (lux): 19, 40, 60, 81, 100, 120, 140, 160, 180, 200 respectively, which is 100% correct (Table III). Compared with RGB input, the result is the same [1].

The detection system process

![Figure 3. The detection system process](image-url)
The best Learning rate for RGBHSI input is different with RGB input which was 0.01 [1]. It shows that every input system has its own characteristic.

### D. The effect iteration (Epoch)

Table V shows that varying epoch gives different result and does not guarantee that bigger epoch will has the best result. The best result for the system is MaxEpoch 1. Logically, smallest epoch makes system run faster in learning but often has more detection errors.

<table>
<thead>
<tr>
<th>No</th>
<th>Paper currency</th>
<th>Brightness (%)</th>
<th>Category class</th>
<th>ME=100</th>
<th>ME=1000</th>
<th>ME=&gt;1000</th>
<th>ME=0.1</th>
<th>ME=&gt;1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Orig Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>22</td>
<td>Counterfeit</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Categories: 1 = original; 2 = counterfeit

It is shown that the best Learning Rate is 0.02 based on speed of system learning and accuracy. Smaller learning rate for LVQ neural network does not guarantee that it will have the best result. But if it will be applied to a machine, the best result is Learning Rate 0.04 because it was faster and for brightness more than 70% (almost white) will not be found in reality (Fig. 4).

![Figure 4](image-url)
V. CONCLUSION

It is revealed that UV lamp can be used to shows up the invisible ink in original paper currency and use it as the unique feature for LVQ neural network to distinguish between original and counterfeit paper currency. In addition, the most appropriate setting to get the best accuracy for a machine implementation is Learning Rate = 0.01 and MaxEpoh = 10. The accuracy of RGBHSI are 100% for real data and 96% for simulated data. Finally, for next research is aimed to make the system usable for more general paper currency data based on the invisible ink.

REFERENCES


AUTHORS PROFILE

Dewanto Harjunowibowo, was born in May 2nd, 1979 in Yogyakarta Indonesia. Both undergraduate and postgraduate were finished in Physics Department of Gadjah Mada University. He is lecturer in Physics Education of Sebelas Maret University with interest in Electronics and Instrumentation.

Sri Hartati, finished her master and doctoral programme in Fac of Computer Science, Univ of New Brunswick, Canada. She is lecturer in Computer Science and Electronics in Gadjah Mada University. Her research interest are Intelligent Systems (Knowledge Based Syst., Reasoning Syst., Expert Syst, Fuzzy Syst., Pattern Recog, Decision Support System, Medical Computing and Soft Computation (ANN, Fuzzy Logic, Genetic Algorithm).

Aris Budianto, was born in December 17th, 1980 in Klaten. He interest in Web Programming and is taking his postgraduate in Electronic Engineering, University of Gadjah Mada. He is a lecturer in Politeknik Indonusa Surakarta.