TOMATO ANALYZER – COLOR TEST: USER MANUAL

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PART 1: OVERVIEW OF COLOR AND TOMATO ANALYZER – COLOR TEST

The Tomato Analyzer module called Color Test (TACT) is designed to collect objective color measurement from JPEG images (**Figure 1**), which are collected from scanning fruits on the flatbed surface of a scanner.

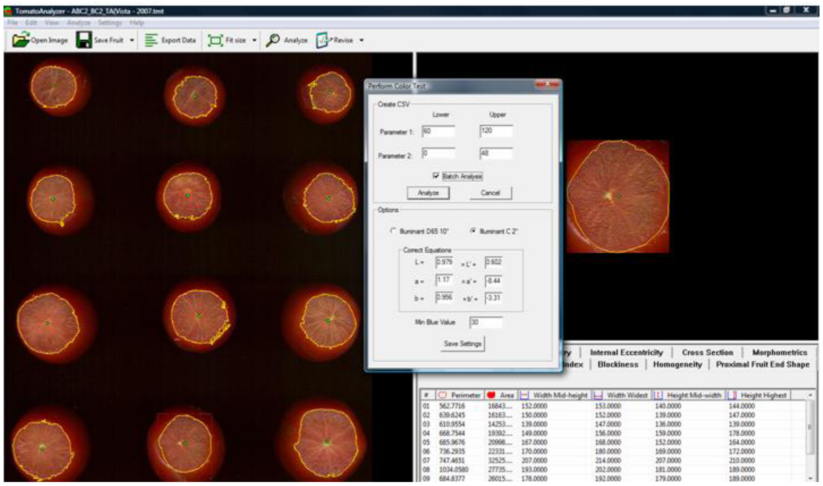

Figure 1. Tomato Analyzer – Color Test application.

Digital color and the RGB color space. Computer color measurements are based on the RGB color space. This system is additive, at it measures the strength of each R (red), G (green), B (blue) color in each pixel to reproduce other colors. The additive RGB color space is a cube with each axis representing variance in one of the primary colors and a white reference point. This color space is nonlinear and does not mimic the nature of color perception. It is not generally standardized. While there is a standardized version (sRGB) for which conversion formulas exist, measurements may differ among hardware and software. These differences can be corrected by calibrating the devices involved in the process of collecting and analyzing color images.

Tomato Analyzer and the CIELab color space. TACT takes the average RGB values for each pixel and translates the color measurements to L*, a*, b* values of the CIELab color space. Unlike the RGB color space, the CIELab color space is able to approximate human visual perception. It is a spherical color space with the vertical axis representing lightness (+L*) to darkness (-L*). The chromaticity coordinates are a* and b* and their axis indicates color directions: +a* is the red direction, -a* is the green direction, +b* is the yellow direction and –b* is the blue direction (**Figure 2**).

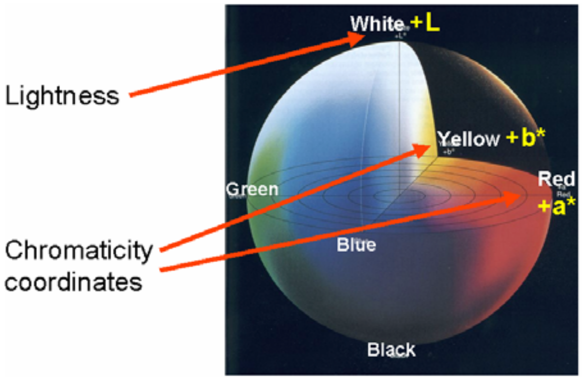

Figure 2. Representation of the CIELab color space (Original image reprinted with permission from Konica Minolta).

Hue and chroma are descriptors of color based on a* and b* values (**Figure 3**). Hue represents the basic color. It is an angular measurement in the quadrant between the a* and b* axes. Chroma is the saturation or vividness of color. It is measured radially from the center of each quadrant with the a* and b* axes.

