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Color Characterization for Scanners: Dpi and Color Co-Ordinate Issues

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***ABSTRACT** Characterization and estimation of device independent color co-ordinates of scanned or photographic images of through empirical models is a typical issue for commercial desktop scanners and cameras. As a domain of complex problem for optimising suitable color model to evaluate textiles and paints, we investigated the effect of different DPI and device independent color coordinate selection for color Characterization using 140 color patch standards of SGA Colorchecker on Fabric Eye D 2000 scanner. This paper extensively discusses the polynomial regression and neural network characterization techniques and their respective model performances in order to relate typical scanning devices to spectrophotometer i.e., get CIE XYZ/ L*a*b*/L*c*h* from RGB values of scanned image of for D65 10 illuminant and observer.*

***KEYWARDS** Tristimulus values, Color matching function , Color characterization, Polynomial regression, CIE illuminant and observer ,back propagation, neural network*

I. INTRODUCTION

All commonly used imaging systems, from digital cameras to scanners and CRTs, use a similar three band color encoding scheme since their purpose is to provide input to the human visual system. One consequence of this color-encoding scheme is that there are many spectra, called *metamers*, that can lead to the same triplet of responses and sensor triplets is many-to-one. We cannot either perfectly reconstruct the original spectrum from its reduced counterpart and impossible to recover the precise surface reflectance properties of surfaces in a scene from a three band image of that scene, or recover the exact spectrum of the light illuminating the scene. The best that we can expect is a three parameter specification of the reflectance and illumination properties: (Computational Vision Lab Research).

Yet the human visual system, using a three band encoding of color, exhibits a remarkable resiliency to changes in incident illumination. The CIE adopts a set of cleverly designed primary stimuli that have special properties; they are designated as tristimulus values X, Y, and Z with corresponding X(λ), Y(λ), and Z(λ), color-matching functions.

$$\left.\begin{aligned} X &= \sum_a^b K.E(\lambda).\bar{X}(\lambda).r(\lambda).d\lambda, \\ Y &= \sum_a^b K.E(\lambda).\bar{Y}(\lambda).r(\lambda).d\lambda, \\ Z &= \sum_a^b K.E(\lambda).\bar{Z}(\lambda).r(\lambda).d\lambda \end{aligned}\right\} \text{-----------------} \quad \textbf{(1)}$$

E (λ) = Energy Distribution function
X (λ)= Color matching function of standard observer
R (λ)= Reflectance factor of the object.

The color interpretation of Red Green Blue (RGB) data from a scanner depends on the Illuminant type and characteristics of the optical filters that are used to separate the wavelengths of visible light into color components. Common desktop scanners have notoriously poor color characteristics, and this causes scanners to fail to "see" colors the same way that we do. Reproduction of color in all of these systems; CRT displays, scanners, color printers and prepress systems, etc. are highly device-dependent: if RGB values from one device are sent to another without consideration of different device characteristics, then different colors are likely to result [1]. This situation is more typical for textiles, and needs highly-specialized systems or empirical model that take proper account of device color reproduction characteristics as the surface profile and exposed illuminated surface of the image contributes noise for estimating correct RGB value at pixel levels.

II. Terminology

Calibration defines the setting up of a scanner (or any process) such that it gives repeatable data day in and day out. The reliability of scanners depends on the certain tests [2]. Geometric accuracy, Geometric resolution, radiometric accuracy and Color accuracy are most common calibration prerequisites before forming certain tasks ([3]-[4]) .
Characterization: This defines the relationship between the device 'color space' and CIE system of color measurement. Thus for scanner or camera it normally defines the relationship between the voltage quantized as data recorded on disc and the CIE measurements of the colors scanned. The characterization may be defined as a mathematical model based on a set of equations or a definition of discrete number of points which constitute a look-up table. So it is a special case of color transformation based on device to standard device independent color coordinates bearing some logical relationship to the original.

