Correcting the Lateral Response Artifact in Radiochromic Film Images from Flatbed Scanners

Background

The lateral response artifact (LRA) in radiochromic film images from flatbed scanners was first pointed out by Menegotti (Med. Phys. 2008, 35(7) 3078). The lateral position is measured in the direction perpendicular to the scan direction. For the purpose of correcting this artifact we define lateral position L relative to the center of the scan window perpendicular to the scan direction. By definition, the center of the scan window is at lateral position zero and the value of L can be positive or negative depending whether the position is to the right or left of the center axis.

The lateral response artifact stems from the polarization of scanner illumination transmitted through GafChromic film. To reach the detector, the transmitted light is reflected from mirrors in the optical path. Owing to the dependence of reflectivity on the angle of incidence on the mirror, there is less light reaching the detector from film located near the edge of the scan area than from film located in the center of the scan window. Furthermore, the polarization of the transmitted light becomes greater as the film progressively darkens with increased radiation exposure. As a result, the magnitude of the artifact is dependent upon the position of the film on the scanner as well as the exposed dose.

Approach

The recommended approach to compensating for the LRA is to measure a set of calibration films at known locations on the scanner. This data is used to determine correction coefficients specific to each lateral location. When the correction coefficients are applied to raw response data the mage is corrected as though the entire film was located at the reference position at the center of the scanner.

In principle, films with just two different doses are required and one of those films could be unexposed, i.e. zero dose. If the second film was exposed to dose D, the correction coefficients could be applied to image data for any film exposed to a dose between zero and D. However, for this work a more thorough investigation will include using a set of five or six exposed films at doses up to 24 Gy.

The method is applicable because the shapes of the calibration curves measured at specific locations on a given scanner are related to one another. For example, we define a calibration function $X(D,L_1) = a_1 + b_1/(D-c_1)$ where $X(D,L_1)$ is the response of film exposed to dose D at position L_1 and a_1, b_1 and c_1 are the coefficients to be determined. If the shapes of the calibration curves at two locations are the same then $X(D,L_1) = A_{1,2} + B_{1,2}.X(D, L_2)$ and we can solve for the coefficients $A_{1,2} + B_{1,2}$ using the response of films exposed to two doses. In particular we define position 1 as our reference location at the center of the scanner. By measuring the same two films at a number of discrete locations, including the center of the scanner, we can obtain the values $A_{1,L}$ and $B_{1,L}$ at those locations and obtain the intermediate values by interpolation. Once values for $A_{1,L}$ and $B_{1,L}$ are available we can take response values from any film image and correct the values at any lateral position L to obtain a corrected image as though the entire film was located at the center of the scanner. At this time the corrections are restricted to images of films from the same production lot, but we will also explore the

Fimecorp
International s.l.

hypothesis that on a given scanner the corrections are the same for any production lot of the same type of film, I.e. the values of $A_{1,L}$ and $B_{1,L}$ film lot independent.

Materials

Epson 10000XL or 11000XL scanner
Paper cutter – guillotine type not roller-blade type – or scissors
Scalpel or razor blade
Four 8" x 10" sheets of EBT3 film
Paper
Adhesive tape
3 or 4 mm thick glass sheet of the same size as the scanner window.
Ruler
Fine felt-tip marker
FilmQAPro software
Epson Scan Software
Microsoft Excel

Important Note about FilmQAPro and Epson 10000/11000XL Scanners

FilmQAPro always displays images with the origin in the top left corner, I.e. the scan starts at the top of the image and ends at the bottom. The A4 and smaller format Epson scanners display images in this same manner, but Epson Scan displays the A3 size images from the 10000XL and 11000XL scanners with the origin in the top right corner and with the start of the image to the right and end of image to the left.