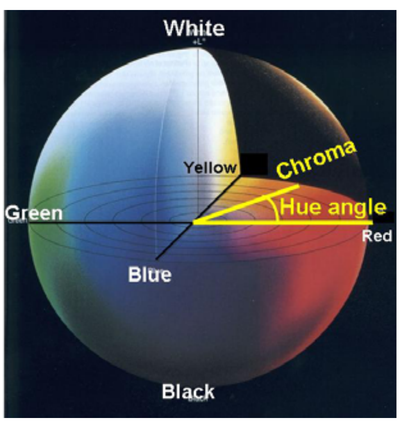

Figure 3. Representation of hue and chroma, two attributes of perceived color (Original image reprinted with permission from Konica Minolta).

Standard illuminant and observer angle. Different light sources will make colors appear different. A standard illuminant has a specific spectral distribution. Standard illuminant D65 represents natural daylight. It should be used for specimens that will be illuminated by daylight, include ultraviolet radiation. Illuminant C was also constructed to represent natural daylight, but its spectral distribution excludes ultraviolet radiation.

In addition to the light source, the angle of view will also affect color sensitivity of the eye. Colors are perceived most precisely if they strike the area of the fovea in the eye, which is most sensitive to color. The 2^{o}

Standard Observer angle is used for viewing angles between 1^{o} and 4^{o}, whereas the 10^{o} Standard Observer is used for angles larger than 4^{o}.

TACT application

TACT collects RGB values for each pixel of an object. It then translates them to L*, a*, b* values of the CIELab color space, as well as luminosity. Algorithms were written for TACT to compute hue and chroma based on L*, a*, b* values. The output of each image analyzed with the TACT consists of the averaged values of RGB, luminosity, L*, a*, b*. In addition, two parameters based on specific ranges of hue values can be defined by the user (see Part 4: Defining parameters).

PART 2: BASIC FEATURES

The basic features of the Tomato Analyzer (TA) were presented in the original user manual (Version 2.1.0.0). It can be downloaded from the following URL: http://www.oardc.ohio-state.edu/vanderknaap/. The features will be briefly described, unless they have to be adapted specifically for the Color Test.

Collecting and formatting images for TA. Set the resolution of the scanner at 200 dpi and the output image size at a million colors. Scan the surface of the fruit to be analyzed with a black background. A label with descriptive information for the fruits (year, plot number, etc) can be included on the scanner. A ruler and a color standard can also be included. TA will not consider the objects as fruits to analyze. Save the image as JPEG. Using any image editing software, crop the image to remove all objects (label, ruler, color standard, etc) and save it as the image for color analysis with TACT.

Generating automated fruit boundaries. The automated analysis will use the default settings for shape attributes. The settings should be changed to meet the user's demand and interest. For the color test and prior to analysis, open the Color Test dialog box under the Settings menu. Set the minimum blue value to 30 and save the setting. Open the image to analyze. It will be displayed in the left panel. Click on the Analyze icon. The TA-defined boundaries of the fruits will appear in yellow. Lower the minimum blue value if the fruits are large (in which case TA may crash) or if the boundaries are much erroneous.

Adjusting boundaries. If the boundaries need to be adjusted, select the fruit by left-clicking on it. The selected fruit will be displayed in the upper-right panel. Click on the Revise icon, selecting Boundary (shift+B). Click on the boundary at the start of the area to adjust and at the end. The delimited boundary will disappear. The distance between the start and end points should be left than half the entire boundary, as only the shortest boundary distance will disappear. Left-click at multiple points on the boundary to delimit the desired contour. Any action can be undone by right-clicking. Press the Enter key to accept the changes. Click the Save Fruit to save any changes on the image. A TMT file containing all information and adjustments will be saved along with the image. Both files should be kept in the same folder to avoid reanalyzing the image.

PART 3: CALIBRATION

Obtaining color standards. Color standards should be chosen based on the broad range of colors observed in the crop of interest. For the color analysis of tomato, we chose 28 color standards (**Figure 4**). They were custom-made into a 28-patch color checker (X-Rite, Grand Rapids, MI). The Munsell notations for each patch are provided in Table 1.

