

Target Validation and Image Color Calibration

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Abstract—The process of document image preservation and analysis starts from a correct acquisition of scanned or photographed digital information. It may sound simple but, unfortunately, it is not. The photo or scanning devices employed in the process need constant check and maintenance in order to certify the quality of their output. Even in case of perfectly functioning devices, small deviations may appear. The purpose of this paper is to examine the available methods of measuring the correctness of an imaging device functioning, to propose a set of methodologies for specific target validation in terms of tonal reproduction, geometric distortion, and image sharpness and to ensure that the correct output is obtained if only minor deviations occur.

Keywords—image color calibration, MTF, sharpness measurement, target validation, tonal reproduction.

I. INTRODUCTION

PAPER documents such as newspapers, books and other prints suffer in time of various forms of autonomous decay that can affect paper, among which are paper acidification and ink and copper corrosion. In the 1980's and 1990's research was carried out – e.g. the Metamorfoze project in the Netherlands, a collaborative effort of the Koninklijke Bibliotheek (National Library) and the Nationaal Archief (National Archives) – to develop reliable methods and standards for the conservation of paper heritage material that was considered of national importance. The research focused on two directions: preservation – concerned with slowing down the decay on the original documents through means of deacidification, treatment of ink corrosion and copper corrosion, small repairs, acid-free wrappings and climatized storage – and conversion – dealing with the transfer of the threatened material to another storage medium by means of

document. However, in recent years, digitization is preferred over microfilming, leading to an additional challenge of converting pre-existing microfilms to digital media, in order to avoid handling the original documents, an action which is both costly and potentially damaging for the decaying prints.

A further direction pursued in recent years is converting scanned documents (either of the microfilms or the original paper prints) into electronic files, especially for large electronic libraries, for easier access to documents. Content conversion systems, based on optical character recognition (OCR), enable operations such as editing, word searching, easy document storing and multiplication, and the application of a large set of text techniques including text-to-speech and text mining to be performed on the digitalized document. In addition, this ensures a better preservation of original documents, due to minimizing the need for physical use.

Undoubtedly, digitization has many advantages over microfilming on the access side: digital images include color reproduction, they allow remote access and they can be easily searched by using OCR. From the point of view of preservation, digitization offers exciting possibilities as well. Since digitized copies contain color; a high quality digital image is closer to the original than a microfilm could ever be.

There are nevertheless a number of issues to be tackled before digitization can definitively be used as a conversion method for preservation and access. Standards and guidelines, the workflow, the metadata, long-term storage and retrieval of digital images all have to be developed and dealt with. Scanning system calibration is one of the areas for which accurate standards and methodologies are needed. There are many factors which can affect the scanning quality: defective equipment, variations in illumination conditions, aging scanner

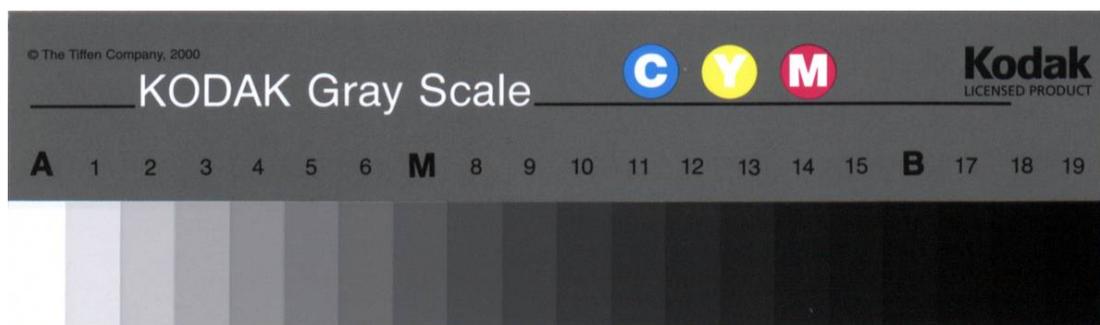


Fig. 1 Kodak Gray Scale

either microfilming or digitization.

When research programs first started, microfilming was a reliable method to preserve the content of an endangered

lamps, out-of-focus cameras, failing sensors on specific color channels, etc. This article proposes a set of methodologies for calibrating scanners to ensure optimal quality in the