For consistent display and alignment of images from all types of Epson scanners, with origin at top left, x axis horizontal and y axis running vertically down from the start of a scan, FilmQAPro contains a means for correcting Epson's anomalous display of 10000/11000XL images. Right-click the 'Treatment selection' icon at the bottom of the left-hand panel. From the drop-down/pull-out menus, as shown in Figures 1 and 2 below, select "Twain scanner" and click at the bottom to select and activate the "Scanner rotates image" option for the 10000/11000XL scanners. For all other scanners turn off this selection.
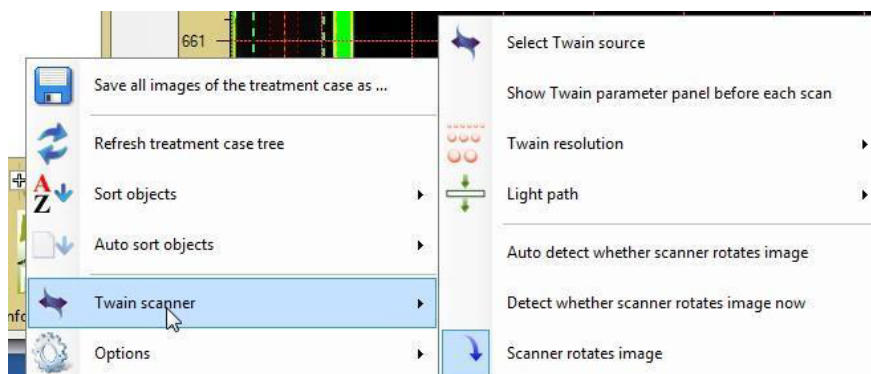

Figure 1: Activate 'Scanner rotates image' option for Epson 10000/11000XL scanners

Fimecorp
International s.l.
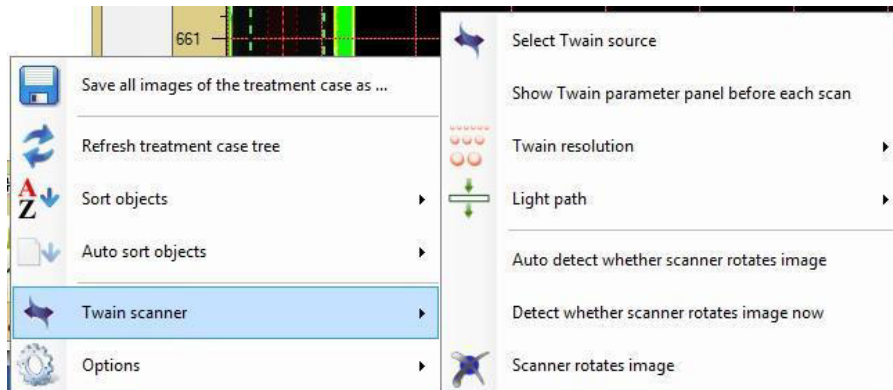
Figure 2: De-activate the 'Scanner rotates image' option for all smaller format Epson scanners

Procedure

Step 1: Create two linear metric scales on strips of film or paper. Mark the center of the scale zero and place marks at -13.0 cm, -8.7 cm, -4.3 cm, 4.3 cm, 8.7 cm and 13.0 cm. Guided by the markings on the scanner showing the width of the scan area, tape the scales across the bed of the scanner at either end of the scan window. Take care not to encroach on the calibration area in the first 2 cm of the window at the start of the scan.

Step 2: Clean all glass surfaces – including the glass in the lid of the scanner. Ordinary glass cleaner is the best choice, but an alcohol swab could be substituted

Step 3: Use paper and scalpel/razor blade to create a template similar to that in Figure 3. There should be one window for each calibration film. Windows should be of equal size about 2-2.5 cm wide and 3.5 -4 cm long. Borders around the windows should be 5-7 mm. The total length of the template should not exceed 36 cm.