III. Color Calibration and Characterization of Scanners Using Polynomial Transformation: Prior Art

Baltsavias and Waegli (1996) found the geometric accuracies of desktop publishing scanners used in photogrammetric and cartography between 4 and 7 micron[5]. Baltsavias (1996) concluded that the geometric accuracy of desktop publishing scanners was low [6]. He suggested limiting cartographic scans to A3 size, checking and calibrating them regularly. Vrhel and Trussel [7] (1999) presented the mathematical formulation of calibrating color scanners and found that the mapping from scanned values to colorimetric values is nonlinear. They applied artificial neural network for calibration, then compared this method with other calibration methods based on a test performed with 264 samples. Hardeberg et al (1996) propose an analytic method based on 3rd order polynomial regression techniques[8]. They used CIE color space values and scanned values of 288 parts of the IT8.7/2 color calibration card. They found out that the polynomial regression delivers better results than other methods.

Finlayson and Drew (1997) mentioned that the color values measured by color devices (e.g. scanners, color copiers, and color cameras) must be transformed to colorimetric "tristimulus" values in order to characterize them in a device independent fashion[9]. Two well-known methods for this transformation are the simple least squares fit procedure and Vrhel's principal component method. They propose a new constrained regression method based on finding the mapping which minimizes the sum of squared distances between the mapped RGB data and corresponding XYZ tristimuli values even when the calibration data is incomplete. Ostromoukhov et al (1994) performed 3D-transformations between RGB and CIE XYZ color spaces in order to calibrate electronic display systems [10].

Mohd and Kirby (1997) tested geometric accuracy of desktop publishing scanners by using a calibrated grid plate and applied affine transformation and polynomial regression between scanned Cartesian coordinates and the calibrated ones[11]. They found out that 2nd and 3rd order polynomials are suitable for geometric improvement of scanned images. Higher order polynomials are no more useable and the order of polynomial depends on the scanner used.

Kang (1997) mentioned that many scientists have successfully applied regression method for transformation of scanned RGB values to colorimetric values and used IT8.7/2 calibration card and Sharp JX 450 scanner. He compared the results obtained by different order of polynomials and different standard illuminants [13].

Previously, Berns and Shyu (1994 and 1995) proposed a color mixing method based on theories of Beer-Bouger and Kubelka-Munk and scanner signals. They also applied polynomial regression([14],[15]).

Hardeberg [16](1999) investigated on AGFA Arcus 2 scanner with AGFA IT8.7/2 calibration card and suggested methods based on linear regression, polynomial regressions of 2nd and 3rd order. Yilmaz (2002) worked on five different scanners and applied conformal, affine, projective and polynomial transformations for reducing color inaccuracies [17]. He found out that the polynomial regression of 3rd order delivers the best results in general.

Noriega et al (2001) determined some properties of scanners by using negative and positive density measurements on the scanned RGB values and the CIE XYZ color space values. They concluded that the inaccuracies of the colorimetric values by scanner depend on the properties of the device and the related color management system. In the models based on polynomial regression, including more samples in this part of the colorant space could reduce the errors at the gamut boundary. Common test targets such as the ISO 12640 and 12641 have only a limited number of patches at the gamut boundary. However, Green (2000) proposed a new target for defining media gamut boundaries. He used 2nd order polynomial regression in his application.

Recent literature suggests that colorimetric characterization methods include polynomial regression, ([18]–[20]) neural networks ([21]–[22]) and look-up tables ([20],[23]). Look-up table method usually requires a large number of color samples, it is not preferred in scanner characterization [24]. However, as a neural network does not offer obvious advantages [25], polynomial regression is actually the most appropriate method in scanner characterization [26]. The major limitation of the colorimetric characterization is its constraint to specific combinations of illumination and observer functions. Under the same illuminant condition, the color accuracy of the colorimetric characterization is reported to be better than that of the spectral one ([25],[27]).