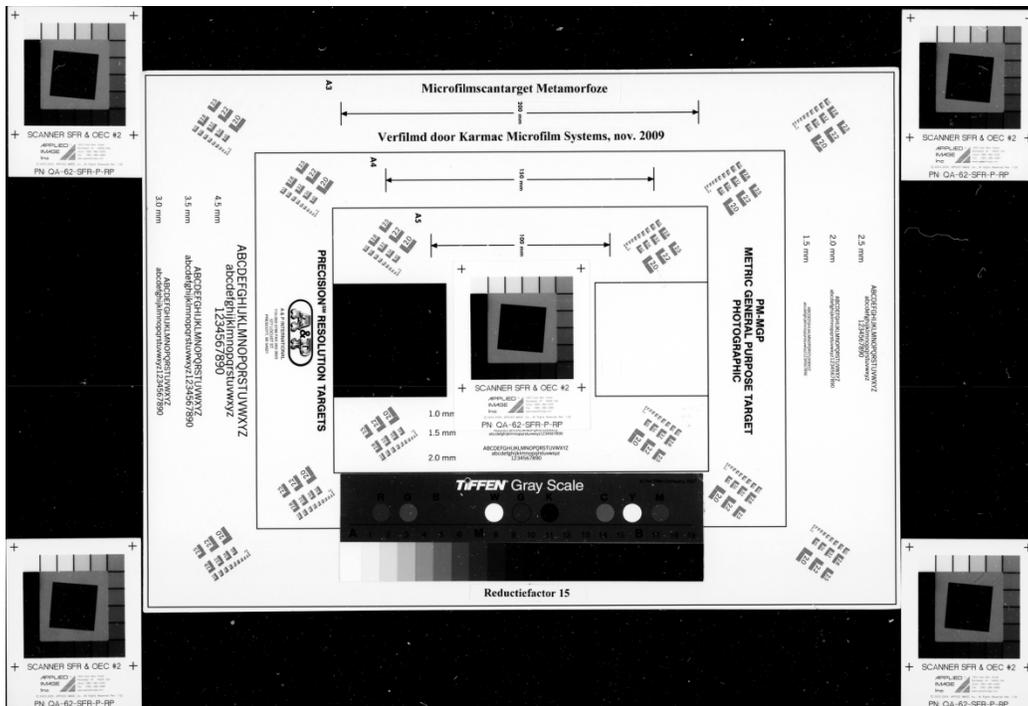


Fig. 3 5 x QA-62 targets plus Tiffen grayscale

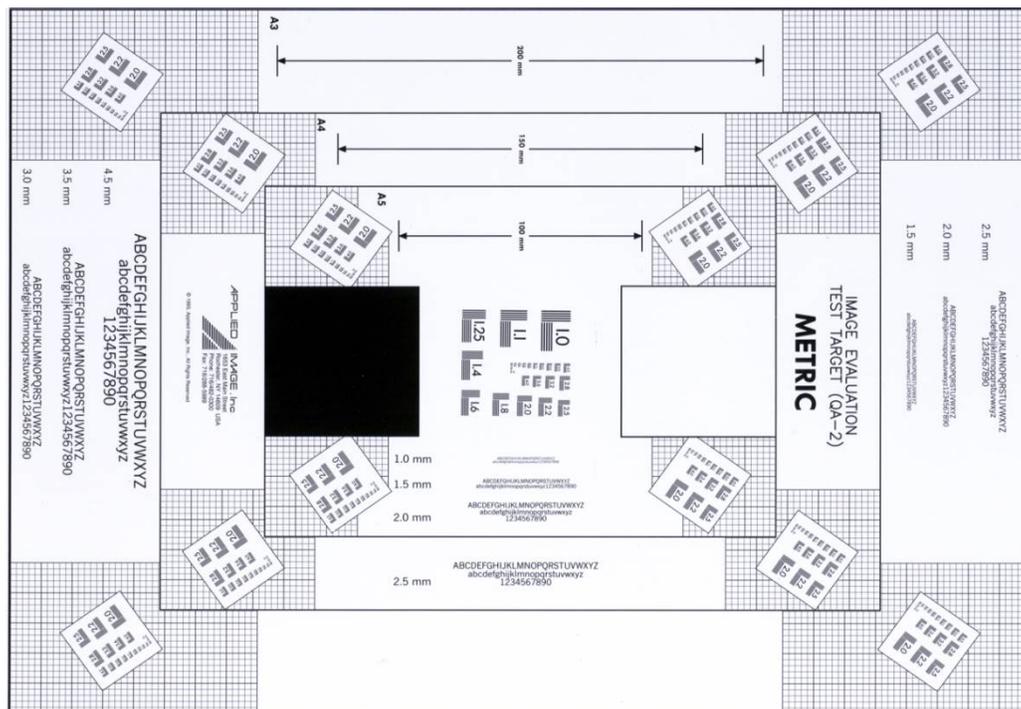


Fig. 4 QA-2 metric test target

digitization of both microfilms and paper prints, covering the following issues: tonal reproduction and illumination, color cast and color accuracy, calibration and tonal reproduction, image sharpness and optical distortion [1].

II. TARGET VALIDATION

Scanner calibration is performed using special technical targets. Target validation refers to the process of checking if certain parameters of the scanned images of the targets verify some predefined standards. There are two kinds of technical

targets: targets that must be captured with every individual image that is made from an original, and technical target sheets that must be captured for every batch (a specified number of images) or for a series of images made in a specified period of time (for instance one morning or afternoon) [2].

