Improved output device characterisation test charts

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Abstract

Many test charts popularly used for color output characterisation purposes, are based on a regular orthogonal sampling of device space. Mathematically such a rectangular sampling is not the most efficient way of exploring a multidimensional space, so an alternative based on a simplex sampling of device space has potential for improving the efficiency of device profiling, requiring fewer test point for a given profile accuracy, or returning a higher profile accuracy for a given number of test points.

Introduction

Fundamental to the application of color science to the reproduction of color, is the characterisation of color output devices and subsequent encoding into a profile that allows the prediction of the devices response to any given device values. The device response is generally characterised by reproducing a known set of device values (the test chart), and then measuring the test patches in a device independent colorspace such as CIE XYZ. These test values are then interpolated in some fashion into a profile, so that a response value can be predicted for any given device value.

Charts sizes are often constrained for practical reasons such as instrument patch size, media size, time and cost constraints to have a certain fixed number of test patches. For a given number of test chart data points, an ideal test chart would have test values located to minimise the error of the subsequently constructed profile, compared to the actual underlying device characteristics.

Existing Approaches

Many existing commercial or documented output device profiling approaches seem to be based around the idea of generating a regular or semi-regular orthogonal grid of device test values for use as a test chart. Sometimes this is due to the subsequent profile creation algorithm requiring such input values, but mostly this seems to be about simple convenience and ease of setting charts up.

Various standard output device characterisation charts such as the IT8.7/3 [Ref. 1] chart, and the more recently introduced ECI2002 chart [Ref. 2] which expands on the IT8.7/3, are heavily based around rectangular grid values in device space, although they also aim to sample the device response in more detail in certain areas, and less in others.

One approach to improving the efficiency of the output test chart, is to change the distribution of points along each device channel in a way that anticipates the devices characteristic, or, more aggressively, to choose sample points based on an error metric between the expected device response, and an estimate of the resulting profile that would be created from the sample points so far chosen. [Ref. 3, 5 & 8]. Such "bootstrap" methods rely on having some model already existing for the device to be characterised. The method to be described here, gives improved results compared to a rectangular grid test charts, without relying on an existing model, and as such, might be useful as an improved "starter" chart for bootstrapping, or for creating general non-device specific test charts.

Principles of improved approach

The characterisation of a devices response using a restricted number of test points is essentially a sampling/reconstruction problem. A basic principle that can be used when little is known about the nature of the function that is being sampled, is that the higher the sampling rate, the less likely it is that high frequency detail will be missed. In terms of color test charts, this means that the more tightly packed the test points are, the better. From [Ref.. 4] it can be seen that the packing/quantisation efficiency of the typical cubic (in 3D) sampling is inferior to the theoretical best tetrahedral/simplex packing by a factor of 53%, or nearly 2:1. In 4D, the difference is even more stark. A simplex based grid of test points therefore seems to be a worthwhile approach to investigate.

Method

A constraint assumed is that a test chart point "budget" has been set, and that the device gamut may have an additional boundary imposed by the device having a total ink limit.

These constraints, together with the possibility of rotating the simplex grid relative to the device axes, means that it may not be easy to compute the simplex grid points spacing needed to have the budgeted number of points fall within the device gamut. An iterative approach was therefore used, where a grid scale factor was adjusted so that the simplex grid generates (or almost generates) the desired number of points. An additional behaviour was that rather than simply discarding points just outside the gamut boundary, they are clipped to be within the boundary, in an attempt to ensure that device extreme values are sampled.

An issue noticed with laying test points out in rectangular grids, is that it means that the per channel device response is poorly sampled (since and sample point device values are being drawn from a rather small set of values), and this can make it difficult to create detailed device linearisation "shaper" curves from the resulting measured data. Ideally, in any colorspace (input or output), when viewed from any possible angle, none of the test data points should appear align, providing a diversity of values. The Method described here can be adapted to address this concern by simply rotating the simplex grid to an angle not correlated with any of the device axes. The ECI2002 chart tackle this problem by providing finer pure colorant step values.

To illustrate the difference between rectangular and simplex sample point layouts visually, Figure 1 and 2 show a 2 dimensional representation of this approaches. A budget of 85 points together with a total ink limit of 1.5 was used for these figures:

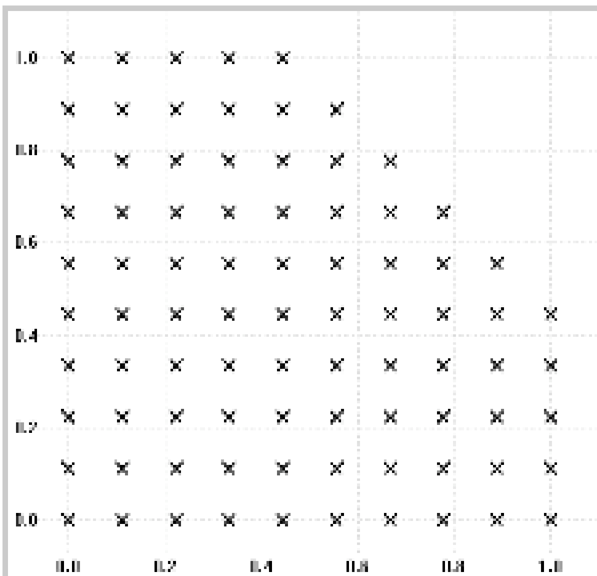

Figure 1, 2D Rectangular grid.