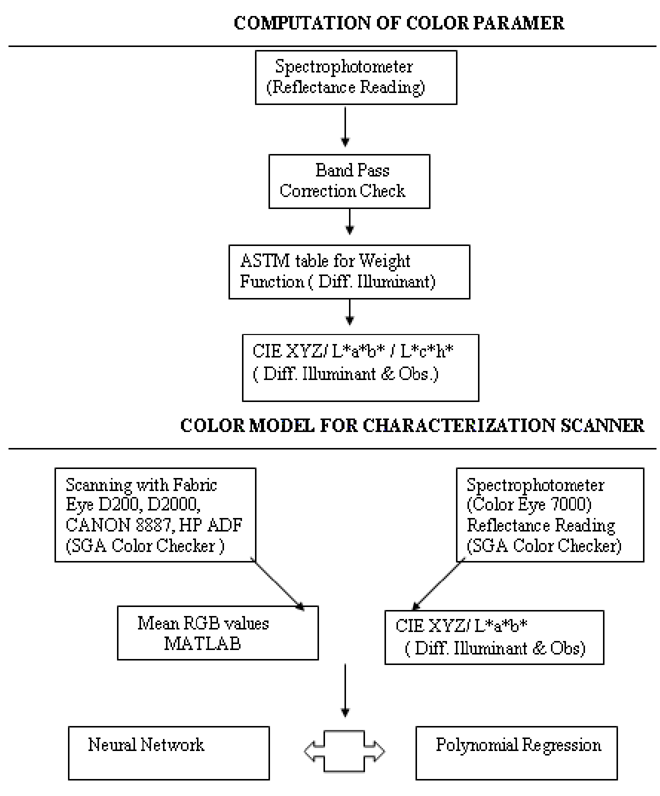
In fact, in the majority of previous studies, the polynomial regression is applied to transform the *RGB* values to the CIEXYZ values. ([18]-[20], [25]). Usually, the polynomial regression is solved using either a least-squares method or a total least-squares method. ([28]–[29]).

IV. Characterizing Scanner with optimal standard color selection

The color characterization of digital systems often requires the use of standard charts containing uniform solid color samples. A common practical consideration for any data-based characterization is the choice of the characterization target; that is, how many (and which) known samples to choose from which to construct the chart. The GretagMacbeth ColorChecker and GretagMacbeth ColorChecker DC charts are widely used as targets for color characterization tasks. ([9],[32]-[34]). Characterization charts such as the GretagMacbeth ColorChecker, the GretagMacbeth ColorChecker DC and the ANSI IT8 charts are designed to be used in a color management process with the aim to allow a system to reproduce colors with acceptable tolerance. Some work has been reported to investigate which characterization target is optimum for the characterization process ([35]-[36]).

The optimal choice for color characterization charts—how many (and which) known samples to include: is known to affect characterization performance. Cheung and Westland [31] , Experimentally verified and proposed that the standard GretagMacbeth ColorChecker and Gretag Macbeth Color Checker DC colors constrained to be a subspace of optimum color samples from a set of 1269 Munsell surface colors though the polynomial regression and neural network techniques for RGBXYZ though the mapping are not so good [12] . So standard color checker X-rite SGA 140 were being tried to characterize the scanner for color values.

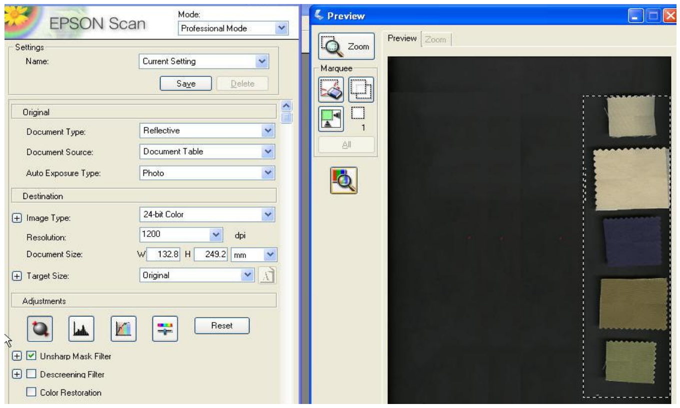
The work tried in this study deals with the analysis and development of methods to characterize color, i.e. to predict device independent color co-ordinates specifically CIE XYZ/ L*a*b* from RGB coordinates of scanned image of the textile fabric for all ASTM CIE illuminats. The out-line of the study is described in the flow chart shown in fig.1 below.



