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To Predict the Lightfastness of Prints on Foil Applying Artificial Neural Network

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Abstract

The lightfastness of prints is an extremely important characteristic for assessing their print stability. The fastness properties of prints can be described in terms of print durability and image stability. Good lightfastness assures the good print stability after long use. This study has focused to describe the lightfastness of printed foil samples due to long time exposure. It may also be used for the authenticity or validity of the product. Moreover, any kind of deterioration in package print quality will affect the sale value of the product adversely. Little work has been done to study the fastness properties of printed films and foils. In this work, blister foils printed in the gravure printing process are taken as the sample as it has extensive usage in food and medicine packaging. The samples are exposed in artificial lightfastness tester BGD 865/A Bench Xenon Test Chamber (B-SUN) for assessing the light fastness of cyan, magenta, yellow and black ink on the foil. The spectral curves and colorimetric values of prints are measured in the ocean optics spectroradiometer (DH2000BAL) before and after exposure. An Artificial Neural Network model (ANN) is proposed to predict the fading rate of the printed foil. The optimal model gives excellent prediction with the minimum mean square error (MSE) for each color and a correlation coefficient of 0.98-0.99.

Introduction

Flexography and Gravure printing processes are considered as the leading process for flexible package printing. In recent days the roles of the modern package are wider than previously. Packages are playing the role of silent salesman attracting the attention to the product through its color or images or text. So, package printing is becoming more and more important to make the product desirable to consumers and to sell it. Sometimes it has been observed that the initial print quality is bright and attractive. However, with time, it degrades due to the poor fastness properties. Thus it reduces the sale value of the product if its color degrades before its expiration. The lightfastness properties of prints are the amount of resistance to fade or color change of a printed surface due to the influence of daylight or an artificial light over a set period. Sometimes the change in color appearance of packages helps to find out the authenticity and validity of the products because different kinds of packaging materials used for food and medicine packaging are subject to different kinds of storage conditions from open market to the deep freeze. Recently, the counterfeiting of food and beverage and pharmaceutical packaging is a worldwide issue. In the case of food or medicine products that may require long stability, it is required that the print surface does not change its original color or fades away, as it may create confusion about the authenticity and validity of the product. A lot of praiseworthy studies are performed to discuss the lightfastness properties of prints. The print stability is becoming more complex in the field of research on print quality and has received wide attention. In recent days, flexible packaging is drawing wider attention in the packaging world. However, there is a limited number of published papers on the fading of flexible substrates. Some researchers have investigated the lightfastness properties of flexible package printing materials so that one can choose the proper substrate and inks on the basis of its lightfastness that is used in the flexible packaging industry [1-5]. Several previous studies have demonstrated the effects of light on paper substrates, dyes, pigments, and photographs [6-13]. The extensive application of densitometry or spectrophotometric measurements for the evaluation of the lightfastness of the printed sample is discussed [14, 15]. The effect of temperature, humidity, illumination, and air pollutants on the image permanence is detailed by H.Wilhelm et al. [16-18]. Color degradation has been demonstrated by applying the first-order kinetic model [19-21]. O. Haillant [22] has discussed the photofading mechanism of colored materials where the photochemical behavior of organic or mineral colorant molecules and resin are investigated due to exposure of real or artificial light conditions. In recent days, some researchers have applied artificial neural network (ANN) to predict the light fastness of fabric samples. An artificial neural network model has been proposed to determine the Lab and wash fastness values of nylon in the textile printing industry [23]. The authors have estimated an accurate reaction rate applying the feed-forward neural network method [24-28]. Few studies have applied ANN to predict the color change (ΔE) of fruit or pumpkin due to the dehydration process [29, 30]. M.Mandal and S.bandyopadhyay [31] have applied the ANN model to estimate the lightfastness performance of film substrate.

Much of the previous researches have reported on the finding related to lightfastness of paper. A few studies have been obtained on the lightfastness data on the film or blister foil prints. Besides, most of the experiments are on offset or digital prints. Little work has been performed on lightfastness of gravure printing on the foil. Considering the huge effect of fading on the marketability and authenticity of prints on foil especially in the food and pharmaceutical packaging industry, the blister foil prints on gravure are chosen as the substrate of studies. The present study will analyze the lightfastness of printed foil samples under controlled temperature and humidity conditions. Different models may describe fading rates of print. The aim of this paper to predict the degradation of image quality with the variation of time by applying an artificial neural network model (ANN).

