Table of Contents

1 The Brontes colorimeter

The Brontes colorimeter is a tristimulus meter, meaning that the output of the Brontes is X,Y and Z from which other colour spaces can be derived. Many colour measurements do not require the actual colour spectrum to be measured but just colour and light intensity or reflection. In these cases a colorimeter often is the preferred device because it also has some advantages over spectrometers. Most significant advantages are :

- Speed (a colorimeter produces less data and is often faster)
- Easier to use
- Easier to keep stable results in a production environment (less calibration – linearity, dark current, absolute calibration)

The Brontes is very suitable to measure very small colour differences in a production line environment and do that for a very long time without the need for periodic calibrations.

For many users, the ability to measure very small differences is enough. For other users, also the absolute colour point of their sample is of great importance. For these customers, Admesy provides a calibration service or in case the user owns a reference system they can perform this calibration themselves.

This application note is about how users of the Brontes colorimeter can calibrate their Brontes devices towards their own reference system. Also measurement gage R&R will be discussed in this document. The data presented in this paper are actual customer examples (LCD industry).

2 Calibration of colour and luminance

Calibration of colour and luminance are usually performed using a calibration light source. The major problem in all of this, is that there's not a very accurate standard, which means that calibration light sources used all over the world give slightly different results. Typical problems of light sources :

- Not a flat spectrum, sometimes causing low S/N ratio in some areas of the spectrum
- Warm up time (every lamp needs time to reach a stable output)
- Lifetime (the calibration light source degrades over time)

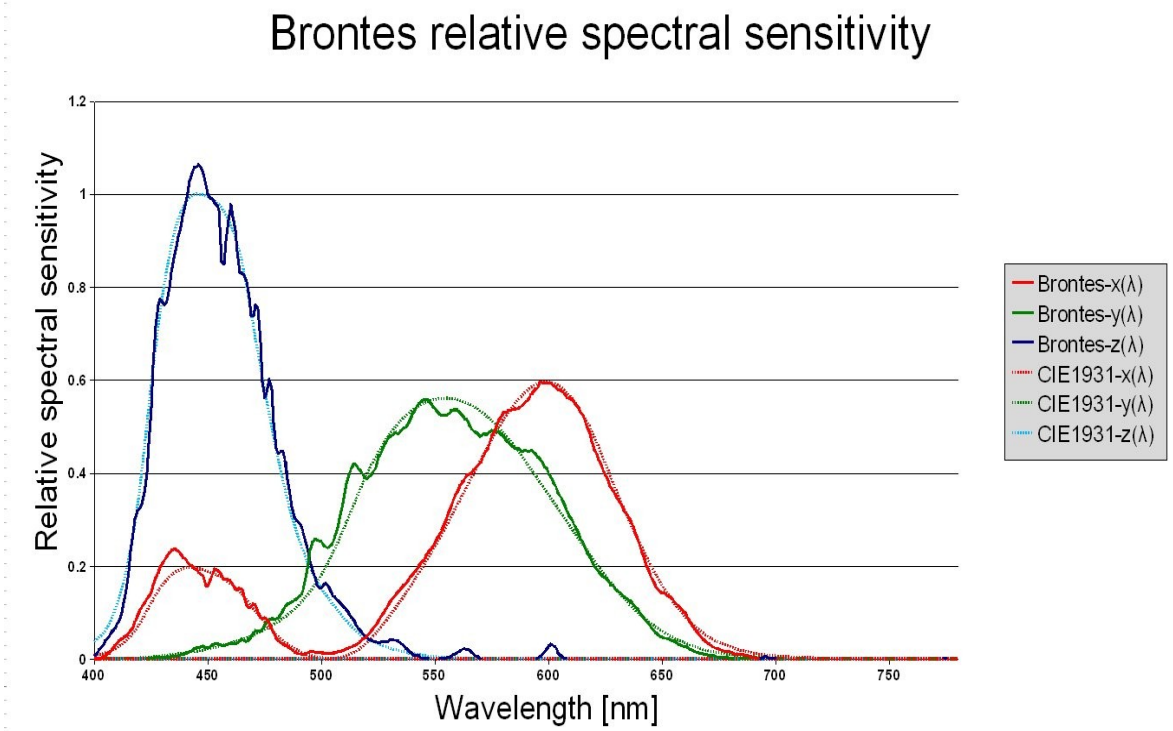
This also causes colour and luminance measurement to deviate when different measurement equipment is compared. This often causes confusion between suppliers and customers.

Looking at the above items, it may be clear that comparing results of different measurement equipment isn't all that easy. The above problems are also difficult to solve since they result from pure physics of the used lamps.

2.1 Absolute colour and luminance of the Brontes

The Brontes colorimeter has a fixed tristimulus sensor. The characteristics of the sensor closely match the CIE1931 colour matching curves as used by many spectrometers to calculate colour. Within a spectrometer the measured spectrum can be multiplied by these curves and integrated. The resulting three values are X,Y and Z. The Brontes gives X,Y and Z straight away, so spectral correction can not be performed.

The Brontes relative spectral sensitivity can be seen in the below graph.