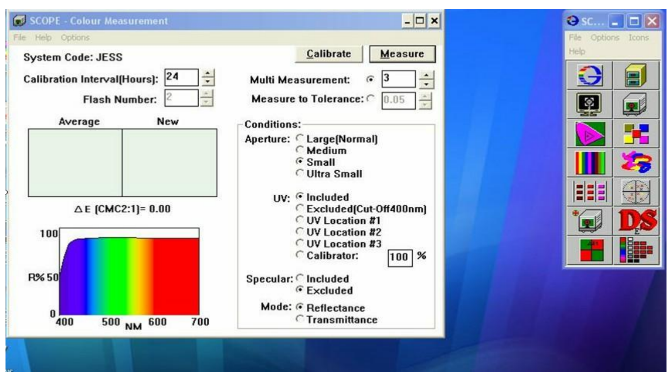
[Fig.1:Flow chart of Work]

V. EXPERIMENTAL METHODS

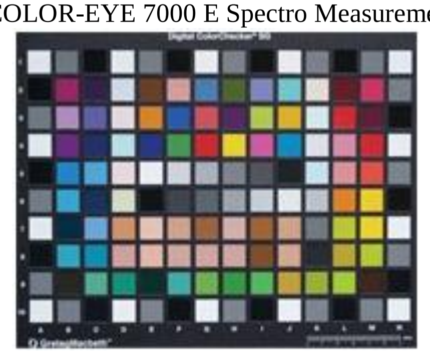
As the characterization of crucial parameters influence the color evaluation, controlled experiments are followed to obtain RGB valuses from scanned image and Tristimulus values/CIE L*,a*,b*/L*c* h* for all ASTM illuminant and observers combinations. Initially the spectrophotometer is checked for Band-pass error and the tabulation of CIE color coordinates are calculated from reflectance measurement of each color patches of SGA colurchecker at 400-700nm with reference to ASTM E 308 – 06 (Standard Practice for Computing the Colors of Objects by Using the CIE System). RGB values are obtained by reading image in MATLAB. Fig.2, and Fig.3 below depict the typical measurement condition followed for the experimental color analysis on scanning images on Fabric Eye D-2000 and Color-Eye 7000, Spectrophotometer. Scanned image pixels for further experiments have been varied from 200,300,400,600 and 1200dpi, 24 bit color mode and spectrophotometer measurement was on reflectance mode, small aperture, UV included, specular excluded with three multiple measurements for a single sample.



[Fig. No.2 Fabric Eye D2000 Scanning parameters]



[Fig.3 COLOR-EYE 7000 E Spectro Measurement Mode]



[Fig.4 Color checker X-Rite SGA140 patches]

VI. RESULTS AND DISCUSSION

RGB Chanel Response model, we tried initially, found to be unsuitable for different scanners,. The summary of results obtained for Canon8887 and Fabric Eye-D2000, HPADF at 1200 DPIs are given in table no.1 Here large number of database is required for estimating optimized 31X3 weight coefficients like we calculate device independent XYZ at 400-700nm with 10 nm difference. Thus, further work has not been tried for Chanel response models from Reflectance response.

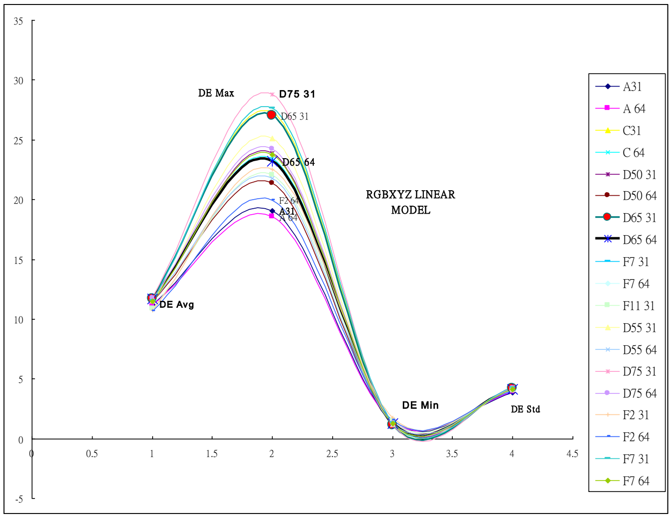
	D2000	HP ADF	CANNON

RSSE Avg	8.7916	23.7082233	19.2643
Max	25.2891	61.457029	52.0458
Min	0.4016	2.7156816	1.8202
St.dev	4.7045	14.419622	10.8694

[Table No.1:Chanel Response estimation results based on reflectance RGB]

RSSE= $[(R-Rp)^2+(G-Gp)^2+(B-Bp)^2]^{1/2}$ **---------- (2)**

The case was similar in case of linear model mapping for RGB for all ASTM Illuminant and observer pair XYZ. The graph shown on Fig.5 are the experimental results obtained for RGBXYZ linear model showing color difference (DE) average, minimum, maximum and standard deviations. Hence non- linear models and neural networks are being tried further.