Materials and Methods

The testing was carried out on the blister foil substrates printed by a gravure printing press using solvent-based foil inks as mentioned in the Experimental section of our previous studies [20, 31]. The printing was completed at a constant speed (60 meters/min) and constant pressure with electronically engraved four color printing cylinders. The drying temperature was set at 50°-60°C for the printing. The experiment was done on 100% solid patch of Cyan, Magenta, Yellow and Black inks of 152 lines per inch resolution. The ambient conditions inside the press were: temperature - 17 ± 3°C and humidity- 35±5%. The experiment was carried out with multiple samples and five samples were taken for each color patch to check the repeatability. Samples were collected from five different runs.

In this experiment, the BGD 865/A Bench Xenon Test Chamber (B-SUN) is used for determining the lightfastness of foil prints. The test procedure was performed as per ASTM D3424-01standard, Test method 3 for evaluating the lightfastness of prints [34]. The print samples were exposed to a Xenon source. The irradiance on the test prints was 0.35 W/m^2. nm (± 0.02 W/ m^2. nm) at 340 nm. The uninsulated black panel temperature was set at 55 ± 2°C and the relative humidity was set to 40±5 %. The test samples of the substrate were cut at 150mm ×70mm sizes and mounted in the sample holders for the lightfastness test. The samples were exposed in an artificial xenon chamber as per the ASTM G155 procedure. The test was conducted by exposing the test print samples for a different time interval. The samples were continuously exposed to xenon light tester up to a total of 200hrs under a controlled environment to support repeatability.

Measurement

Ocean Optic Spectroradiometer (DH2000BAL) was used for the measurement of the lightfastness test as per the ASTM D3424-01 standard. Tungsten Halogen and Deuterium light source were used for all measurements of unexposed and exposed samples used in the experiment. The spectral reflection curves and the color coordinate values $L*$ $a*$ and $b*$ of each print specimens were measured using Ocean Optics Spectroradiometer (DH2000BAL) at standard illuminant and 2° standard observer before and after exposure. Spectroradiometric measurements were taken at 17°C-23°C. The exposed samples were also observed under viewing booth with D50 light source as per ASTM D3424 standard for visual estimation. In this study, initially spectral data and $L*$, $a*$, $b*$ data were collected first at 15 minute time interval for the first one hour. Then data was taken like an hourly basis till 25 hours, then taken at 5 hours interval and later on at 10 hours interval till 200 hours. Five measurements were recorded for each sample at every interval. The process was repeated for five different print runs. The five individual datasets were prepared for the proposed model so that the accuracy of the model might be checked. The unexposed and exposed print samples were evaluated by the colorimetric measurements where L* is lightness, a* is a measure of the degree redness to greenness and b* is a measure of the degree yellowness to blueness. The * and b* values contribute to defining the chroma of prints. The color changes are determined using unexposed and exposed sample data to calculate ΔE_{00} at individual time interval [35].

Theory

Overview of Artificial Neural Network

An artificial neural network (ANN) model is considered as a computing system consisting of interconnected processing components named neurons. ANNs model has been widely preferred over other conventional modeling techniques as the ANN can be built based on no prior assumptions concerning the nature of the phenomenological procedures and understanding the mathematical background of the problem underlying the process and its ability to learn linear and nonlinear relationships between variables directly from a set of examples [29]. The present study has implemented a multilayer feed-forward network for modeling to determine the light fastness behavior of prints on the foil over time. In this study, the Neural Network Toolbox of MATLAB (Mathwork, 2011) software is used to design the proposed model[36]. The model developed in this study consists of three layers which is shown in figure 1. The first layer is input layer, representing two input parameters to the problem which are wavelength and different time intervals. The second layer is hidden, consisting of the variable number of neurons that help to capture the nonlinearity in the system. The third layer is the output layer representing the dependent variable and it is consisted of one output parameter i.e. the reflectance value at different exposure time. The input layer transmits the signal through the hidden layer to the output layer in a feedforward procedure. Figure 2 presents the basic neuron where the input vector is multiplied by the weights and then added with a scalar parameter called bias. This sum is fed to the differentiable function called an activation function [31,33], and finally, the neuron's output can be produced from Eq. (1):

$$O_j = \sum_{i=1}^{n} f\left(W_{ij}X_i\right) + b_j \qquad (1)$$

where n is a number of inputs to the ANN, W ij is the weight of the i^{th} input that is connected to the jth neuron; X_i is the i^{th} input signal to j^{th} neuron, bj is the bias associated with the j^{th} neuron and f is the activation function that defines the processing inside the neuron.