Fimecorp
International s.l.
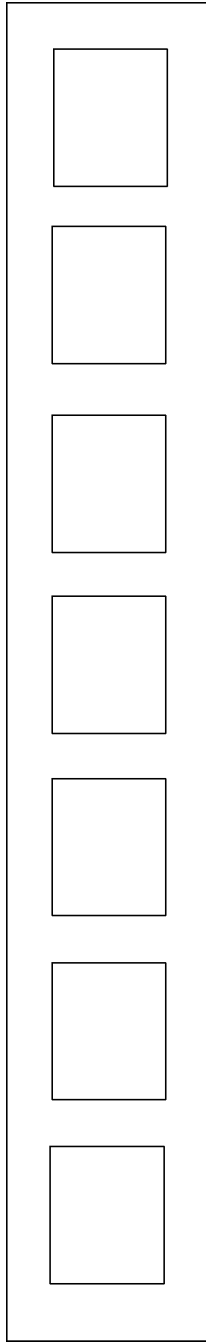
Figure 3: Template for Calibration Films

Step 4: Take four sheets of 8"x10" film and mark them as in Figure 4. The small rectangles should be about 4 mm longer and wider than the frames in the template. Mark an ID number in the corner of each of the small rectangles .The films will first be cut to the red lines yielding eight 4"x5" pieces. Keep the films in the dark until needed for exposure. After the films have been exposed the small, marked rectangles will be cut out.

Fimecorp
International s.l.
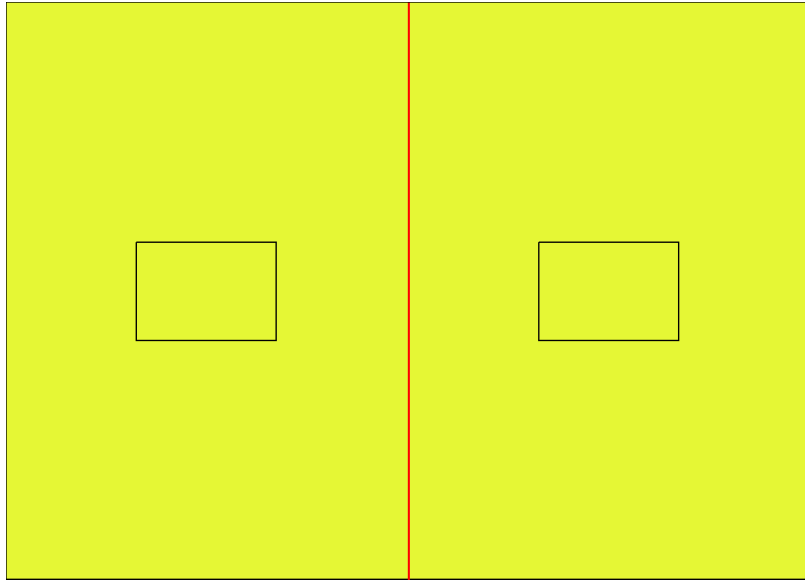
Figure 4: Calibration Film

Step 6: Choose a radiation source producing a uniform field of exposure at least as large as the small rectangle on the film samples. Position a film in the center of the field and one-by-one expose the 4"x5" film samples to a series of radiation doses covering the range up to 24 Gy. Use dose values of 75, 150, 300, 600, 1200 and 2400 cGy and note the time at which each exposure occurred. Place the exposed films and the remaining unexposed films in the dark until needed.

Step 7: Carefully cut the small rectangular pieces from the center of each film and use small pieces of adhesive tape to attach them behind the windows in the template (Step 3). Include also one of the unexposed film pieces. Keep the template and films in the dark until needed for scanning. Take care that the adhesive tape does not project into the windows.

Step 8: Before the films are scanned wait for the post-exposure changes to slow down. If the time between exposure of the first and last films was T hours then wait at least 4T hours after the last film was exposed. With a time period of at least 4T any differences in the response values due to variability in elapsed time post-exposure will be reduced to less than 0.2%.

Step 9: Turn on the scanner, connect a computer and open the FilmQA Pro application. From the drop-down menu (Figure 5) under "Case Object Management" select "Images only (multiple scans)".