[Fig.5: Linear Model Result with D 2000 for ASTM Illuminant and observers]

Model with polynomial regression with least square constrain:

The polynomial functions are chosen with 3, 8, 11, 20 and 23 arguments mentioned below.

No. of	Arguments in Polynomial function (R, G, B)
3	R G B
8	R G B R×G×B R×G R×B G×B 1
11	R G B R×G×B R×G R×B G×B R^2 G^2 B^2 1
20	R G B R×G×B R×G R×B G×B R^2 G^2 B^2 R^3 G^3 B^3 $G×R^2$ $B×G^2$ $R×B^2$ $B×R^2$ $R×G^2$ $G×B^2$ 1
23	R G B R×G×B R×G R×B G×B R^2 G^2 B^2 R^3 G^3 B^3 $G×R^2$ $B×G^2$ $R×B^2$ $B×R^2$ $R×G^2$ $G×B^2$ $G×B×R^2$ $B×R×G^2$ $R×G×B^2$ 1

[Table No.2: Arguments in Polynomial function]

11 Argument Model: Here in eqn.3, Xp,Yp,Zp are predicted Tristimulus values after optimizing the argument coefficients $a_{1,1}$ to $a_{3,11}$ that are suitable to match corresponding RGB values with experimental XYZ.

$$\begin{bmatrix} Xp \\ Yp \\ Zp \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,11} \\ a_{2,1} & a_{2,2} & a_{2,11} \\ a_{3,1} & a_{3,2} & a_{3,11} \end{bmatrix} X \begin{bmatrix} 1 \\ r \\ g \\ b \\ r^2 \\ g^2 \\ b^2 \\ rg \\ gb \\ rb \\ rgb \end{bmatrix} \text{---------------------- (3)}$$

ERROR = $\sum_{i=1}^{n} [(X - Xp)^2 + (Y - Yp)^2 + (Z - Zp)^2]^{1/2}$ **--- (4)**

Or

$$\begin{bmatrix} Lp* \\ ap* \\ bp* \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,11} \\ a_{2,1} & a_{2,2} & a_{2,11} \\ a_{3,1} & a_{3,2} & a_{3,11} \end{bmatrix} X \begin{bmatrix} 1 \\ r \\ g \\ b \\ r^2 \\ g^2 \\ b^2 \\ rg \\ gb \\ rb \\ rgb \end{bmatrix} \text{----------------- (5)}$$

ERROR = $\sum_{i=1}^{n} [(L* - Lp*)^2 + (a* - ap*)^2 + (b* - bp*)^2]^{1/2}$ **----------------- (6)**

General multiple regression with MATLAB forward Slash (\ ) operator and optimization with two important nonlinear - solvers **fsolve** and **lsqnonlin** has been tried to get the suitable characterization coefficients. These solver without constrains giver better results than that of un-constrained one (XYZ/L* a* b* have specific range of values) and the values obtained from these methods are only significant after 2 decimal places.

Polynomial regression with 3, 8, 11, 20, 23 argument functions are followed for RGBXYZ, RGBL*a*b* and RGBL*c*h* color characterization model at 1200 DPI and D65 10 degree. The respective errors in average, minimum, maximum and standard deviation are shown in the table below for in terms of DE and RSSE .