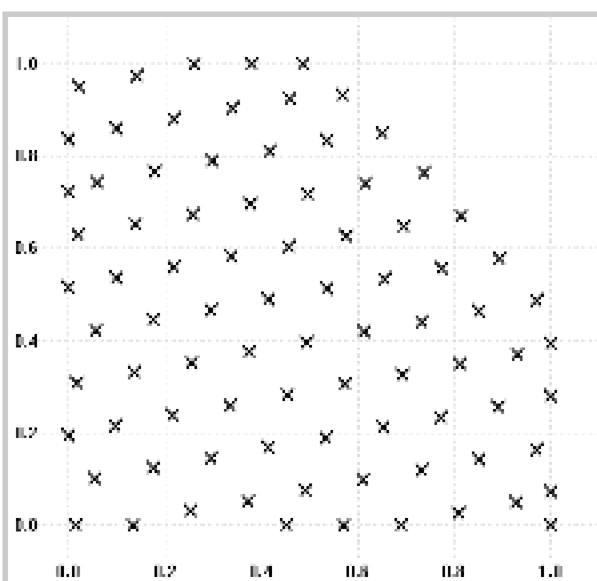

Figure 2, 2D Simplex (triangular) grid (at an angle).

Test Method

For testing, a simulated test chart measurement environment was developed. Since it is not possible to truly know the underlying, real response of a device, the following approach was adopted: Six output devices (A xerographic printer and two variations of it, an inkjet printer, and two CRT displays, one being the sRGB standard profile [Ref. 7]) were sampled with a very high number of test points, approximately 10 times the typical number used during characterisation. A real world profile based on “CLUT” type interpolation arrays (as exemplified by the ICC profile standard [Ref. 6]) will typically reproduce much of the sampling and measurement noise present in the measured values, and this could obscure the effects of the test chart point placement, so in an attempt to avoid this during testing, simpler ”model” type profiles were created from the large number of samples, which, while reasonably faithfully modelling the device, result in smooth, low noise references. These profiles were used to define the simulated devices response. The test chart under test was then “read” by looking up its device values using the reference profiles, and the resulting device/CIE pair used to generate a high resolution CLUT based profile. To measure the profiles accuracy, 100000 random device values were applied to both the reference and the profile under test, and the resulting CIE94 delta E values captured as an average, and maximum. For the RGB devices the reference profiles were matrix/shaper based model profiles, and 50000 test points were used to measure accuracy.

Since all of the devices chosen are relatively “well behaved” devices (the full range of device values generally producing useful output colors), either being inherently well behaved in the case of the CRT devices, or having been made to behave in a reasonable manner by the use of a calibration system, one of the devices profiles (the CLC1180 copier) was artificially modified to make a “light” and “dark” version, to simulate two less well behaved devices, and provide some more diversity in testing.

Results

For the four CMYK devices, there were three sets of tests performed. The first is of a simple uniform device grid test chart, then the improved test chart with an identical number of test points. The second test set is with the IT8.7/3 test chart compared to the improved test chart, while the third uses the ECI2002 test chart, compared to the improved chart. Real world ink limits are being complied with in regard to all the created charts and the verification values used in testing. The RGB devices were tested with one test point count. Table 1 contains the numerical results.

Analysis

For the CMYK devices, it is clear that the simplex grid test charts give uniformly superior results judged by the average delta E values, on average reducing them by 33%, while the effect on maximum errors was not always an improvement (perhaps due to the somewhat arbitrary nature of whether a sample point lands near a particularly high variability locality in the devices characteristic), but on average improved maximum errors by 25%. In contrast the results for the two RGB devices was less clear. The results were generally about the same, with no compelling advantage either way.

The results presented here are probably sensitive to the exact nature of the profiling algorithm, as well as the characteristics of the devices used to provide the behaviour being modelled, but non the less provide some indication of each approaches merits.

Device and chart type/ point budget.	Rect. (Peak)	Rect. (Avg.)	Smplx. (Peak)	Smplx. (Avg.)
Canon 1180 (556 pnts)	2.940	0.327	1.872	0.288
Canon 1180 IT8.7/3 (928 pnts)	2.950	0.344	1.780	0.255
Canon 1180 ECI2002 (1485 pnts)	1.952	0.329	1.843	0.183
Canon 1180 "light" (556 pnts)	2.449	0.734	3.155	0.482
Canon 1180 "light" IT8.7/3 (928 pnts)	7.304	0.705	3.870	0.376
Canon 1180 "light" ECI 2002 (1485 pnts)	5.060	0.645	2.139	0.297
Canon 1180 "dark" (556 pnts)	4.122	0.414	4.013	0.356
Canon 1180 "dark" IT8.7/3 (928 pnts)	2.503	0.383	3.809	0.274
Canon 1180 "dark" ECI 2002 (1485 pnts)	2.492	0.376	3.344	0.228
Epson 10000 (556 pnts)	3.774	0.458	4.115	0.503
Epson 10000 IT8.7/3 (928 pnts)	10.40	0.636	5.54	0.382
Epson 10000 ECI2002 (1485 pnts)	6.120	0.584	3.675	0.324
Hitachi 2112 CRT (730 pnts)	3.902	0.879	3.996	0.818
sRGB (730 pnts)	2.567	0.139	2.741	0.141

Table 1. Results in Delta E94.

Conclusion

When a characterisation test chart is to be created for a CMYK output device, and the response of the device to be tested is not known in advance, then a device space simplex grid may be a better choice for test chart values, than the more traditional rectangular grid sample arrangement.

The software used for creating the test charts, making the profiles and testing the results is embodied in the Argyll CMS package, available at (http://web.access.net.au/argyll/), licensed under the GNU licence.

References:

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Biography

Graeme Gill is the R & D Manager of Color Technology Solutions (A Colorbus Company), which develops colour printer controllers for digital printing and colour proofing applications. He received a B.E. degree in Electronic Engineering in 1984 from the Royal Melbourne Institute of Technology. Mr Gill is a member of the IEEE, ACM and IS&T.