CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Print Mottle Phenomenon

In terminology of printing, mottle is caused by the flow properties of the ink in interaction with the substrate and the printing conditions. Irregular and unwanted variation in color or gloss is referred to as mottle. In practice appearing as pearling, pebbling streaks, etc.[2] Mottle arises when there are significant differences in the ink absorptivity in various parts of the sheet. A mottled, or galvanized, appearance in solid prints is defined as a visible, gross nonuniformity in ink density, color, or gloss, or any combination thereof. Mottle is found more commonly with paperboard than with paper.

There are a number of different types of mottle. Absorptive mottle is caused by an imbalance in the ink and the paper. All paper has nonuniform absorptivity, although some textbooks state that handmade paper is uniform. Fibers from which the paper is made cannot be distributed completely uniformly. If the ink is absorbed more by one part of the sheet than by another, nonuniform penetration may yield the visible pattern of mottle. One way to overcome mottle is to select an ink that is either uniformly held out or uniformly absorbed by all areas of the sheet. If the sheet is reasonably uniform, this will not be a difficult task. However, for some types of substrates, especially paperboard, differences in absorptivity may be so great as to make the selection of a suitable ink very difficult.

Mottle is also aggravated by the responses of the eye. Variations in brown, blue, and green solids are more visible than are variations in other colors. Pattern prints show less mottle than do solids. Inks that set and dry quickly probably cause less mottle than those that set and dry slowly. The longer it takes for the ink to set, the more time there is for differences in the absorption to become apparent.[3]

When ink is the cause of mottle (sometimes it might be due to an inconsistency of ink acceptance by the paper) it is thought to be connected with the ink being drawn out into strings as the film splits (Figure 2-1).[4] The strings then collapse on to the print, producing a characteristic mottled appearance due to slight differences in film thickness all over the surface. It often appears to be aggravated by some combination of a heavy impression, a paper of high surface absorption (which may prevent the strings of ink flowing out when they relax back to the print surface) and inks of low viscosity and low yield value. Mottle may be somewhat reduced by adding an extender whose oil asborption will reduce the flow of the ink, or a paste containing starch and wax which has a similar effect.