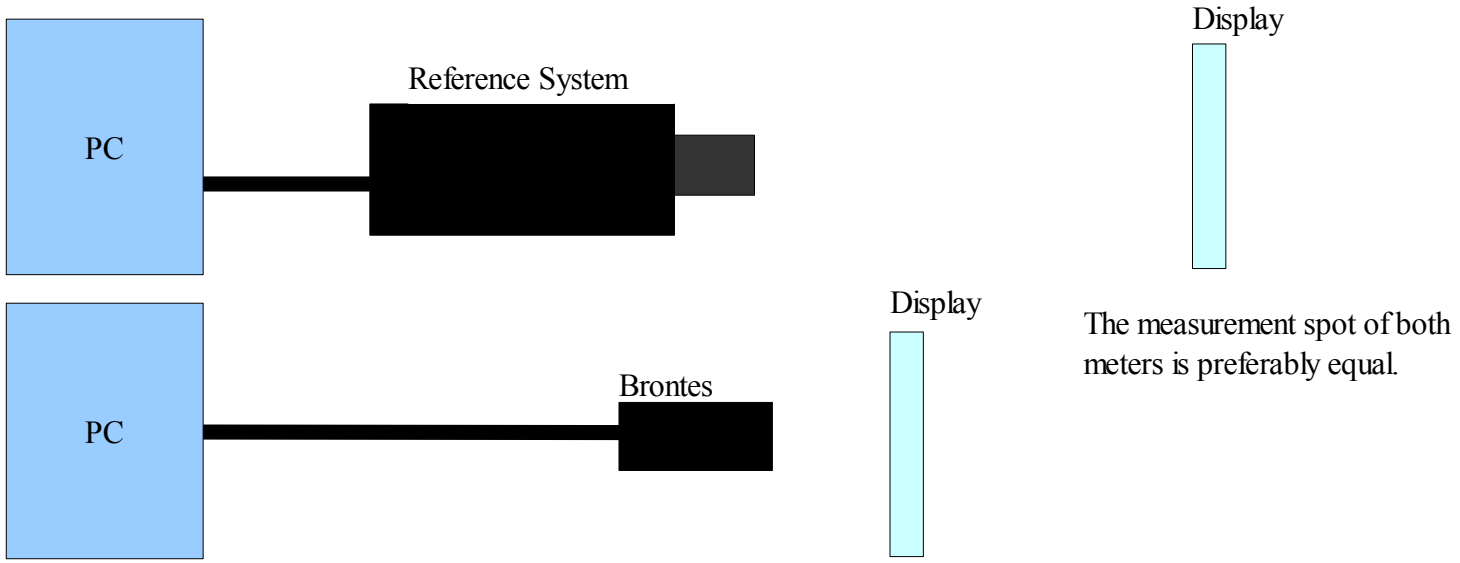
It can be seen that at some wavelengths in the spectrum the Brontes sensitivity differs a little from the CIE1931 colour matching curves.

The Brontes colorimeter provides the user not with the spectral data, but the X,Y and Z value, meaning that calibration can only be performed on those values.

In order to measure absolute colour and luminance the Brontes colorimeter can be calibrated towards a reference system. Since many users require the Brontes to measure the same results for their in-line production as their laboratory results, this way of calibration is explained further in this document.

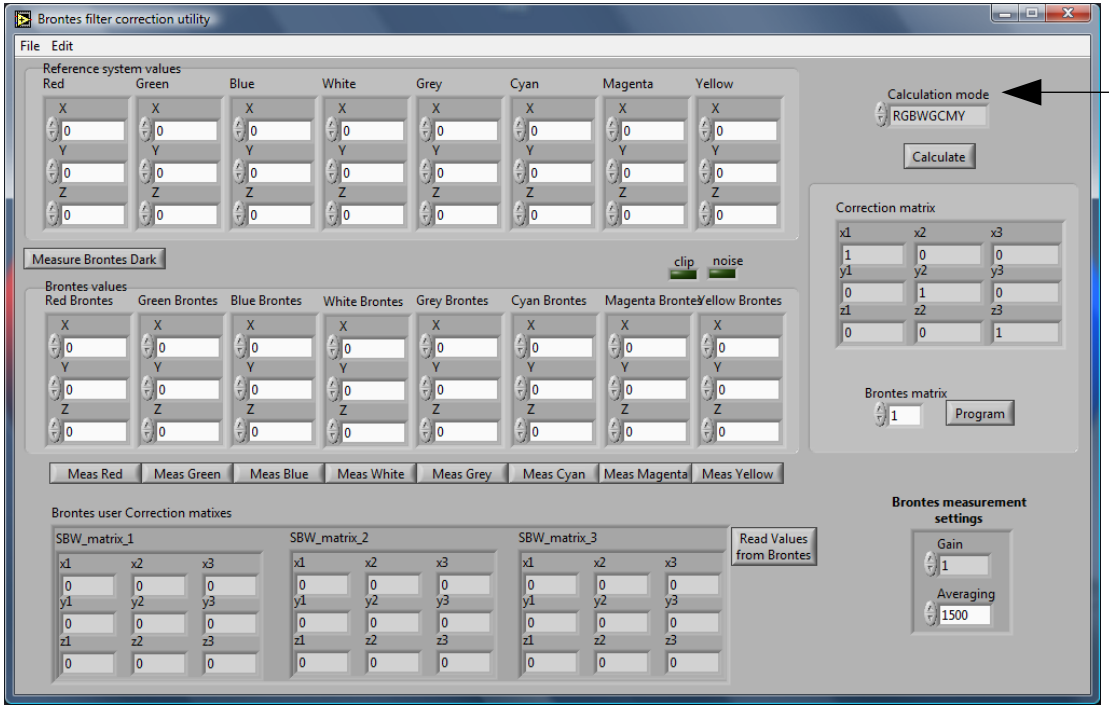
3 Calibration of the Brontes using a reference system on mobile phone displays

The described calibration includes a laboratory grade spectrometer and small mobile LCD's (Mobile phone/PDA) using white LED back light. The test set up is shown in the diagram below :



The Brontes can be calibrated by applying a 3x3 matrix. This matrix can be calculated using measured values of both the reference system and the Brontes. Admesy supplies software that will calculate the matrix from these measured values. Up to three calibration matrices can be stored in the Brontes. In case more are required, additional methods exist.