Fimecorp
International s.l.
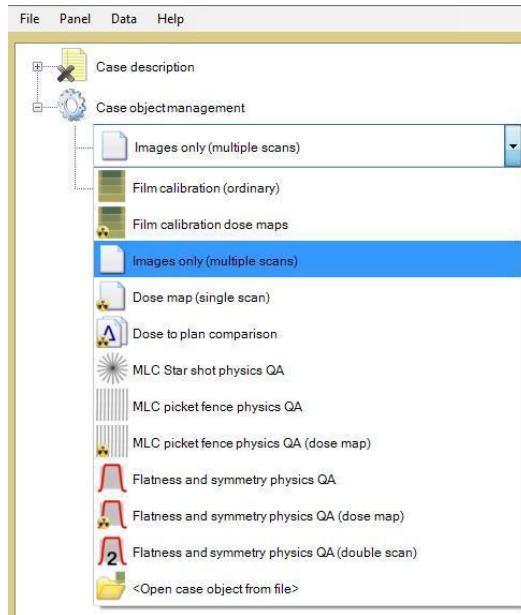
Figure 5: Images only 'Multiple scan' Case Object

Step 10: Expand the' Images only' case object and click on "Data Image scan #1 (empty)" (Figure 6). When the Epson Scan window appears choose the settings in Figure 7C. If the color correction icons are active (red arrow in Figure 7A) they must be de-activated by opening the Epson Scan Configuration window (Figure 7B) and checking "No Color Correction". The icons will appear gray (green arrow below, right). Then run six preview scans to warm up the light source in the scanner.

Note: Scan using image resolution of 50 dpi. The accompanying Excel template is set up on that basis.

Fimecorp
International s.l.
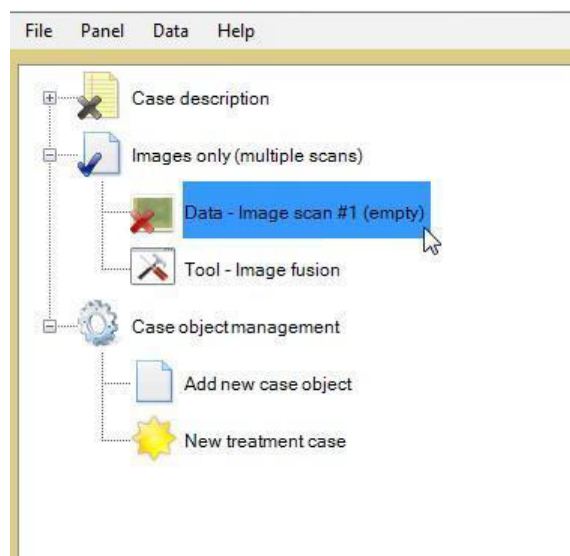
Figure 6: Scan an image
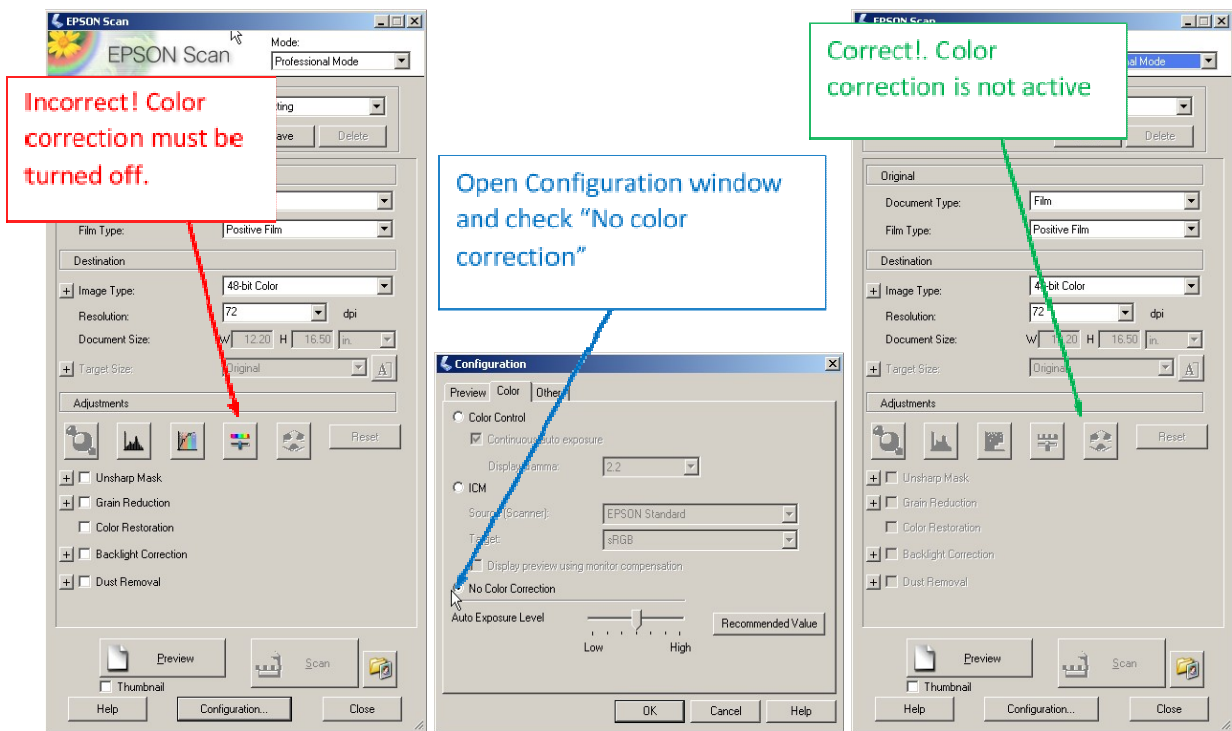
Figure 7A   Figure 7B   Figure 7C