In the proposed ANN model, a hyperbolic tangent activation function is used in the single hidden layer which is defined in Eq. (2) because this activation function helps to lower the calculated mean squared error values (Eq.3) than the sigmoid function and a linear function is retained in the output layer[30].

$$tanh = \frac{e^x - e^{-x}}{e^x + e^{-x}} \qquad (2)$$

$$MSE = \frac{1}{P}\sum_{p=1}^{P}\left(D_p - O_p\right)^2 \qquad (3)$$

Where P is the total number of training data and D_P is the desired outputs and O_p is calculated outputs for the pth training data

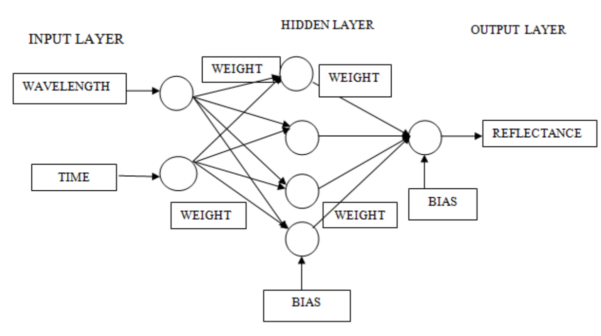


Figure 1. *Structure of feed-forward ANN*

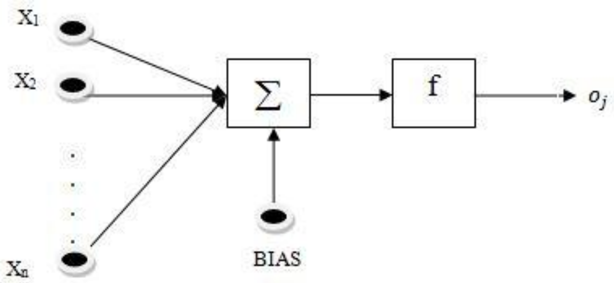


Figure 2. *Structure of a basic neuron*

The basic flow of developing an artificial neural network model is shown in figure 3.

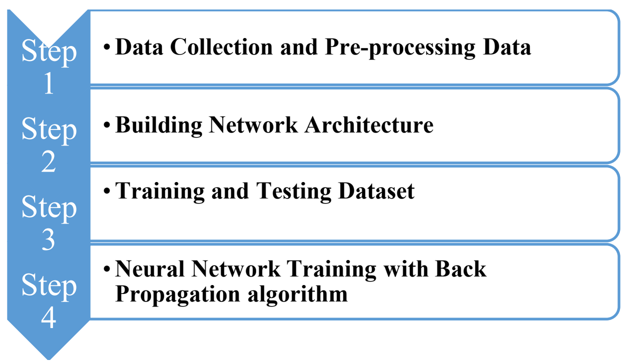


Figure 3. *The Basic flow of developing an artificial neural network model*

In this study, the dataset has been divided into three subsets to avoid over-fitting. The first set is used to train the network (70% of the data), the second one is cross-validation (CV) (15% of the data) used to monitor the prediction quality during training. In the third set, a test set (15% of the data) is used to estimate the accuracy of the network on unknown data and compare the performances of various network structures[30]. After generating the structure of an ANN, it is needed to adjust the weights and biases values of its neurons. This adjustment technique is called training. The training is done to achieve a unique set of connection weights needed to calculate outputs that are very close to the target values for all the examples used in training. Chen et al. [32] have reported that a sufficiently trained network may produce outputs that are satisfactorily close to actual outputs. In the proposed model, the most widely used training algorithm i.e. Backpropagation Levenberg-Marquardt (BP) algorithm has been applied to obtain the lowest mean square error during neural network training through adjustment of the network bias and weights. So, trainlm function is used in the Matlab tool to train and test the ANN. The criteria for evaluating the optimum Neural network performance is based on the MSE of the test data as well as the correlation coefficient (R^2). The most important factors that need to be considered in creating a successful neural network model is the selection of hidden layers and the number of neurons in hidden layers.

This study aims to apply the ANN model for predicting the lightfastness of printed foil at any unknown time. Therefore the ANN model has been tested twice for predicting the lightfastness. First, the proposed model has been trained up to 100hrs time data to determine the lightfastness of 180 hrs and 200 hrs. Then the model has been trained up to 140hrs time data to predict the lightfastness of 180 hrs and 200 hrs. In the second case, 60 hours of data has not been fed and it is also used for verification. Figure 5 presents only 200 hr data predicted when the model has been trained up to 100hrs time data. MSE and correlation coefficient R^2 are also reported for this set. However, the data are available for 140hrs time data also. The values are more or less similar. So the study may claim that the ANN model works as a predictive model. In the second case, the model has also predicted the lightfastness at 60 hrs which may act as the behavioral model.