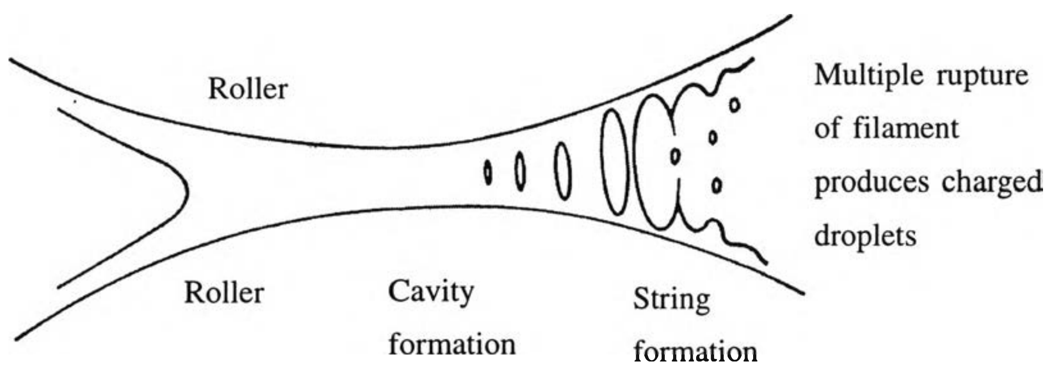

Fig. 2-1 Representation of an ink film splitting

When paper is printed, the ink has a tendency to fill in some of the low spots and present an optically flat surface that specularly reflects part of the light striking it. The amount of specularly reflected light determines the print gloss. Specularly reflected light is not affected by the color of the reflecting object; therefore, if white light is used as the incident beam, the reflected beam will be white also. However, some of the light will penetrate into the ink film, and will be scattered and emerge as diffusely reflected light of the color of the ink. Therefore, the light used to measure gloss will be a combination of the white specularly reflected light and that part of the colored diffusely reflected light that happens to emerge parallel to the specularly reflected beam. If the surface is optically smooth, the specularly reflected light will be confined to a small solid angle at the angle of reflection and the colored diffuse reflection will be distributed over the whole hemisphere. Therefore, by viewing the paper at an angle other than that of specular reflection, the white specularly reflected light can be excluded. However, if the surface is optically rough, the white specularly reflected light will be distributed over a wide solid angle and no viewing angle will exclude this white light. There is using polarized light to separate the specularly reflected light from the diffusely reflected light. The method is based on the assumption that polarized light will remain polarized after specular reflection but will be completely depolarized when scattered and diffusely reflected.

Print gloss is important in papers. However, uniformity of gloss is more important than the average level of gloss. The nonuniformity in printed gloss is called mottle. Variations in the paper contribute to the development of mottle in the print. The reflectance of a very small area is compared with the reflectance of a much larger surrounding area; the ratio of the two measurements is poltted as the paper is scanned; the viewing angle is 0°, but illumination can be at 0° or 45° depending on whether the specular component is to be included or excluded; and a grazing illumination can be used to include roughness.[5]

In coloring materials, acid dyes tend to follow the water in drying operations migrating to the surface of the sheet, thus resulting in a mottled appearance.

Mottle appearance is caused by the poor formation if the fibres are unevenly distributed. Formation is defined as the uniformity with which the fibers are distributed in the paper. It is thus a physical property of the paper, although it is customarily measured by the degree of uniformity of light transmission through the paper. Formation is judged visually and subjectively by looking through the sheet at a uniform light source. Paper is said to have a uniform or close formation if the texture is similar to ground glass when viewed in transmitted light.

Formation is determined by the intensity or density of the clouds or mottled areas and their spacing.[6] Naturally, the results of visual examination cannot be expressed numerically, and it becomes necessary to compare the specimen with a standard paper of acceptable formation or to rely on the judgment of the observer. Formation is affected by the transparency of the paper since, in general, the more transparent the paper, the more readily poor formation shows up. For example, waxed paper generally appears more poorly formed than does the same paper before waxing. The color of the paper is another factor since blue papers generally appear wilder than do white or yellow ones.

2.2 Print Mottle Measurement

To be able to measure variations in print density, mottle, it needs to be able to measure the reflectance properties in small enough spots. In an image analyser, the spot readings can be the individual pixel grey values in an image of the print.

There are several methods to determine print mottle as follow :

2.2.1 Texture based method

The solid print's unevenness is considered as a texture. A co-occurrence matrix entropy based method is used to study solid print quality.

Solid print quality has so far been characterised by density measurements. Density measure is, unfortunately, a pointwise measure and cannot describe local disturbances, e.g. mottling.

Texture classification is one part of image analysis. Texture classification has been applied to characterise paper formation.[7]

Texture can be defined as a structure composed of a large number of more or less ordered similar elements or patterns without one of these drawing special attention whereby a global unitary impression is observed. A texture can be considered as a strictly ordered array of identical sub-patterns, like a chessboard. Such a texture is called deterministic and it can be described by the characteristics of one sub-pattern or primitive and by the placement rules defining the spatial distribution of the primitives. The impression of a pattern can also obey statistical laws. Such a texture is said to be stochastic. A look through image of a paper sheet is a good example of stochastic texture.

The method is in three stages. The image acquisition part consists of image formation and image correction. The feature extraction part calculates a pattern vector of the actual stochastic texture. In the third stage the pattern vector is then reduced to a measure that characterises the evenness of the captured solid print image.

2.2.2 Spatial frequency based method

This method is related to detail rendering. A particular aim was to try to link microscale paper-ink interactions to macroscale appearance such as mottling. The measures are based on image analysis methods, most of which were specially designed for line patterns with different spatial frequencies. The measures were mottle in line patterns.

The detail rendering, a resolution line test pattern with different spatial frequencies can be used.