Step 10: Create a reference by fixing a strip of scrap unexposed film about 0.5" x 10" across the end of the window where the scan terminates. The reference strip will appear in each image and the measured response values will be used to correct for the scan-to-scan variability.

Step 11: Place the template and attached films in the center of the scanner window and use the scales attached at the ends of the window to align the template and calibration films parallel to the scan direction. Then place the glass sheet over the template and films.

Scan the film and mark an area of interest in the center of each film in the image – Figure 8. Activate the "Statistics" tab in the right-hand panel and copy and save the statistics table to an Excel worksheet. The table contains the average response values in the three color channels, plus minimum, maximum and standard deviation.

In addition, use the frame tool to draw an area of interest on the reference strip at the end of the scanner. Measure and record the response values.

Note: Once one or more areas of interest have been defined, they may be saved or copied and pasted. Point and click on the Frame tool and select the "Copy" or "Recent frames" options from the drop-down menu to copy or save the frame(s). Repeat the process using the "Paste" or "Recent frames" commands to add the frames to an image.

Fimecorp
International s.l.
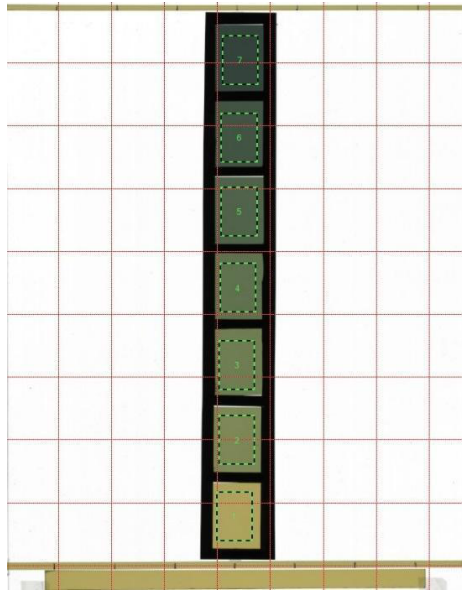
Figure 8: Calibration films and measurement frames

Step 12: Use the scales to align the template/films at positions 13.0 cm, 8.7 and 4.3 cm on either side of the center. Acquire an image at each position and repeat the process in Step 11 to measure and record response values of the calibration films and reference strip.