			D65 64		
RGBXYZ	**Linear**	**8arg.**	**11arg.**	**20arg.**	**23 Arg.**
RSS Avg	10.263	2.1297	1.274	1.0775	1.0687
RSS Max	23.976	5.2943	5.1576	5.1306	4.9157
RSS Min	0.2585	0.2029	0.035	0.0678	0.1087
RSS Std	5.896	1.1772	1.026	0.9897	0.9438

[Table No.3: Root Sumed Square Errors on different polynomial arguments]

Here RSSE Avg is the root of sum squared avarage = $\sum_{i=1}^{140}[(X-Xp)^2+(Y-Yp)^2+(Z-Zp)^2]^{1/2}/140$ ------- **(7)**

	D65 64				
RGBL*a*b*	**Linear**	**8arg.**	**11arg.**	**20arg.**	**23 Arg.**
DE Avg	11.665	3.9337	2.2619	1.7879	1.7485
DE Max	23.212	17.721	10.8007	9.6654	9.3249
DE Min	1.269	0.0786	0.1631	0.1962	0.2211
DE Std	4.1627	3.1656	2.0494	1.5841	1.5277

[Table No.4: DE Errors on different polynomial arguments]

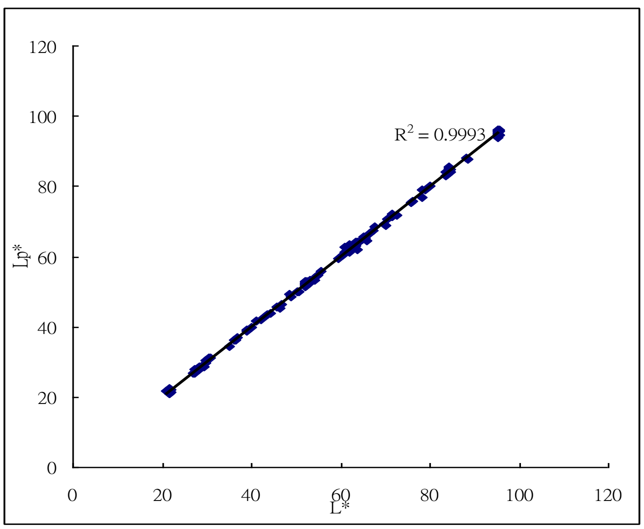
DE Avg = $\sum_{i=1}^{140}[(L^*-Lp^*)^2+(a^*-ap^*)^2+(b^*-bp^*)^2]^{1/2}/140$ …**(8)**

It has been observed that as the argument in number increases, the Error average, maximum, minimum and standard deviation decreases, but there is no significant increase in first decimal places on further increasing the argument. It is concluded that 23 argument model may be considered for optimum characterization results. Though, RSSE for XYZ seems to be lower, but we observed that the DE values are higher as compared to RGBL*a*b* in each argument case. It has been found that Characterization on RGBL*c*h* models shows very poor results in terms of DE.The comparative results based on 23 argument model for RGB scanned values at 1200DPI on D65 10 XYZ/L*a*b* are given in table no.5

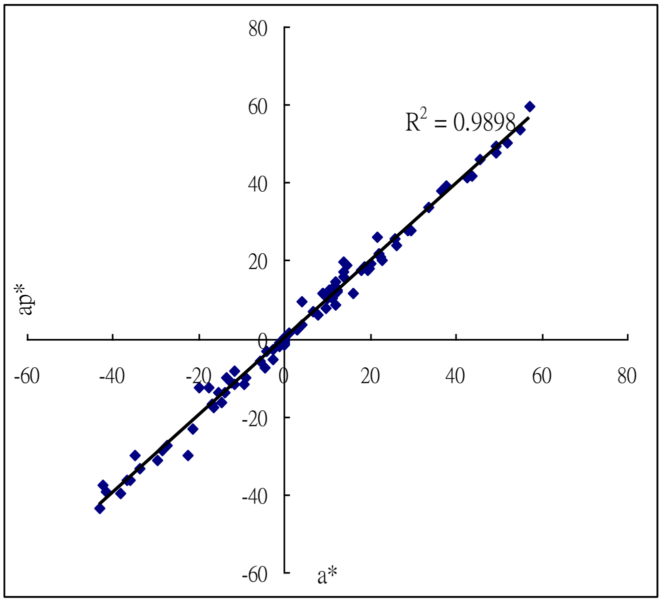
	RGBL*a*b*	**RGBXYZ**	**RGBL*c*h***
DE Avg	1.7485	1.9463237	10.3340507
DE Max	9.3249	9.7333012	66.405972
DE Min	0.2211	0.3140053	0.22636208
DE Std	1.5277	1.636592	12.8098953

[Table No.5: 23 argument model characterization results on different colour coordinates]