The bar test patterns is the large-scale, i.e. low-frequency, mottle that sometimes appears at higher line frequencies. Large-scale here refers to feature sizes clearly larger than the pattern line width. Print mottle is a quality defect that is not directly linked to detail resolution. On the contrary, one can easily imagine a print with a high degree of detail resolution but modulated by a low-frequency intensity pattern which thus gives a mottled appearance. However, in practice one may suspect some correlation between detail rendering and mottling. An imprecise detail printing may at least pose a risk for a macro-influence of the paper structure and thus a mottle print.

The print mottle was therefore determined in the line patterns is order to explore a possible relation to the detail data.

The mottle was evaluated with the line pattern suppressed. The suppression was achieved by neighbourhood averaging in the image analyser using a square window with a side length equal to the line pattern wavelength. All disturbances with characteristic sizes smaller than half the wavelength of the line pattern were thus also suppressed.

At low inking levels, the mottle increased with increasing frequency. Higher inking levels led to higher print mottle. The higher inking levels introduced a maximum in mottle and that this maximum was shifted towards lower line frequencies when the inking level was increased. The mottle increased with increasing print density for all paper types, but at a given density the highest mottle level appeared on newsprint. Thus the mottling propensity seemed to be linked to surface roughness. However, since the the smoother papers are normally printed at higher density levels than the rougher, the differences in mottle in practical situations may be small.[8]

2.2.3 Area based method

This evenness is affected by the uniformity of the two-dimensional ink distribution on the paper surface which may be characterized by stochastic grey level distribution. To achieve a high correlation with visual perception, the structure and contrast parameters of this distribution have to be taken into account. Whereas the contrast corresponds to the first order statistic, the structure can be described by algorithms based on second order statistics such as a co-occurrence matrix or two-dimensional autocorrelation function. These parameters can be measured by means of an image analyser.

Relationships exist between the specific perimeter (power spectrum), correlation length (autocorrelation function) and correlation (co-occurrence matrix) parameters.

Correlation COR is a measure describing correlation length which also reflects the average feature size e.g. the average area of ink distribution or the average floc size of unprinted paper (measured in transmitted light). The contrast is the overall variation of the grey tone image of printed or unprinted paper which can be simply quantified by its variation coefficient. A combination of both parameters leads to the mottling index.

Using image analysis, it is possible to quantify the texture of printed solids measured in reflected light. If the characterisation of two-dimensional distributed grey levels is to correlate with the visual impression, image-analysing processes must be used that record both structure and contrast parameters.

In halftones, the absolute print contrast K_{abs} is defined as the difference in density between the solid density D_V and the halftone density D_R

$$K_{abs} = D_V - D_R \qquad \ldots (2.1)$$

The relative print contrast K_{rel} used to measure the ink acceptance is defined as :

$$K_{rel} = \frac{D_V - D_R}{D_V} \qquad \ldots (2.2)$$

The transfer of minor details and the resolution are quantified by the contrast transfer function. The contrast of the rectangular gird, K_R, is the result of micro-measurements and is defined as :

$$K_R = \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \qquad \ldots (2.3)$$

There are two different definitions and measuring rules for the concept of contrast, depending on the area of application concerned. Another definition for the contrast calculated by image analysis is the contrast of the solid, CV :

$$CV = \frac{SD}{\overline{X}} \qquad \text{... (2.4)}$$

This is the ratio of the standard deviation (of the grey levels) SD to the average grey level $\overline{X}$ of the solid, i.e. the coefficient of variation CV of the grey value.

The variation coefficient, or the standard deviation, or a value deduced from it such as entropy, is named as the gauge by which to measure the unevenness of the solid. This may well be justified in many cases. It is important to bear in mind two facts :

• the standard deviation and the coefficient of variation quantify the ink distribution in the *z*-direction

• different textures may reveal similar first-order statistics, therefore, in relation to mean value and standard deviation.

Local reflectance measurements and statistics is the method in relation to the subjective experience of print mottle. The variation among such readings (pixels) should have some relation to the mottle sensation. Mottle measurement has been suggested denoted Mottle Index (MI).[9] MI uses the specific perimenter (SP) which is an inverted measure of typical dimensions of features in an image. The specific perimeter is defined as the sum of pattern border length divided by image area when the image is thresholded to 50% feature area. For a chessboard pattern, 1/SP equals half the edge length of the small squares. For a snakelike pattern, 1/SP equals the snake diameter. 1/SP is thus a measure of pattern courseness.