Step 13: Then use the Statistics tab in FilmQAPro to display a table of response values for each image and copy/paste the values into an Excel worksheet. From the response values measured on the reference strip in each image calculate and apply corrections to the RGB response values of the calibration films in that same image to compensate for scan-to-scan variability in response measurement.

Step 14: Employ the corrected response values of two of the calibration films to calculate the values of the coefficients $A_{0,L}$ and $B_{0,L}$ at each of the of the seven (7) locations (see the Approach section). To make the coefficients usable over the widest dose range choose the unexposed film as well the calibration film exposed to the highest dose. However, if a narrower range is desired then use the response values from one of the other exposed calibration films.

The coefficients $A_{0,L}$ and $B_{0,L}$ relate the measured responses at lateral location L to the responses at the center of the scanner, lateral location zero. To aid the calculations an Excel file has been included with these instructions. Just copy your corrected response values into the tables in the worksheet labelled Discrete Response Values. The interpolated values of the coefficients will be contained in the worksheet labelled Correction Matrix.

Step 15: Please plot the values of A and B vs. position for all color channels and send the data, tabular and graphical, to dlewis@ashland.com

Fimecorp
International s.l.

Correcting an image for the lateral response artifact

If you wish to proceed further and perform the lateral response correction on an image from your 10000XL scanner, then here is how to proceed.

Step A: Calculate a pixel-by-pixel correction matrix

The accompanying Excel file is set up for a scan resolution of 50 dpi. At this resolution the width of a full frame image from an Epson 10000XL or 11000XL is 610 pixels. You will calculate a correction matrix for each pixel location across the full width (12.2", 30.99 cm) of a 10000XL/11000XL image. Starting with the values of the coefficients $A_{0,L}$ and $B_{0,L}$ for the seven discrete locations (see Step 14) and each color channel, use linear interpolation to calculate the values of $A_{0,L}$ and $B_{0,L}$ at all the pixel positions across the scanner.

Set up a worksheet with two rows of correction values across the sheet for the coefficients $A_{0,L}$ and $B_{0,L}$. The first three columns contain the coefficients for the red, green and blue channels respectively at pixel location 1. The next three columns contain coefficients for location #2, etc.

Note 1: Open the **"Info"** tab in the right-hand panel of the FilmQAPro screen. This displays information about the size the image, its position relative to the entire scan window of the scanner as well as the size and position of frames defining areas of interest within the image.

Note 2: The origin of the co-ordinate system for Epson 10000XL and 11000XL images is in the top left-hand corner of the image. This corresponds to the position -15.49 cm relative to the center of a full-frame image.

Step B: Apply the pixel-by pixel correction matrix to an image

Open the image to be corrected in the center window – note that it **must** have the same spatial resolution in dpi as the correction matrix - and use the "Image export" tool (Figure A) to copy the RGB color channel values as CSV columns. Preferably use the "Frame" tool to outline just a portion of the image and then export the color channel values of the selected region as CSV columns. Then paste the RGB color channel values into an Excel worksheet (Figure B)
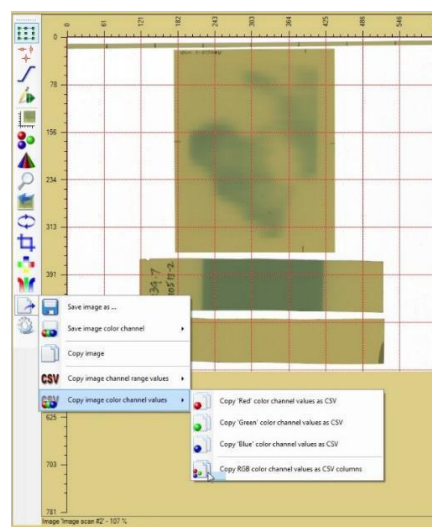

Figure A: Copy image response values as CSV columns

Fimecorp
International s.l.