The Brontes calibration software is called Brontes_Filter_Utility. The software and user manual are supplied with the Brontes and can be found on the Admesy web site : http://www.admesy.nl/brontes_soft.php



The Brontes filter correction utility, used for calibration.

4 Calibration

For the following calibration, the display was measured using the following colours :

- Full screen Red
- Full screen Green
- Full screen Blue
- Full screen White

More colours are allowed, but in principle the calibration stays the same. The resulting matrix is at all times a 3x3 matrix.
The measured values can be seen in the table below:

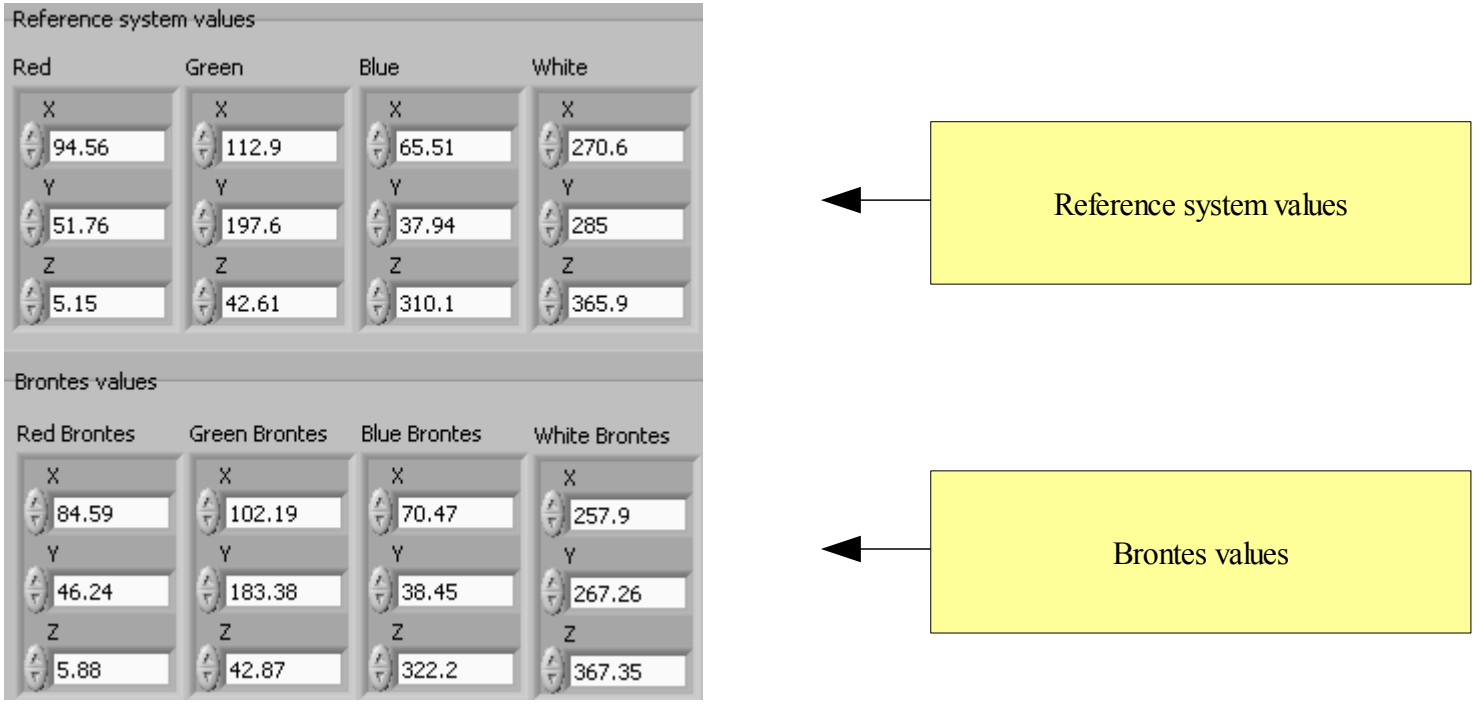
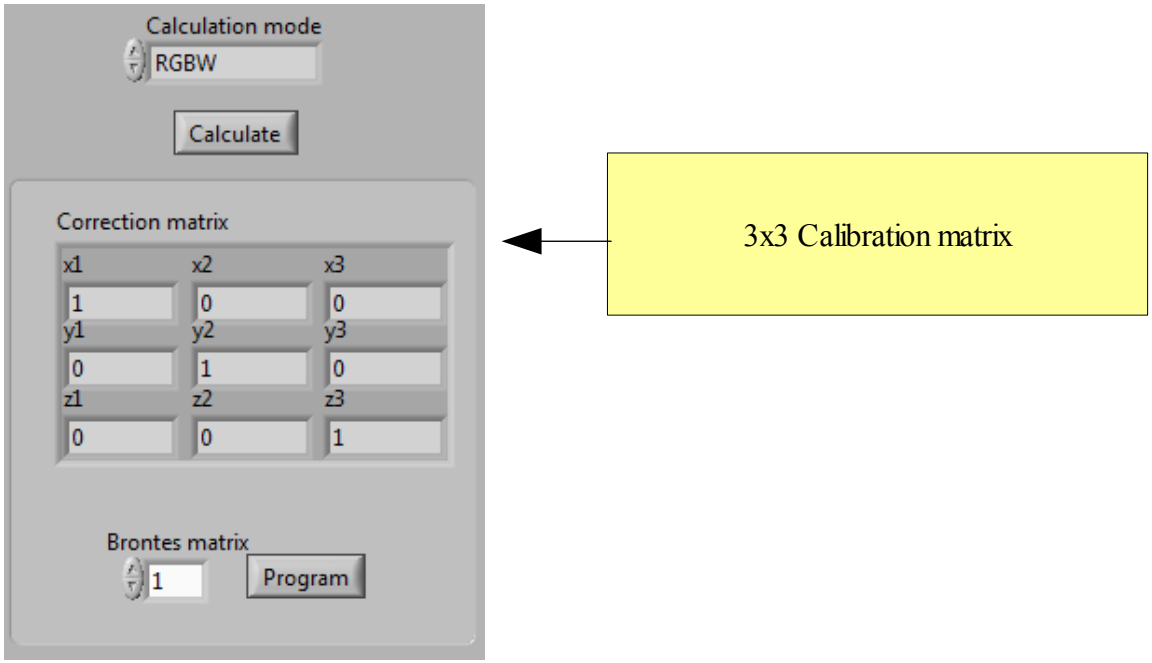