Because of the low-pass characteristic of the 'sensor's' eye, both the contrast (grey level distribution in the *z*-direction) and the two-dimensional ink distribution (grey level distribution in the *xy*-plane) on the surface of the printing substrate must be taken into account in order to obtain a correlation between the measured mottling and the visual perception. The same principle is valid for the analysis of the formation of unprinted paper. The non-homogeneity of a paper sheet, with its wildness visualised by light transmission, is determined mainly by the two parameters of contrast and floc size.

The combination of the structure parameter COR and the contrast give the mottling index MI :

The Mottle Index MI is defined as :

$$MI = CV / \sqrt{SP} \qquad \text{... (2.5)}$$

or alternatively

$$MI = CV \bullet \sqrt{COR} \qquad \text{... (2.6)}$$

Where COR is a correlation length measure which also reflects the average feature size.

The effect of the size weightings of the CV value that the MI introduces, is the implication that the coarser the pattern, the worse is the mottle.

Specific perimeter was found to be sensitive to the degree of detail present in the image and will therefore be strongly influenced by focusing.

The cofficient of variation gives an indication of the degree of variation presented in the sample while the specific perimeter indicates the form of that variation. A plot of SP versus CV allows non-uniformity to be quantified (Figure 2-2)

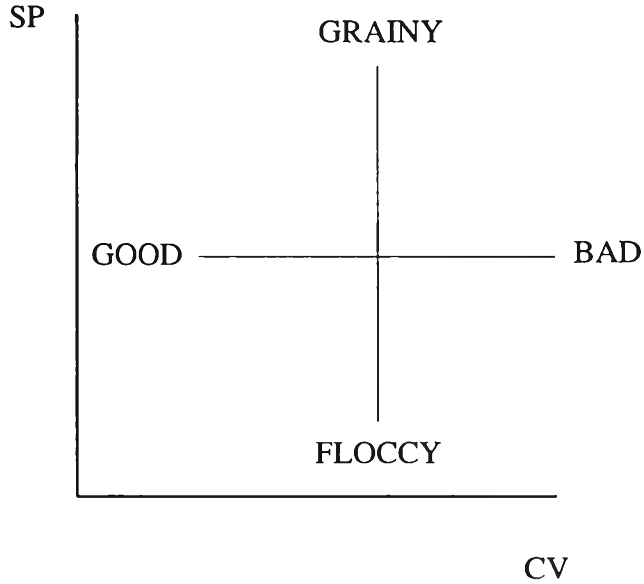

Fig 2-2 Non-uniformity of SP versus CV

The lower standard deviation results in less variation of white spots in the image, by which the ink film appears uniformly on the surface. The higher the specific perimeter is the more specky of the image becomes, and thus, the ink film appears non-umformly.

2.3 Image Analysis Principle

The image analysis process can be devided into three main steps. The first step, the most critical one, consists in the acquisition of the image which must be performed under calibrated illumination. The second step, the binarization, is the transformation of the image, acquired as a grey level image, into a black and white image : i.e. a binary image. This step includes grey-noise processing, segmentation, and interactive enhancement like filtering and smoothing. The third step consists of data processing of the binary image and measurement of various parameters used to quantify and/or describe the original grey level image.[10]

In image analysis, all data treatment is performed on the binary image transformed by various operations from the original grey-level image. It is therefore of prime importance that the shapes, textures, objects, etc. of the binary image remain unchanged through the various transformations or, at least, that any changes be minimised.