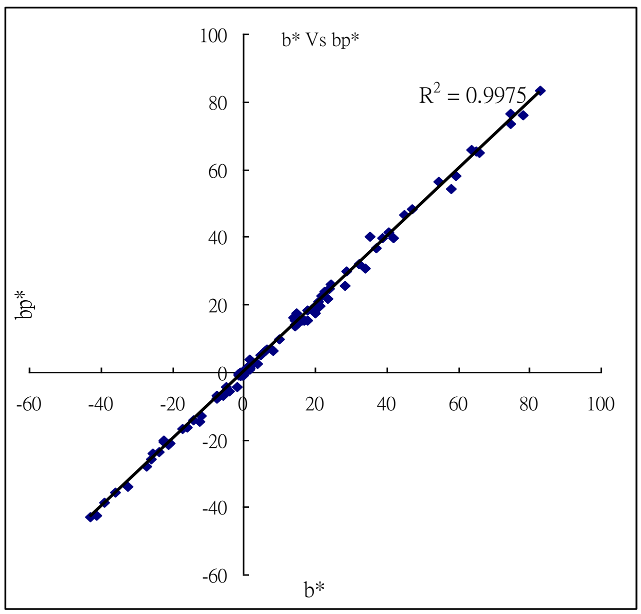
In Addition, for all cases , the experimental are predicted L* values are more likely , than comparison to b* (yellower / bluer), then to a* (redder/ greener). The correlation coefficients for experimental and 23 argument based polynomial RGBL*a*b*model i.e., L* vs. L_p*, a* vs. a_p*, b* vs b_p* at D65 10 and 1200 DPIs , D-2000 scanners for color checker SGA patches 140 found to be 0.9993, 09898, 0.9975 (Fig.6-8)



[Fig.6 : L* vs. L_p* at D65 10]



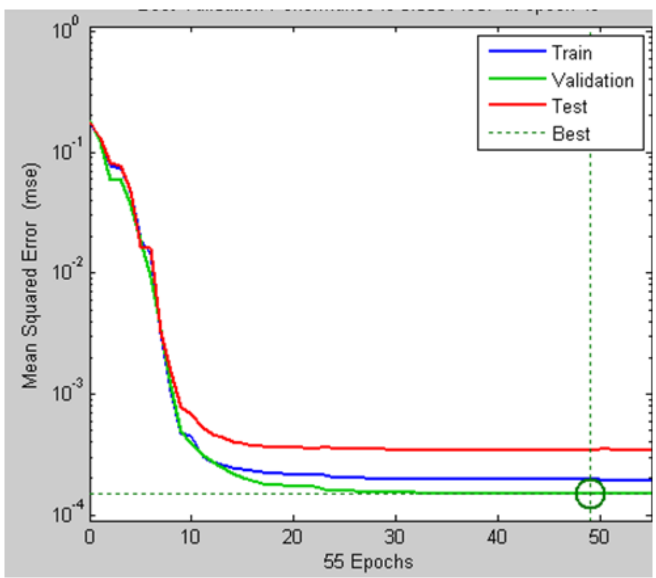
[Fig.7 : a* vs. a_p* at D65 10]



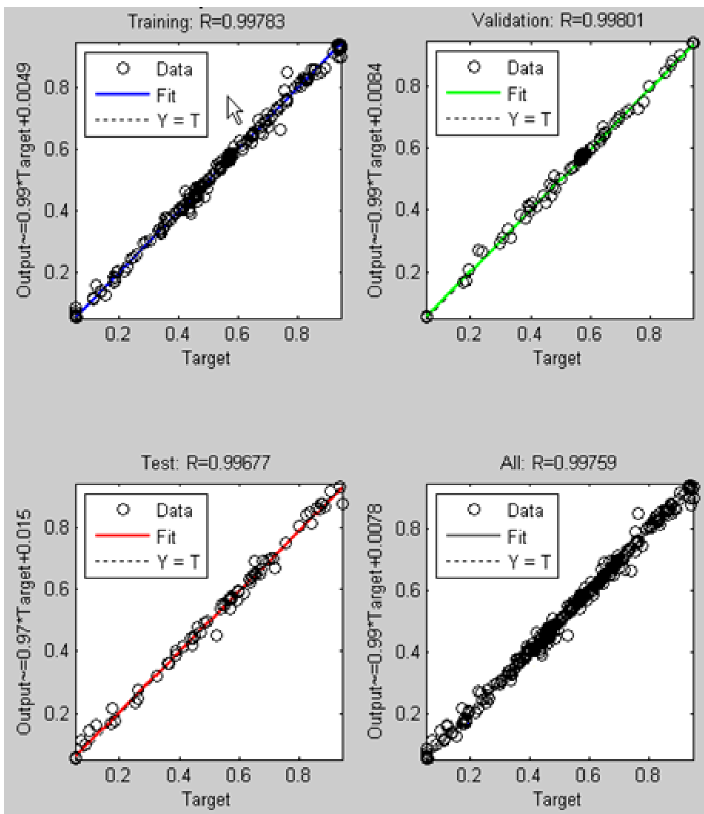
[Fig.8: b* vs. b_p* at D65 10]