Bitmap	Image scan #2		
Color chan	Red	Green	Blue
Channel n	Red	Green	Blue
Resolutio	50	50	dpi
Quantity	Color cha	Color cha	Color channel
Unit	%	%	%
Size W x -	266	334	

R	G	B	R	G	B	R	G	B	R	G	B
8.60E+01	8.55E+01	8.21E+01	6.76E+01	6.57E+01	5.42E+01	7.09E+01	6.86E+01	5.55E+01	7.19E+01	6.95E+01	5.58E+01
8.26E+01	8.14E+01	7.39E+01	6.75E+01	6.28E+01	3.71E+01	6.73E+01	6.29E+01	3.69E+01	6.76E+01	6.30E+01	3.67E+01
8.32E+01	8.21E+01	7.49E+01	6.74E+01	6.30E+01	3.72E+01	6.74E+01	6.30E+01	3.68E+01	6.75E+01	6.31E+01	3.67E+01
8.56E+01	8.46E+01	7.77E+01	6.79E+01	6.34E+01	3.73E+01	6.75E+01	6.30E+01	3.67E+01	6.75E+01	6.30E+01	3.66E+01
8.55E+01	8.43E+01	7.75E+01	6.78E+01	6.34E+01	3.72E+01	6.75E+01	6.31E+01	3.68E+01	6.76E+01	6.32E+01	3.67E+01
8.58E+01	8.49E+01	7.82E+01	6.77E+01	6.33E+01	3.73E+01	6.75E+01	6.31E+01	3.68E+01	6.76E+01	6.30E+01	3.67E+01
8.52E+01	8.42E+01	7.77E+01	6.80E+01	6.32E+01	3.73E+01	6.77E+01	6.31E+01	3.67E+01	6.75E+01	6.30E+01	3.65E+01
8.56E+01	8.45E+01	7.81E+01	6.77E+01	6.34E+01	3.72E+01	6.76E+01	6.32E+01	3.68E+01	6.77E+01	6.29E+01	3.67E+01
8.58E+01	8.49E+01	7.87E+01	6.80E+01	6.35E+01	3.74E+01	6.76E+01	6.32E+01	3.68E+01	6.76E+01	6.33E+01	3.67E+01
8.59E+01	8.48E+01	7.85E+01	6.77E+01	6.33E+01	3.74E+01	6.78E+01	6.34E+01	3.69E+01	6.75E+01	6.31E+01	3.66E+01
8.57E+01	8.47E+01	7.85E+01	6.78E+01	6.33E+01	3.73E+01	6.77E+01	6.31E+01	3.68E+01	6.75E+01	6.29E+01	3.66E+01
8.52E+01	8.41E+01	7.82E+01	6.78E+01	6.33E+01	3.73E+01	6.79E+01	6.35E+01	3.69E+01	6.76E+01	6.30E+01	3.65E+01
8.60E+01	8.51E+01	7.91E+01	6.76E+01	6.33E+01	3.72E+01	6.76E+01	6.32E+01	3.67E+01	6.76E+01	6.31E+01	3.67E+01
8.62E+01	8.51E+01	7.90E+01	6.77E+01	6.31E+01	3.73E+01	6.76E+01	6.32E+01	3.67E+01	6.74E+01	6.28E+01	3.66E+01
8.64E+01	8.55E+01	7.96E+01	6.79E+01	6.33E+01	3.73E+01	6.75E+01	6.30E+01	3.67E+01	6.77E+01	6.30E+01	3.65E+01
8.59E+01	8.49E+01	7.94E+01	6.78E+01	6.34E+01	3.74E+01	6.75E+01	6.29E+01	3.66E+01	6.75E+01	6.29E+01	3.65E+01
8.60E+01	8.51E+01	7.95E+01	6.74E+01	6.30E+01	3.72E+01	6.73E+01	6.28E+01	3.65E+01	6.72E+01	6.28E+01	3.63E+01
8.63E+01	8.54E+01	7.97E+01	6.76E+01	6.31E+01	3.72E+01	6.40E+01	5.99E+01	3.50E+01	6.75E+01	6.28E+01	3.65E+01
8.66E+01	8.59E+01	8.02E+01	6.77E+01	6.33E+01	3.74E+01	6.77E+01	6.30E+01	3.67E+01	6.76E+01	6.31E+01	3.67E+01
8.66E+01	8.58E+01	8.01E+01	6.79E+01	6.36E+01	3.75E+01	6.76E+01	6.31E+01	3.69E+01	6.76E+01	6.33E+01	3.68E+01
8.71E+01	8.63E+01	8.10E+01	6.77E+01	6.33E+01	3.72E+01	6.76E+01	6.31E+01	3.67E+01	6.75E+01	6.29E+01	3.65E+01
8.70E+01	8.64E+01	8.10E+01	6.76E+01	6.33E+01	3.72E+01	6.77E+01	6.32E+01	3.67E+01	6.76E+01	6.29E+01	3.66E+01