In the original image, grey levels usually range from 0 to 255 low values correspond to white. Grey level will show the number of pixels corresponding to each grey level of the original image. Once the original has been properly acquired, binarization or segmentation of the image is used to transform the original into a binary image. For prints, it means separating the image into inked area, i.e. areas physically covered by ink pigments, independently of the local ink layer, and non-inked areas, i.e. areas not covered by any ink pigments. The binarization step is needed to calculate image parameters such as surface covered by ink, shape of halftone data, raggedness of dots, etc. This is true for all image parameters defined by a border between inked and uninked areas. It should be emphasised that through the various transformations, some information is lost. The purpose of the proposed method is to recover such lost information by comparing the binary image to the original grey-level image. This is done by using the surface of the inked portions of the binary image as a reference point. A step not yet considered in most image analysis processes is the analysis of image information content or variations in image object of various grey-levels or colours. This last step, presently ignored by most researchers in the field, should eventually be included as a last step in image analysis.

To convert a grey-level image into a black and white image (binary image), one needs to select a grey-level value, between 0 and 255, to separate black from white or inked from uninked areas. This grey-level value is called the threshold value. In thresholding a grey-level image, any pixel whose value is above or equal to the threshold value is given a value of 1. The screen image of the pixel is then shown as white (or blue). Pixels whose values are below the threshold value are given a value of 0: these appear black on the screen. Thresholding is often a very subjective operation where one relies mainly and solely on the discriminating power of the eye to separate inked from uninked areas. Although acceptable for most applications, this procedure lacks reliability, repeatability and reproducibility. To ensure repeatability and reproducibility, thresholding should be based only on objective criteria, independent of subjective judgement. It should however be stressed that such an objective automatic method needs somehow to simulate what the standard CIE observer would see. In other words, any thresholding technique should duplicate what the average eye will discriminate.

2.4 Mutiple Regression Model

Multiple regression is a well-known method of statistical experiment. For example, in the mottle-determination problem, the result might depend on the amount of illumination in addition to the level of mottle index itself. Such problem can be analyzed within the general framework of the regression model by using multiple regression analysis technique.

In this chapter, the problems involving several independent variables using multiple regression analysis are considered. Multiple regression means that one result has statistical relationship with many factors.[11] This relationship can be writen in mathematical model as follows.

Mottle-determination problem = f (illumination, mottle index)

Mottle-determination problem is a dependent variable, and is the result of illumination and mottle index. For clearly understanding, we can say that illumination and mottle index are independent variables.

The relationship has to be linearly-relationship. This assumption is easiest way to explain the result. Basically, we can draw a mathematical model as follow:

$$Y = f(X_i) \qquad \ldots(2.7)$$

where Y : dependent variable

X_i : independent variable

i : 1, 2, 3, ..., n

Same as above, Y (result) is the function of X_i, this means that Y will vary systematically with various X_i, based on with the linear relationship.

2.4.1 Mathematical formulation

Each observation on dependent variable can be characterized as a function reflecting the line of the systematic relationship between independent variable and a random element. Apart from the relationship of Y and X_i, the another important factor that will effect the result is random element (ε_i). Random element is a disturbant term. It is unpredictable and thus affecting the result. The proper mathematical model should be the random element (ε_i) as least as possible.[12]

In general, the linear multiple regression model may be expressed as :

$$Yi = f(X_i) = b_o + b_i X_i + \varepsilon_i \quad (i = 1, ..., n) \qquad \ldots(2.8)$$

where i : observation number

b_o : intercept parameter (constant)

b_i : slope parameter

n : number of observation

So, we have the originating function.

$$Y_i = b_o + b_i \sum_{i=1}^{n} X_i \qquad \ldots(2.9)$$

where b_o : constant

b_i : parameter

From equation (2.8) we have to find the value of b_o and b_i

$$Y_i = b_o + b_i X_i + \varepsilon_i \qquad ....(2.10)$$

to rearrange this function, given by :

$$\varepsilon_i = Yi - b_o - b_i X_i \qquad ...(2.11)$$

From equation (2.11) we will use the least-square estimator to find out the value of b_o and b_i by putting index 2 (square) to the both sides and put summations to the both sides as :

$$\sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (Y_i - b_o - b_i X_i)^2 \qquad ....(2.12)$$