Figure 4. 28-patch color checker from X-Rite

Scanning color checker and collecting TACT L, a*, b* values.* Scan the color checker and analyze the image as described previously. Make sure TACT recognizes each patch as an object to analyze (yellow boundary). Under the Settings menu, select Color Test. The dialog box will appear. Select the illuminant and observer angle specific to the scanner used and to be used in the future for color analyses. Make sure the correction values are set to 1 for the slope (left boxes) and 0 for the y-intercept (right boxes). Click on the Analyze button. A new window will appear to save the output in a comma-delimited (CSV) Excel document. Specify the name and the directory for the data file. The output data file will contain L*, a*, b* values, as well as values for the other parameters, to be used for calibration.

Collecting colorimeter L, a*, b* values.* Verify the settings of the colorimeter for its source of illuminant and observer angle. They should be consistent with the scanner. Calibrate a colorimeter with a white tile, following the manufacturer's protocol. Collect L*, a*, b* values for each patch of the color checker. Make sure to report the tile number with its corresponding color values. If using the 28-patch color checker developed at OSU (Figure 4; Table 1), the L*, a*, b* values are available in Table 2 (Part 5).

Determining correction values for calibration. Plot TACT values against colorimeter values for L*, a*, and b*. Determine the regression equation and record the slope and y-intercept for each parameter. Enter the inverse of the slope and the reverse the sign of the y-intercept values; they are used as correction values in the dialog window of the TACT (**Figure 5**).

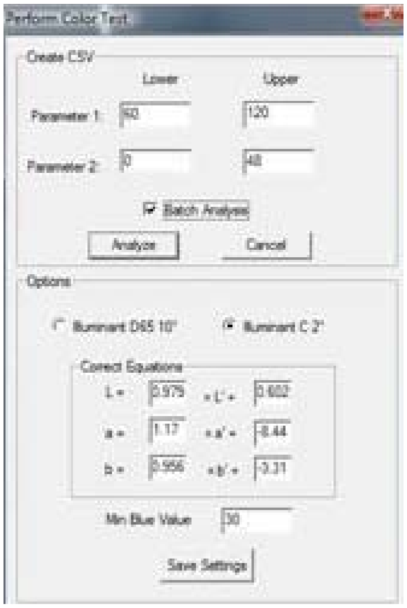

Figure 5. Tomato Analyzer – Color Test window. Correction values used to calibrate the scanner are entered in the lower panel of the dialog box.

PART 4: COLOR TEST

Defining parameters. TACT allows the user to define two parameters based on specific ranges of hue values. Enter the lower and upper bounds of the selected ranges. Save settings for these values to become default settings until the program is closed.

Analyzing a single image. For a single image to analyze for color, open the image and make the necessary adjustment. Open the Color Test and click on the Analyze button. A new window will appear to save the output in a comma-delimited (CSV) Excel document. Specify the name and the directory for the data file.

Using the batch analysis. The batch analysis consists of analyzing 30-50 images at once. It can be achieved two ways. The batch analysis can use images that were previously analyzed and for which adjustments made to the images were saved. It can also use images that were not previously analyzed, for which there is no TMT file. In either case, open the Color Test. In the upper panel, specify the hue ranges for the parameters of interest. Enter the correction values and the minimum blue value for the boundaries in the lower panel. Check the Batch Analysis and click Analyze. A new window will appear to select the images to analyze. Specify the name and the directory for the data file. Click Save. The output file will contain the name of the image (depicted from the file name) and average color values for each fruit on the image.

PART 5: COLOR STANDARD SPECIFICATIONS

Table 1. Munsell notations for the custom 28-patch color checker used at OSU.