Results

Spectral distribution of prints with time

The spectral distribution reflectance of Cyan, Magenta, Yellow and Black prints are shown in Figure 4 a), b), c) and d) respectively under unexposed and exposed conditions under xenon source. Figure 4a) shows the initial increment in the reflectance peak of Cyan print at 470 nm. However, the reflectance spectra gradually decrease in the blue zone on further xenon light exposure indicating yellowing. Figure 4b) clearly indicates the fading with time for Magenta print as the reflectance value of Magenta Print is continuously increasing in the blue and red zone. It is found from Figure 4c) that the reflectance spectra of Yellow print are continuously increasing with time in all blue, green and red zones increasing grayness of prints. Figure 4d) shows minor changes in spectral reflectance for Black foil prints.

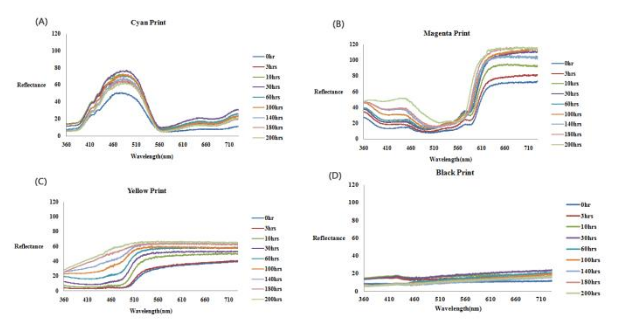
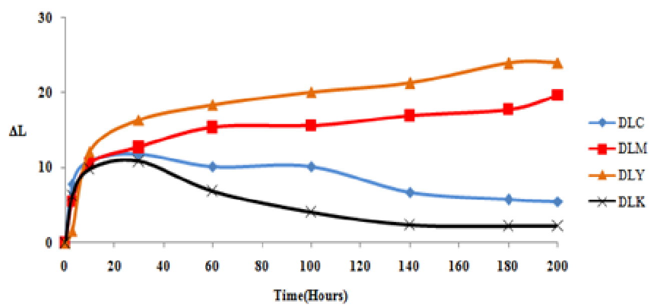


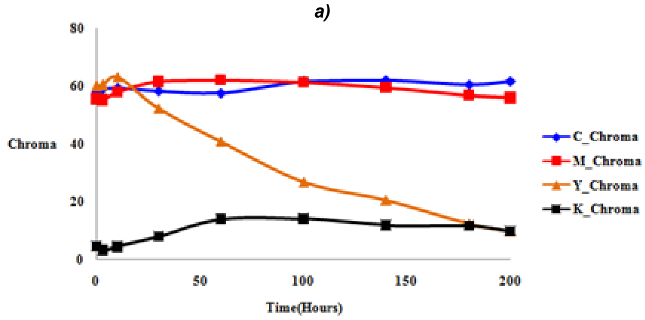
Figure 4. *Spectral data of fading on A) Cyan Print B) Magenta print C) Yellow print and D) Black print on the blister foil*

Effect of Light exposure on Colorimetric Properties of Prints

The variation of lightness $L*$ and chroma at different times are illustrated for each color in Figure 5 a)and b) respectively. Figure 5a) shows the faster fading in Yellow print and Magenta print. In contrast, ΔL value of Cyan and Black prints is initially increased and then decreased with time due to artificial light exposure. In Figure 5b), a sharp reduction in chroma value is found in Yellow print with time which is going to be grayishly followed by a slight increment of chroma of Black prints which becomes slight yellowish. However, minor differences in chroma are shown for Cyan prints and Magenta prints during the artificial light fading test. The color stability due to light exposure can be monitored with the color difference ΔE_{00} and obtained values for each color prints are presented in Figure 6a) where ΔE_{00} is recorded as the difference in color between exposed prints with unexposed prints. The largest ΔE_{00} value is obtained for Yellow print whereas it is found that after 150 hours of exposure, the increase in color difference is not significant for Cyan and Black and relatively less for Magenta. The results of color difference value ΔE* are in a good agreement with spectral changes observed for the reflectance spectra of the printed foil due to artificial xenon light exposure. Moreover, the color difference is analyzed by visual observation of the fifteen observers shown in Figure 6b) through paired comparison. The findings corroborate the experimental results.