3-7-3 Back propagation neural net work with sigmoid transformation function are have been employed for again for RGB L* a* b* color model, after initial trials on different network architecture results. The parameters chosen as follows:

Goal:0, Max Fail:6 , Mem reduction:1
Min Gradiant : 1e -10, Mu:0.001, Mu_dec:0.1
Mu_inc:10, Mu_Max: 10000000000



[Fig.10 : MSE error : for training testing and Validation]



[Fig.11 : Regression : training testing and Validation points]

In most cases as lower DPIs, 200,400,600, has shown some inconclusive trends but surely 1200 dpi gave us better results in case of average, maximum, minimum DE, not standard deviation for both polynomial regression and neural network method. The summary of results for D65 10 with D2000 scanner are given on the table no.6

SUMMARY OF RESULTS : Scanner D 2000 : Different DPIs characterization D65 10

D65 64	**200 DPI**		**300 DPI**		**400 DPI**		**600 DPI**		**1200 DPI**	
RGBLAB	SGA 23	ANN	SGA 23	ANN	SGA 23	ANN	SGA 23	ANN	SGA 23	ANN
DE avg	1.98	2.25	1.99	2.30	2.01	2.21	2.02	2.61	1.75	2.06
DE max	8.44	10.09	8.68	12.63	8.36	9.75	8.43	11.97	9.32	9.87
DE min	0.35	0.18	0.33	0.12	0.28	0.31	0.29	0.41	0.22	0.09
DE std	1.43	1.78	1.46	2.16	1.41	1.91	1.45	1.94	1.53	1.86

[Table No.6: Different DPIs D65 10 characterization]

VII.CONCLUSION

RGB Chanel Response models estimated from reflectances of color checker 140 patches did not give satisfactory results for all three scanners we experimented. Among RGBXYZ, RGBL*a*b* and RGBL*c*h* color characterization model, RGBL*a*b* color coordinates shows better results for both polynomial and neural network. Higher the DPIs, better is the characterisation results in terms of mean, maximum, minimum DE. It has been observed that as the argument in number increases for polynomial regression methods, the Error average, maximum, minimum and standard deviation decreases, but there is no significant increase in first decimal places on further increasing the argument. It is concluded that 23 argument model may be considered for optimum characterization results. For all cases, we found good correlation coefficient between the experimental are predicted L* values, than comparison to b* (yellower / bluer), then to a* (redder/ greener).

Irrespective of methods like channel response, polynomial regression and neural network, DE characterization values based on color checker thus obtained are little bit higher than we expected. Polynomial regression method found to be more suitable and robust So it is likely that practical estimation of device independent color coordinates of different substrates may suffer more inaccuracies. Here arises a question “May we need more color patches, or better hardware set up?” We experimented on 4 different scanners with all ASTM Illuminant and observer combinations for color checker based characterization. In addition, their validation results for textiles and paint substrates based on polynomial regression and neural network were being studied further.

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*** Communication to Author:**
khandual123@gmail.com
**** Fabric Eye TM : Developed in GAMALAB,** Copy-right scanner of HKRITA and the Kong Kong Polytechnic University

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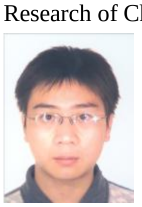

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