Figure B: Paste CSV image as columns of RGB values

Step C: Now open the **"Info"** tab (right-hand window of FilmQAPro), highlight the displayed data and use "Ctrl C" to copy and paste the information into another worksheet (Figure D).

	Name: Image scan #2		
	Dimensions:		
	(X=left, Y=top) (W=width, H=height) □=Area		
	(X=2, Y=1) (W=606, H=550) □=333300 (pix)		
	(X=1.0, Y=0.5) (W=307.8, H=279.4) □=860.1 (mm, cm²)		
	Size: 1999.8 kB		
	Pixel format: 48 bpp RGB		
	Resolution: (X=50 dpi, Y=50 dpi)		
	Light path: transmissive (film)		
	Id: 89ea5617-75a9-4e87-bb6f-45ce0eaa9eca		
	File: N/A		
	Origin: Dave-main-E6530\Dave 2/19/2014 1:00:48 PM		
	Type: Dose Film		
	Red quantity: Red (Color channel)		
	Green quantity: Green (Color channel)		
	Blue quantity: Blue (Color channel)		
	Channel range 'Red': [0.0, 100.0] %		
	Channel range 'Green': [0.0, 100.0] %		
	Channel range 'Blue': [0.0, 100.0] %		
	Source: EPSON Expression 10000XL (EPSON)		
	Dimensions:		
	(W=width, H=height) □=Area		
	(W=610, H=825) □=503250 (pix)		
	(W=309.9, H=419.1) □=1298.7 (mm, cm²)		
	Frames: Not available		
	Fiducials: Not available		
	Registration template: Not available		

Fimecorp
International s.l.

Figure D: Information on size/location of an image and embedded areas of interest

The table contains critical information about the image needed to align the color channel values with the correction matrix. In the lower part of the table the image is identified as coming from an Epson 10000XL scanner. At the indicated resolution of 50dpi (see line 8) the size of the master image on this scanner is 610x825 pixels (see line 23). The master image represents the maximum area that could be covered by the scanner. An actual image could be any size up to this master image size. In the example the actual dimension of the image is 606x550 pixels (line 3) with its origin at position X=2, Y=1 within the master frame.

Step D: Return to the worksheet containing the RGB image and number the columns in sequence as indicated by the Image Information Figure D). In the example the first group of columns contain RGB response values in 16-bit format for pixel position 2

Step E: Now open another worksheet, number the columns to correspond with the sequence in the actual image and use the values of the coefficients A and B from the correction matrix to calculate the corrected RGB 16-bit response values for the image.

Note: Use an IF function (or other logical function) to keep the values in the 16-bit range.

Step F: Now open a "Dose map (single scan)" object in the FilmQAPro Case Tree and copy the corrected image from the worksheet and "Paste CSV data to 'dose film'" from RGB columns. A new window will open up defining the image scaling – size and response range. Type in the linear scale (dpi) values in the x and y directions and the response scale values. Press Enter after each value is typed in and then OK to complete the scaling. In the example the spatial resolution is 50 dpi and the response scale is 0 to 65535 (16-bit response) in all channels. The corrected image is now available for calculation of a dose map.