a)



b)

Figure 5. a) Color difference b) Visual color difference of Cyan Print Magenta print, Yellow print and Black print on blister foil after exposing to xenon light source

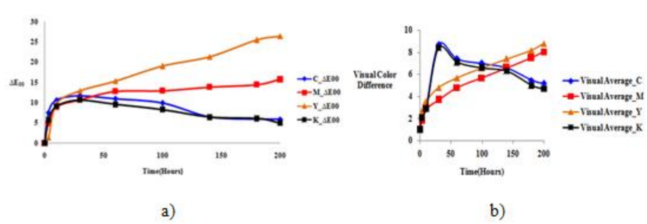


Figure 6. **a) Color difference b) Visual color difference of Cyan Print Magenta print, Yellow print and Black print on blister foil after exposing to xenon light source**

Comparison of ANN Model and Regression Model(assuming first-order kinetic equation)

In the present study, the number of hidden neurons in the hidden layer has been varied in the range of 3 to 10 to get the best ANN topology for estimating the training data. It is found that the designed ANN model with 10 neurons has obtained minimum mean square error (MSE) for the prediction of lightfastness properties of prints on the foil. The proposed neural network structure has been trained best with MSE value 0.1249, 0.1902, 0.1073 and 0.0790 for Cyan, Magenta, Yellow and Black prints respectively. This study has applied the proposed ANN model to 5 experimental datasets to predict the repeatability of the fading behavior of foil print packages over time. Figure 7a),b),c) and d) present the prediction efficiency of the designed ANN model for testing data in which the ANN output (predicted) data are plotted against the experimental data of the best network (10 hidden neurons). The results indicate the good accuracy of the ANN to estimate the lightfastness performance of the prints. The correlation coefficient value R^2 is 0.99 for each color. This calculated correlation coefficient values for determination of lightfastness properties of Cyan, Magenta, Yellow and Black prints claim a good agreement between predicted and experimental values. Therefore, the configuration of the ANN model including 10 neurons in the hidden layer is efficiently proposed for the prediction of lightfastness properties of foil prints with time. A regression model also has been experimented with the same data which are applied to the proposed ANN model training [20]. Though both Artificial Neural Network (ANN) and Regression model (assuming first-order kinetic equation) have their specific advantages, the drawback of the kinetic model is that the accuracy of a fit can not be improved after the development of the model [32]. Figure 7 also shows the predicted reflectance for 200hours exposure using the ANN model and regression model. It shows that values predicted by the ANN have better agreement with experimental data than regression modeling results. In this study, the accuracy of predicting the light fastness property of the printed foil due to artificial light exposure is better for the ANN model than the regression model. The correlation coefficient for regression model is 0.91,0.85,0.50,0.94 and ANN model is 0.99. The result indicates that the proposed neural network modeling is a better approach for the modeling of fading behavior of foil package prints for a long time exposure.

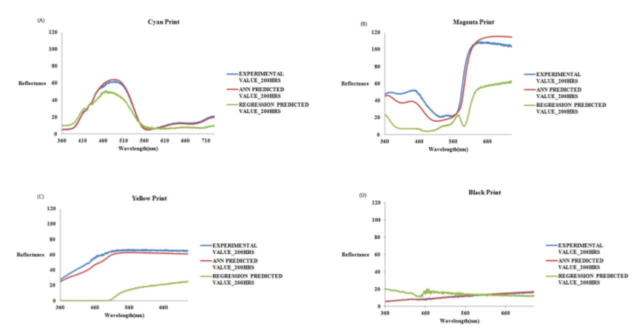


Figure 7. *Experimental Value Vs Predicted Value after 200hours accelerated exposure by ANN model and Regression model for A) Cyan B) Magenta C) Yellow D) Black*

Conclusions

The present study has applied Artificial Neural Network modeling(ANN) to predict the fading behavior of foil samples printed by gravure printing. Based on prediction results, it is possible to determine the lightfastness property of package prints. The most optimal ANN model has been achieved with evaluative criteria (MSE and correlation coefficient R^2). This study has also implemented a regression model (assuming first-order kinetic equation) to compare their prediction capabilities using the same experimental data. It is found that the Artificial Neural Network (ANN) model has better prediction capability than the regression model for each color after comparing the correlation coefficient R^2 value. The present study indicates that values predicted by the ANN have better agreement with experimental data than kinetic modeling results.It may be used for verification of printed expiry date and authenticity or validity of the product.

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