Illustration 1: Measured reference and Brontes values

After the values have been filled in, in the filter utility, the “Calculate” button can be clicked in order to calculate the 3x3 correction matrix.



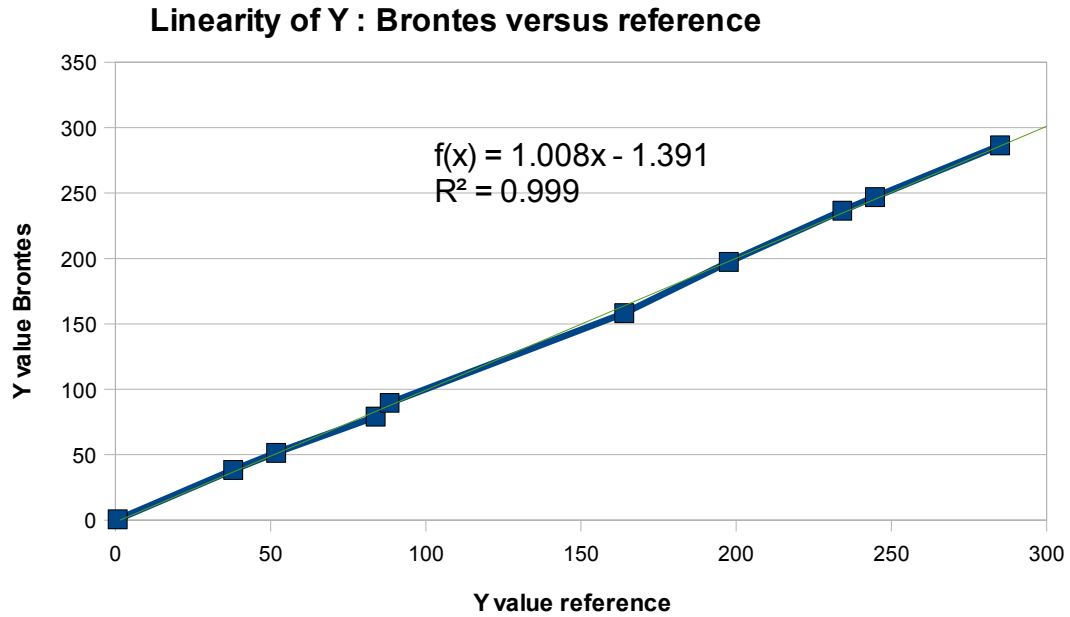
The matrix can be stored in either one of the three user calibration areas in the Brontes and be used in all other Brontes applications.

Note : When measuring the values using the Brontes the calibration matrix in the Brontes main application should be set to "OFF".

5 Calibration results

After the calibration matrix has been stored, it can be verified that the Brontes measures according to the reference system.

The following graphs show luminance (Y) values of the Brontes compared to the reference system, after calibration. The same linearity is found for X and Z.



The following table shows typical calibration results:

comment	Yref	xref	yref	Ybrontes	x_brontes	y_brontes	Delta x	Delta y
white	285	0.294	0.309	286.48	0.295	0.310	0.001	0.001
red	51.76	0.624	0.342	51.49	0.611	0.335	-0.013	-0.006
green	197.6	0.320	0.560	197.32	0.316	0.556	-0.004	-0.004
blue	37.94	0.158	0.092	38.46	0.157	0.092	-0.002	0.000
Grey 50%	83.84	0.264	0.262	79.09	0.264	0.260	0.000	-0.002
Grey 75%	163.9	0.273	0.277	158.27	0.272	0.274	-0.001	-0.003
cyan	234.2	0.232	0.307	236.59	0.232	0.305	0.000	-0.002
magenta	88.34	0.282	0.158	89.67	0.280	0.157	-0.002	0.000
yellow	244.7	0.414	0.493	247.01	0.409	0.488	-0.005	-0.004

It can be seen that most colours match very close to the reference system. The Red colour shows some deviation which is a result of very saturated colour. Very saturated colours cause deviations related to the Brontes deviation from the CIE1931 curves but also for saturated colours there's one of the X,Y or Z components that is very low and may be within noise level (also for the reference system). See also further measurements in this document for further explanation. For different red colours (less saturated) the result will be a closer match.