Patch	A	B	C	D
1	2.5R 5/8	2.5R 6/10	5R 5/14	5R 5/12
2	5R 4/10	5R 5/6	5R 5/2	7.5R 3/6
3	7.5R 6/4	10R 7/10	2.5YR 5/4	5YR 5/2
4	5YR 4/4	5Y 4/4	5Y 5/2	5Y 8.5/10
5	5Y 8.5/4	5Y 8/8	7.5Y 8/6	10Y 7/2
6	10Y 8/4	5GY 8.5/4	5GY 9/6	5GY 8/4
7	5G 5/2	5B 5/2	5PB 5/8	5RP 4/2

Table 2. L*, a*, b* values obtained from a colorimeter for each patch of the color checker. The source of illuminant was C and the observer angle was 2^{o}.

Patch	L*	a*	b*
A1	51.71	32.8	13.55
B1	61.29	39.03	16.61
C1	53.13	55.23	34.38
D1	52.94	48.31	29.02
A2	42.68	41.21	22.95
B2	52.17	23.22	14.97
C2	51.11	7.47	4.98
D2	32.43	23.33	16.44
A3	60.73	14.08	12.41
B3	72.3	31.82	40.07
C3	51.62	11.74	18.07
D3	51.18	4.97	10.9
A4	42.47	10.4	19.44
B4	42.46	-2.36	25.29
C4	51.81	-1.99	14.24
D4	86.18	-7.03	70.09
A5	85.58	-5.39	31.33
B5	81.58	-6.52	57.82
C5	81.4	-10.61	45.26
D5	70.77	-5.79	15.46
A6	81.25	-8.37	29.01
B6	84.86	-13.12	25.65
C6	90.12	-20.44	39.19
D6	79.98	-13.72	24.55
A7	51.07	-9.41	3.12
B7	50.78	-5.15	-7.11
C7	49.65	4.71	-32.96
D7	41.35	8.24	-0.12

PART 6: MATHEMATICAL FORMULAS

The algorithm implemented in TACT to convert RGB values to L*, a*, b* values of the CIELab color space can be adjusted to account for the illuminant (D65 or C) and observer angle (2^o or 10^o). Converting RGB to L*, a*, b* is accomplished in three steps. First, RGB values are scaled to a perceptually uniform color space (equation 1):

Var_R = ((((R/255)+0.055)/1.055)^2.4)*100

Var_G = ((((G/255)+0.055)/1.055)^2.4)*100 (1)

Var_B = ((((B/255)+0.055)/1.055)^2.4)*100

Scaled RGB values are then converted to XYZ trismulus values using the following relationships (equation 2):

X = (Var_R*0.4124)+(Var_G*0.3576)+(Var_B*0.1805)

Y = (Var_R*0.2126)+(Var_G*0.7152)+(Var_B*0.0722) (2)

Z = (Var_R*0.0193)+(Var_G*0.1192)+(Var_B*0.9505)

The XYZ values are converted to L*, a*, b* values using the following relationships (equation 3):

$L^* = 116\, f\,(Y/Yn) - 16$

$a^* = 500\, [\, f\,(X/Xn) - f\,(Y/Yn)]$ (3)

$b^* = 200\, [\, f(Y/Yn) - f\,(Z/Zn)]$

where

$\mathrm{f}\,(q) = (q)$^1/3 $\qquad q > 0.008856$

$\mathrm{f}\,(q) = 7.787q + (16/116) \qquad q \leq 0.008856.$

Yn, Xn and Zn are the trismulus values of the illuminant and observer angle. For illuminant C, observer angle 2^o, Xn=98.04, Yn=100.0 and Zn=118.11. For illuminant D65, observer angle 10^o, Xn=94.83, Yn=100.0 and Zn=107.38.

The L*, a*, b* values were then used to calculate chroma as $\sqrt{(a^2+b^2)}$. Hue is calculated as 180/pi*acos($a/\sqrt{(a^2+b^2)}$) for a*>0 and as 360-((180/pi)*acos($a/\sqrt{(a^2+b^2)}$)) for a*<0.

In addition, luminosity is computed from the following relationship (equation 4):

$$\text{Luminosity} = (\text{maxCol} + \text{minCol}) * 240.0 / (2.0 * 255.0) \qquad (4)$$

where maxCol is the highest of the R, G, B values of a pixel analyzed, and minCol is the lowest value.