First step, we have to find out the value of b_i, from equation (2-12), using partial differentiate with respect to "b_o" :

$$\frac{\partial \sum \varepsilon_i^2}{\partial b_o} = 2 \sum_{i=1}^{n} (Y_i - b_o - b_i X_i)$$

$$= 2 (\sum_{i=1}^{n} Y_i - nb_o - b_i \sum_{i=1}^{n} X_i)$$

Since the variance of ε_i is constant, so the left side will be zero ($\frac{\partial \sum \varepsilon_i^2}{\partial b_o} = 0$), now we have

$$0 = 2 (\sum_{i=1}^{n} Y_i - nb_o - b_i \sum X_i)$$

rearrange the above function again, and devide both sides with 2, thus :

$$\sum_{i=1}^{n} Y_i = nb_o + b_i \sum X_i$$

we devide both side by "n" to obtain b_o and b_i values :

$$\bar{Y} = b_o + b_i \bar{X} \qquad \text{....(2.13)}$$

$$b_o = \bar{Y} - b_i \bar{X}$$

2.4.2 Evaluation of statistical model

From mathematical formulation, we can know the parameter value. The statistical program will give the results of regression model as follows; R^2, F-test, t-test, standard deviation, etc. The R^2, F-test and t-test are the initial valuations at regression. First, we will start with R^2 or coefficient of determination.

Coefficient of determination arises from two component, the first one from predicted value of the model and the second one from actual value of variable. We can explain the source of R^2 as follows :

$$(Y_i - \bar{Y}) = (Y_i - \hat{Y}) + (\hat{Y}_i - \bar{Y}) \qquad \text{....(2.14)}$$

Y_i : actual value of dependent variable

$\bar{Y}$: mean of dependent variable

$\hat{Y}$: predicted value from regression model

The left hand side $(Y_i - \bar{Y})$ is called total deviation, while the first term of the right hand side is $(Y_i - \bar{Y})$ called unexplained deviation and the second term $(Y_i - \hat{Y})$ is called explained deviation.

From equation (2.14), we take square and summation into both sides, to obtain :

$$\Sigma (Y_i - \bar{Y})^2 = \Sigma (Y - \hat{Y})^2 + \Sigma (\hat{Y}_i - \bar{Y})^2$$

$$SST = SSE + SSR \qquad ....(2.15)$$

We call the left side equation as summation sum of square total, the right hand side is summation of square error and summation of square regression, respectively. From equation (2.15), the summation of square total (SST) is devided to achieve :

$$1 = \frac{SSE}{SST} + \frac{SSR}{SST}$$

$$1 = \frac{\Sigma (Y_i - \hat{Y})^2}{\Sigma (Y_i - \bar{Y})^2} + \frac{\Sigma (\bar{Y}_i - \hat{Y})^2}{\Sigma (Y_i - \bar{Y})^2} \qquad ....(2.16)$$

The first term of the right equation is the ratio of unexplained variation to total variation, the second term is so call "coefficient of determination or R^2" and will be shown in percentage term.

The second term is the explained variation to the total variation, it can be percentage of the total variation in the independent variable explained by the regression model.

The measured R^2 provides the investigator with an extremely useful summary of the relationship between the dependent and independent variables. By rearrangement of the equation (2.16) and substitution e_i for (Y_i - $\hat{Y}$), we obtain :

$$R^2 = \frac{\Sigma (\bar{Y}_i - \hat{Y})^2}{\Sigma (Y_i - \bar{Y})^2} \qquad ....(2.17)$$

or $R^2 = \dfrac{1 - \Sigma e_i^2}{\Sigma (Y_i - \bar{Y})^2}$

2.4.3 t-test or hypothesis testing of parameters independent variable (one by one)

t-test is an hypothesis testing of the parameter for regression model. t-test will help the investigator to determine whether the independent variable (one by one) is significant in prediction of dependent variable or not.

This means that if no significance is considered, we can cut that independent variable from the regression model. For example after getting the parameters from the regression model, we have to test it if it equals to 0 (zero) :

$$H_o \quad : \quad B_i = 0$$

$$H_1 \quad : \quad B_1 \neq 0$$

The test statistical is given by

$$t_{n-k-1} = \frac{bi - 0}{S_{bi}} \qquad \ldots(2.18)$$

n : number of observations

k : number of inderendent variables

Where S_{bi} is the estimated standard error of the ith regression coefficient and is provided in the output of SPSS regression program. Where the degree of freedom (n-k-1) is the distribution of the coefficient's error.