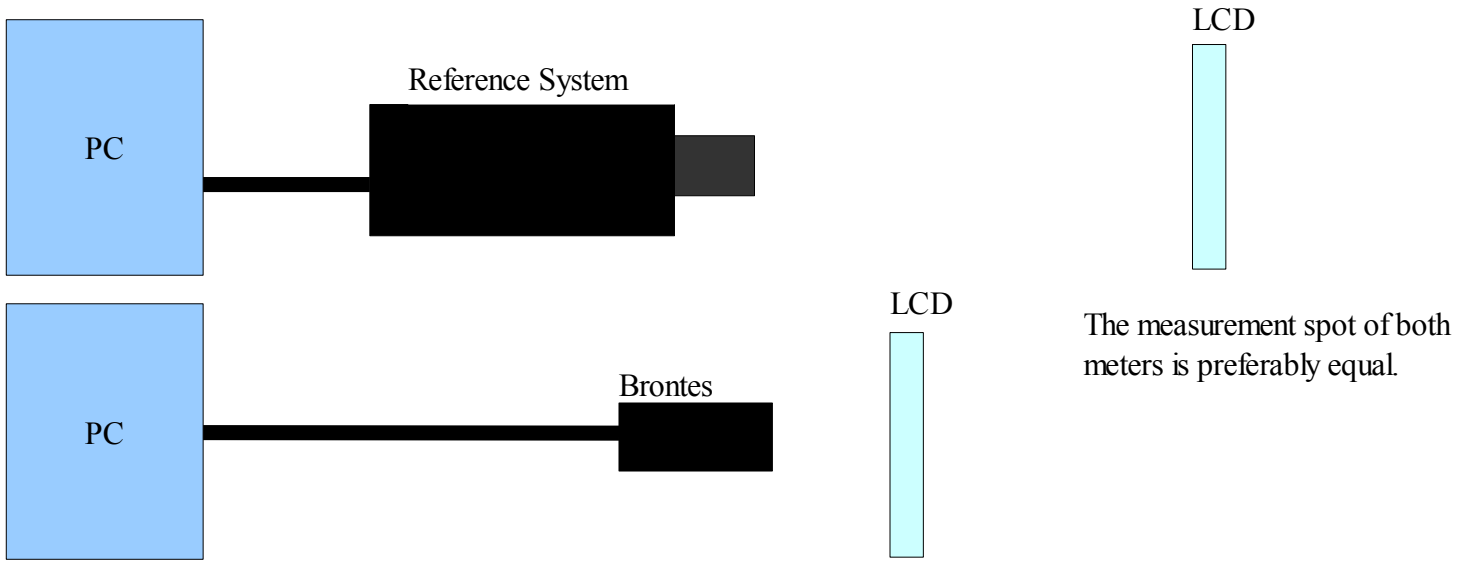
Note that the above are typical results from a customer application. Some outliers can be expected, but in general the match is very close to the reference system for all colours. It is also possible to calibrate for less saturated colours or chose different reference points. This may result in a better match.

Looking at the above results and considering that the Brontes is not lab grade equipment like the reference system, it is clear that the Brontes can be used for absolute measurement of colour for in-line applications. The typical deviations as seen above can also be found between different brands of spectrometers as they all depend on calibration light sources.

6 Calibration of the Brontes using a reference system on large (17-22”) LCD displays

The described calibration includes a lab grade spectrometer and a LCD using white CCFL back light.

The test set up is shown in the diagram below:



The Brontes can be calibrated by applying a 3x3 matrix. This matrix can be calculated using the method of chapter 4, now only for 4 colours.

The calibration of the reference system to the brontes uses the following display colours:

- Full screen Cyan (RGB = 0, 255, 255)
- Full screen Magenta (RGB = 255, 0, 255)
- Full screen Yellow (RGB = 255, 255, 0)
- Full screen White (RGB = 255, 255, 255)

These colours are used instead of Red, Green and Blue, because the reference system can not measure the full saturated colours well. For example, the red colour will cause a very low Z value. In this case the value was below the lowest value of the reference system, that the supplier specified as the lowest level of their meter. Also performing a gage R&R on saturated colours showed that the reference system did not perform very well on saturated colours (the result showed variation due to noise).

When using Cyan, Magenta and Yellow, the spectral data of the R, G and B colours are all added, because the colours are an addition of the RGB colours as seen above. This results in output for all three components of the XYZ colour space, meaning that the calibration becomes less sensitive to errors as opposed to using RGB.

Note: Check your reference systems data sheet before calibrating on colours Red, green and blue. To be sure this will not affect the calibration, measure the colours RGB separately and repeatedly, to notice there is a stable measurement.

When the calibration matrix has been stored, it can be verified that the brontes measures according to the reference system.

The verification has been carried out using many colour points spaced in such a way that they form a triangle in the CIE colour diagram. By changing the saturation, multiple triangles can be created thus generating comparison data between the brontes and the reference spectrometer over the full gamut of the measured display.

In total three of these triangles have been measured using both systems. The outer triangle being fully saturated, the smaller triangles being the less saturated data.

The outer triangle consists of 186 measurement points, the middle triangle consists of 90 measurement points and the smallest triangle consists of 42 measurement points.

This graph shows the x,y space of the brontes according to the reference system. The triangles full, medium and small proof that the brontes measures equally to the reference system and the same linearity is found.

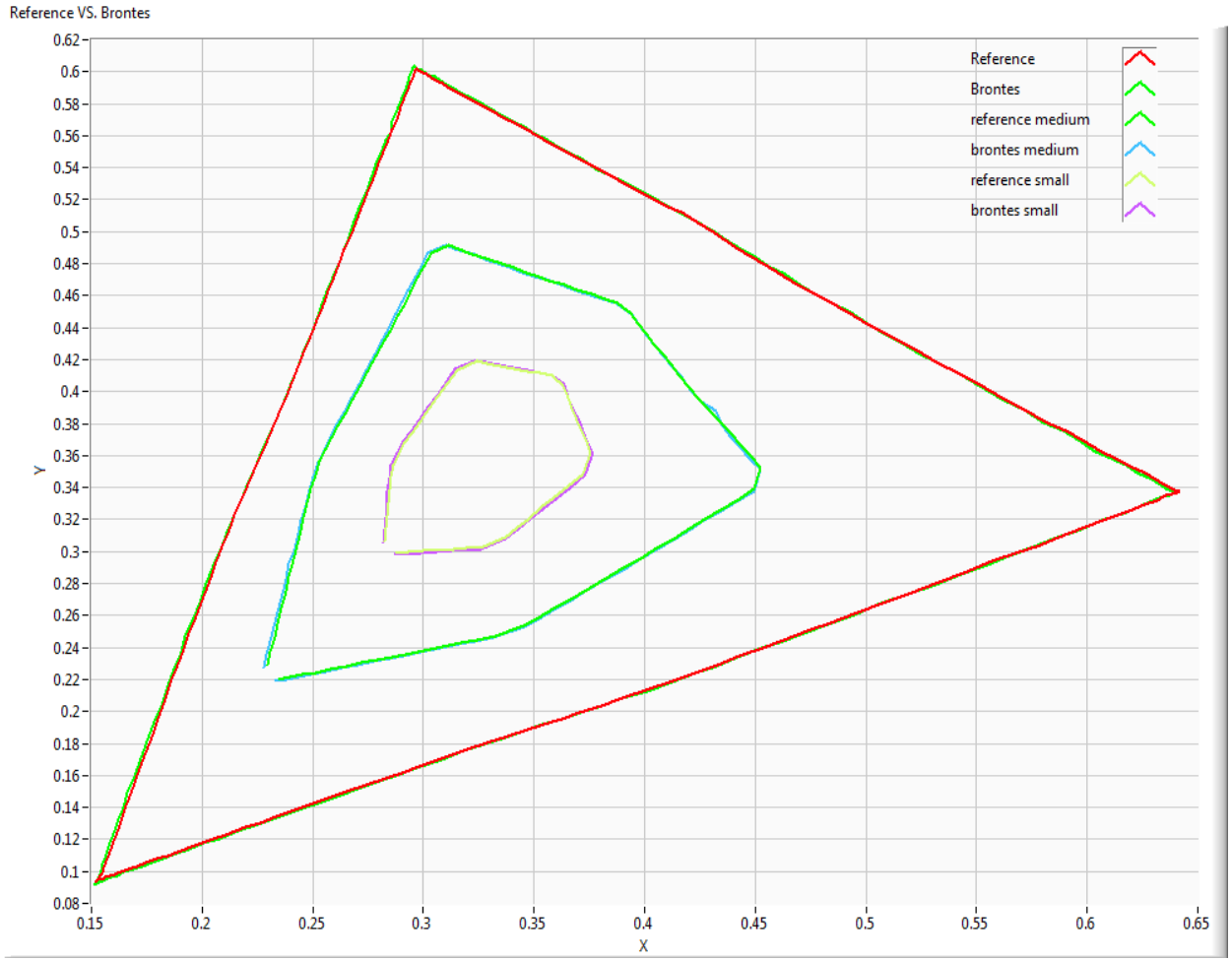
The maximum deviation of the brontes according to the reference system is at maximum 0.003 in x or y.

According to the spectrometer specifications the accuracy for illuminant A is ±0.0015 x or y.

for CRT phosphors it is ±0.006 x or y (e.g. saturated R, G or B).

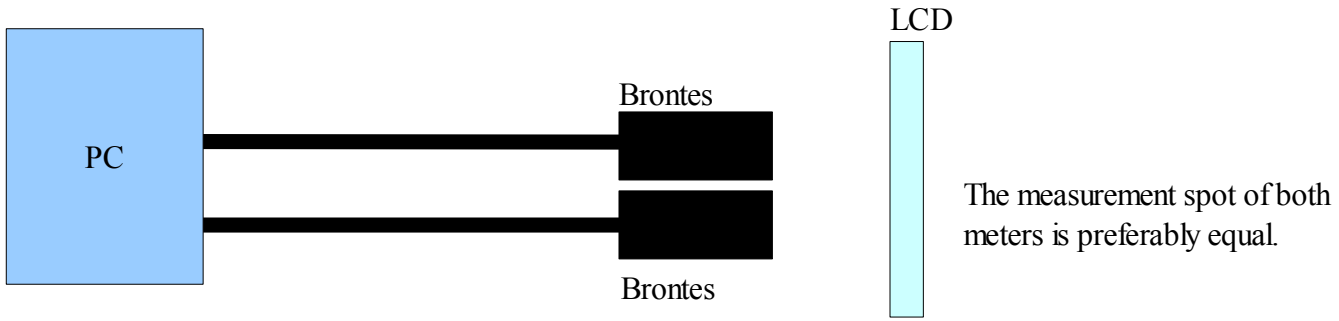
The lowest luminance level for the reference system is 3.5 cd/m², making it impossible to measure today's high contrast displays in dark state.

Knowing these specifications and knowing that typical deviations as seen above can also be found between different brands of spectrometers as they all depend on calibration light sources, concludes that the Brontes can be used for absolute measurement of colour for in-line applications.