2.4.4 F - test

Another hypothesis testing is F - test, From t - test, we know that each parameter is not equal to zero if we test in one by one. For the F test, it is an additional test. F - test is used for group of parameters. This hypothesis will assume that at least one parameter not equal to zero. If F - test result is significant, it means that the group of parameters (B_o, B_i, i = 1, ...n) have statistical significant to the regression model.

$$H_o \quad : \quad Bi = B2 \ldots Bn = o$$

$$H_1 \quad : \quad \text{at least one } Bi \neq o$$

$$F_{k,\, n-k-1} = \frac{\Sigma - (\hat{y}_i - \bar{y})^2 / k}{Se^2}$$

$$= \frac{SSR/K}{SSE / (n - k - 1)}$$

$$= \frac{MSR}{MSE} = \frac{(\text{Mean Square Regression})}{(\text{Mean Square Error})} \quad \ldots(2.19)$$

with degree of freedom $= n - k - 1$

2.5 Literature Review

In 1975, Blokhuis et al.[13] have founded the unevenness occurring in printed areas, and the unevenness in the paper, that can be measured with a dynamic smoothness tester, appear to have periodicities of the same order of magnitude. In principle, it should thus be possible to predict the tendency of the blank paper to cause uneven prints, by means of the dynamic smoothness tester.

In 1991, Visa et al.[14] studied a co-occurrence matrix entropy based method which be applied to characterized the solid print. Method and equipment to characterise solid print evenness based on its texture has been applied to test the two-sideness of paper and it has been shown to work well.

In 1993, Johansson[15] presented choosing a suitable lateral wavelength band, a high correlation between subjective mottling and reflection variation can be obtained. The wavelength analysis can be performed by a simple gliding average band-passing algorithm. A corresponsing analysis can of course also be done via Fourier transform power spectra. The choice of parameters is also in accordance with known facts about the contrast sensitivity of the human visual system.

In 1995, Ness et al.[16] presented the evaluation of mottling and formation by visual evaluation of mottling in accordance with the ranking method, in which the viewer is called upon to rank a series of prints in accordance with the level of unevenness. It is customary for the print displaying the strongest mottling to receive rank 1, With n prints, a total of n ranks are assigned (Figure 2-3)

As with the mothod involving pair comparisons, the ranking method permits the establishment of the pair comparison index (PV-index).

$$\text{PV-Index} = \frac{2\left[\left(\sum_{R=1}^{n} f_{Ri} \cdot R\right) - N\right]}{N \cdot (n-1)} \cdot 100 \qquad \ldots(2.20)$$

where

n = number of prints

R = inverted rank (the print with the lowest evidence of the characteristic concerned (here unevenness in solid) has rank 1)