7 Brontes to Brontes calibration

The described calibration includes two brontes devices, of which one is calibrated to a lab grade spectrometer using a LCD's with a white CCFL back light. The test set up is shown in the diagram below:



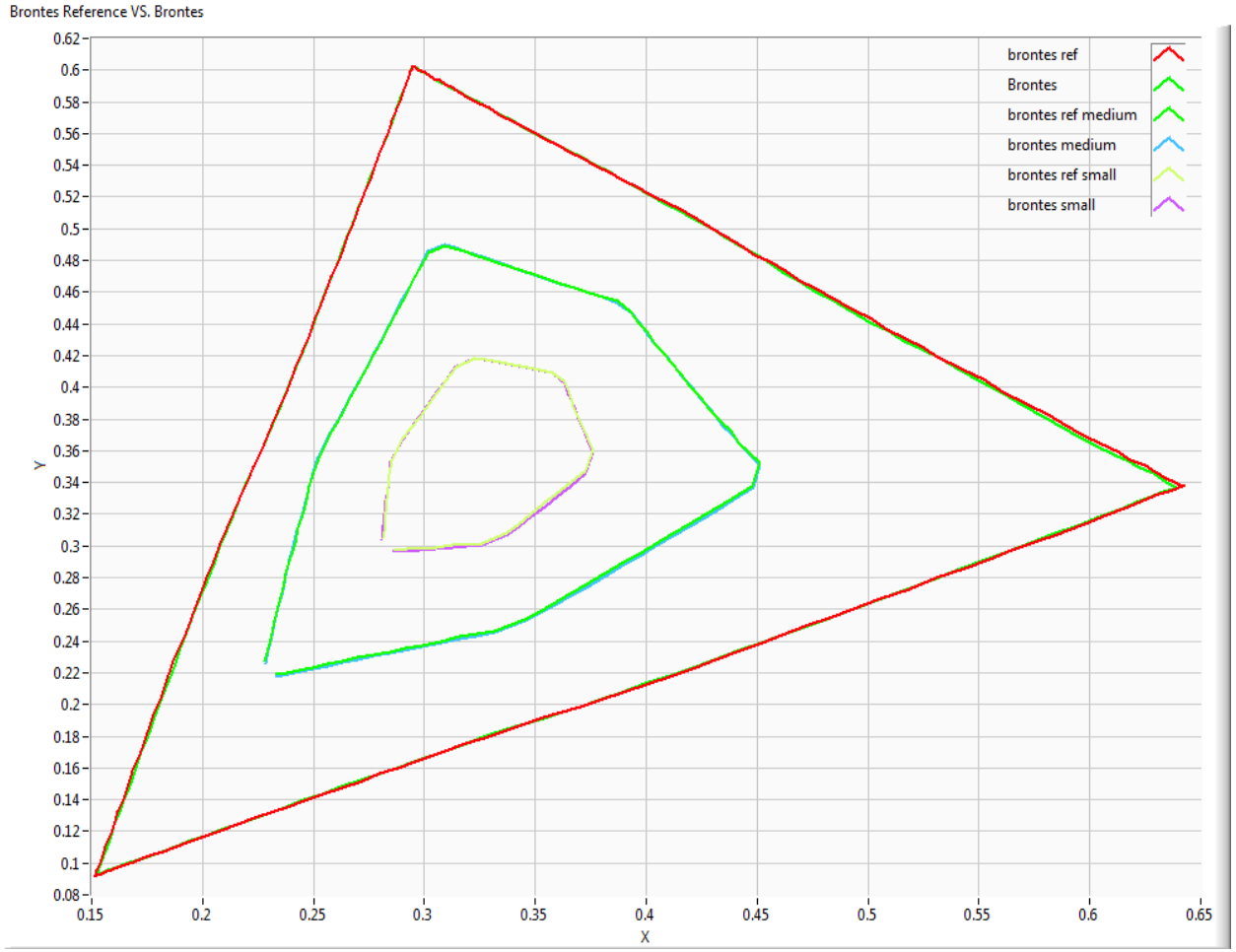
Calibration has been carried out in the same way as specified under chapter 6.

The following graph shows the x,y space of the brontes according to the reference brontes, calibrated to the reference system. The triangles full, medium and small proof that both brontes devices show an equal result.

The maximum deviation of the brontes according to the reference brontes is at maximum 0.0025 in x or y.

The deviations that are found are mostly seen on the saturated colours, which are always most difficult to measure. Specially on LCD, mechanical alignment causes differences in saturation due to viewing angle.

It should be noted that for good results, stable mechanics are always necessary.



8 Gage Repeatability & Reproducibility (Gage R&R)

The Gage R&R is a Measurement Systems Analysis technique which uses Analysis of Variance (ANOVA) random effects model to assess a measurement system.

Gage R&R measures the amount of variability induced in measurements that comes from the measurement system itself and compares it to the total variability observed to determine the viability of the measurement system.

When not familiar with the Gage R&R test method, please read the following info first: Gage R&R.

The Gage R&R is performed with 5 different LCD samples (TFT) and 3 different brontessen, of which one (reference brontes) is calibrated to a lab grade spectrometer. The other two are calibrated to the reference brontes. A single operator was used since the system in use has already been proven to be operator independent (to acceptable level) and we're interested in the repeatability between different brontes devices.
They all measured the x,y colour point of the white colour (RGB: 255,255,255).

When preforming the gage R&R with the above mentioned equipment, the following Gage R&R is found for a white colour in x,y.
Notice that the appraiser is a brontes, with good mechanics the appraiser can be neglected. Resulting in a R&R for only the equipment, a set of brontessen in this case

Measured Data

products:		1	2	3	4	5	6	7	8	9	10	Average:
Brontes 1:												x
Trial:	1	0.3280	0.3041	0.3192	0.3272	0.3430						A1_avg= 0.3243
Trial:	2	0.3281	0.3040	0.3190	0.3271	0.3428						A2_avg= 0.3242
Trial:	3	0.3278	0.3040	0.3191	0.3271	0.3430						A3_avg= 0.3242
Brontes 2:												y
Trial:	1	0.3279	0.3040	0.3187	0.3273	0.3433						B1_avg= 0.3242
Trial:	2	0.3279	0.3041	0.3190	0.3272	0.3433						B2_avg= 0.3243
Trial:	3	0.3279	0.3039	0.3188	0.3273	0.3433						B3_avg= 0.3242
Brontes 3:												z
Trial:	1	0.3279	0.3045	0.3193	0.3271	0.3429						C1_avg= 0.3243
Trial:	2	0.3278	0.3044	0.3191	0.3271	0.3428						C2_avg= 0.3242
Trial:	3	0.3280	0.3043	0.3192	0.3272	0.3429						C3_avg= 0.3243

GAGE R&R REPORT		
Measurement unit analysis	**Total Variation**	**Tolerance %** Tol.= 0.0030 or ± 0.0015
Repeatability - Equipment variation (EV)	%EV = 100(EV/TV)	**EV result**
EV = 0.0005	0.6%	15.6%
Reproducibility - Appraiser variation (AV)	%AV = 100(AV/TV)	**AV result**
Av = 0.0001	0.2%	4.4%
Repeatability & Reproducibility (R & R)	**% R&R = 100(R&R/TV)**	**R&R result**
R & R = 0.0005	**0.6%**	**16.2%**
Part variation (PV):	%PV = 100(PV/TV)	
PV = 0.0809	100.0%	
Total variation (TV):		
TV = 0.0809	=100%	0.0030 =100%

Table 1: data for x

Measured data

Product:		1	2	3	4	5	6	7	8	9	10		Average:
Brontes 1:												x	
Trial:	1	0.3577	0.3215	0.3389	0.3563	0.3760						A1_avg=	0.3501
Trial:	2	0.3579	0.3214	0.3388	0.3561	0.3760						A2_avg=	0.3500
Trial:	3	0.3577	0.3214	0.3387	0.3559	0.3758						A3_avg=	0.3499
Brontes 2:												y	
Trial:	1	0.3577	0.3215	0.3383	0.3559	0.3761						B1_avg=	0.3499
Trial:	2	0.3576	0.3216	0.3385	0.3560	0.3763						B2_avg=	0.3500
Trial:	3	0.3577	0.3213	0.3383	0.3561	0.3763						B3_avg=	0.3499
Brontes 3:												z	
Trial:	1	0.3578	0.3220	0.3390	0.3564	0.3759						C1_avg=	0.3502
Trial:	2	0.3579	0.3220	0.3390	0.3563	0.3759						C2_avg=	0.3502
Trial:	3	0.3577	0.3219	0.3389	0.3562	0.3759						C3_avg=	0.3501

GAGE R&R REPORT			
Measurement unit analysis		**Total Variation**	**Tolerance %** Tol.= 0.0030 or ± 0.0015
Repeatability - Equipment variation (EV)		%EV = 100(EV/TV)	**EV result**
EV =	0.0005	0.5%	18.3%
Reproducibility - Appraiser variation (AV)		%AV = 100(AV/TV)	**AV result**
Av =	0.0006	0.6%	21.1%
Repeatability & Reproducibility (R & R)		**% R&R = 100(R&R/TV)**	**R&R result**
R & R =	0.0008	**0.7%**	**27.9%**
Part variation (PV):		%PV = 100(PV/TV)	
PV =	0.1132	100.0%	
Total variation (TV):			
TV =	0.1132	=100%	0.0030 =100%

Table 2: data for y

The results for the x space are better than the y space, respectively 16.2% and 27.9%. A Gage result less than 30% is acceptable.

9 Considerations

The calibration as shown in this report is valid for the measured type of display only. It may be used for other displays with similar back light spectrum but the Brontes needs to be recalibrated for other types of displays.
This means that when the Brontes has been calibrated on a display that uses a CCFL back light, it can not be used to measure displays that use LED back lights unless a new calibration is carried out.
Since the Brontes sensor itself is fixed the calibration will be valid for a very long time. It is however advisable to check/recalibrate once every year.

When calibrating multiple Brontes devices it is recommended to calibrate one against the reference system and the other Brontes devices toward this reference Brontes.
Starting a calibration on displays or other materials, that have a viewing angle or reflections, take into account that the equipment must measure the same spot size, preferably the same spot and also measuring the same angle with respect to the calibration source.

Check your reference systems data sheet before calibrating on colours Red, green, blue and White. To be sure this will not affect the calibration, measure the colours RGB separately and repeatedly, to notice there is a stable measurement. Otherwise calibrate on the colours, Cyan, Magenta, Yellow and White. When calibrating, warm up the light source (in this note the screen) for about 30 minutes, than calibrate or measure the colours at the exact time for each measurement.

Measuring the gage R&R there must be taken into account, that there are a various number of dependencies that can pass or fail the test. The most common factors that cause the Gage R&R to fail are temperature, part wear out, mechanics and operators. A gage R&R is always specific to the full measurement equipment as it is in use in the factory. Customers should not refer to Gage R&R results from this document, but it may be used as a guideline to show the capabilities of the brontes colorimeter.

Perhaps the most important in good results is the use of very good mechanics. Keeping spot sizes and distances always equal, reduces the risk of deviations due to these factors.