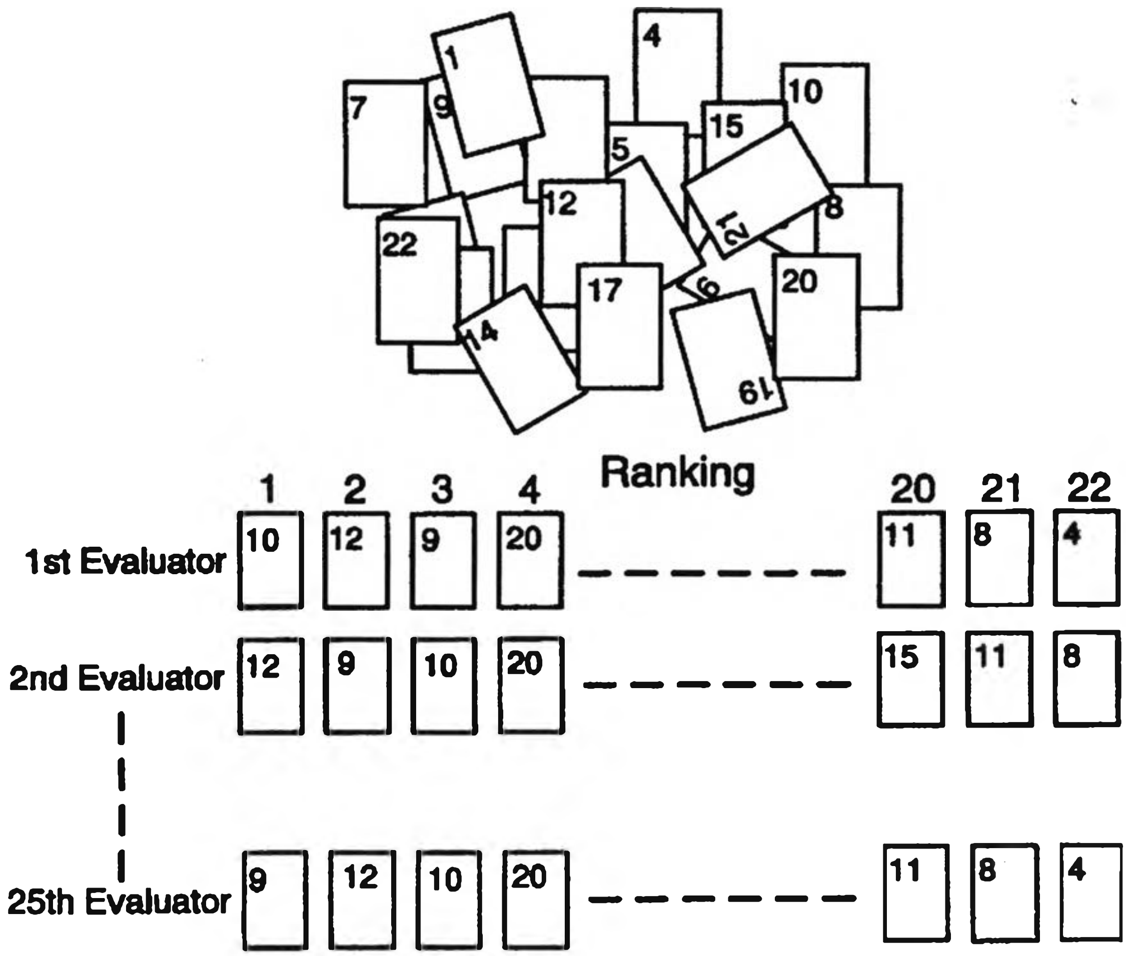

Figure 2-3 To establish the pair comparison index

f_{Ri} = absolute frequency with which a print i has received the inverted rank R

N = number of evaluators

The ranking method should always be given preference over pair comparisons in cases where there is a test series containing a large number of prints to be evaluated.

In 1995 , Heikkilä et al.[17] studied the identification of the formation of print noise using image analytical methods. The contact smoothness of unprinted paper was imaged under dynamic pressure in a printing nip.

The experiments were carried out to identity the interrelations between paper smoothness under dynamic pressure and noise in solid prints and frequency modulated screened areas. Power spectra were used to divide the structure of paper smoothness and print noise on different scales.

Solid prints were found to contain relatively more small-scale noise than unprinted papers in the printing nip. On a scale close to the width of the wood fibers, its origin is likely to be ink transfer. By contrast, the reason for very small-scale variation appears to be ink penetration into paper surface pores as well as ink and coating particle clusters.

In FM screened areas, print noise formation was found to be even more complex than in solid printed surfaces. When an FM screen (non-ordered dot pattern) was printed on a paper surface (stochastic network of wood fibers), an interaction was found between the dot pattern and the paper surface structure. According to the results, as the dot percentage increases, the power of the interaction decreases. In addition, interaction was found only when the screen dot size was close to the fiber width. The ranking of the papers according to print noise was different in FM screened areas from that in solid prints.

In 1995 Ångskog[18] presented a critical study of the usefulness of a number of print quality measures related to detail rendering. At low inking levels, the mottle increased with increasing frequencies. Higher inking levels led to higher print mottle.