A. Initial Setup

The monitor settings (e.g. white point 6500K, gamma 2.2, gray desktop background, etc.), workspace conditions (e.g. ambient illumination 32-64 lux, color temperature 5000K, neutral ambient colors, etc.) and scanning procedure should match the requirements mentioned in the Metamorfoze project guidelines [2]. The aim of these standards is to remove any effects interfering with the subjective, visual assessment of the images, and to support uniformity in assessment between supplier and client.

cardboard must be between 0.05 and 0.15 [2]. For all target sheets, the distance between them and the lens must be equal to the distance between the original and the lens. In other words: the reduction factor used for capturing the target sheets must be equal to the reduction factor used for capturing the originals.

The following four target sheets are used in sequence for evaluating document scanning performance:

First target sheet: tonal reproduction and illumination. Both aspects are assessed with the aid of one single image, which is constructed by centering a Kodak Gray Scale (see Fig. 1) at the bottom of the cardboard sheet.

Second target sheet: color cast and color accuracy. The two aspects are evaluated using a target sheet similar to the first, but with a color test target, the GretagMacbeth Color Checker SG (see Fig. 2), positioned in the center of the sheet.

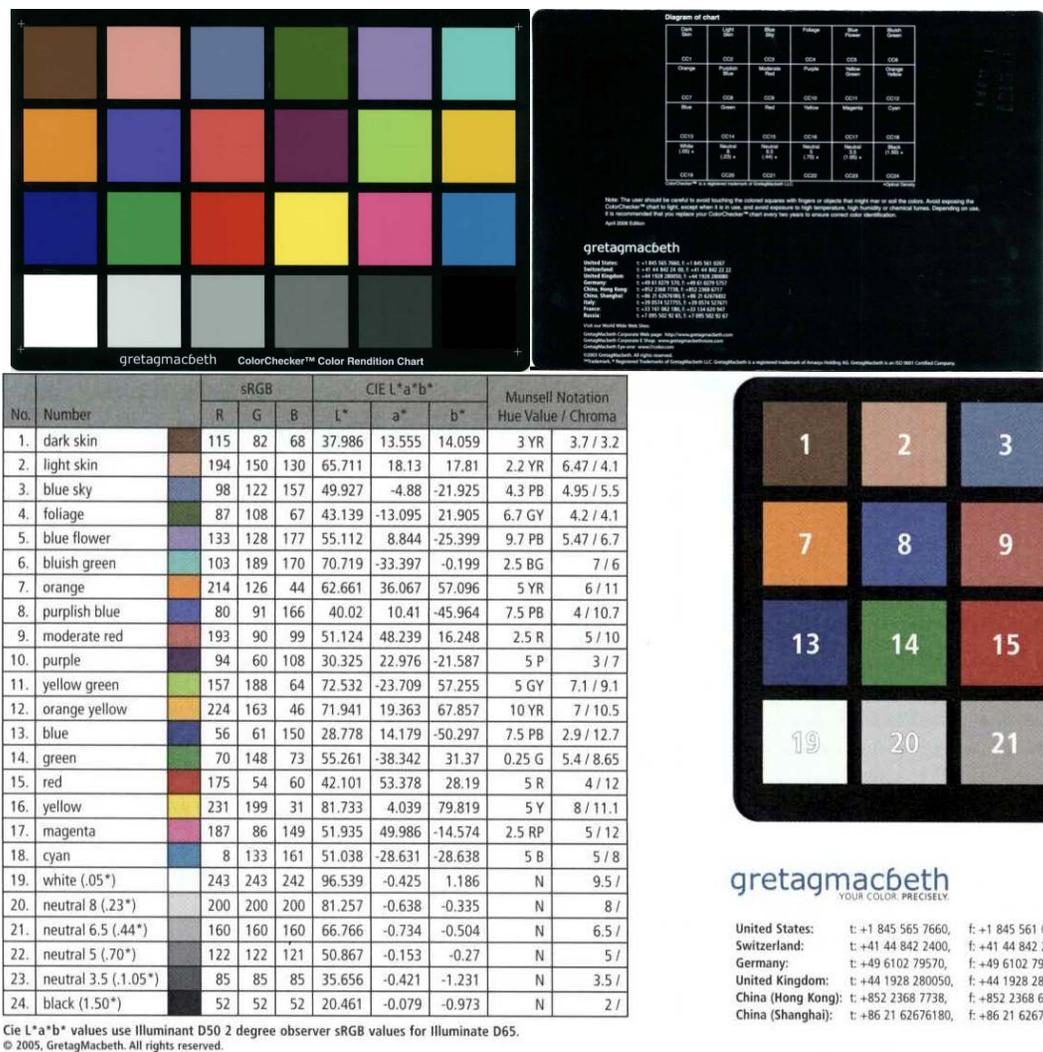


Fig. 2 GretagMacbeth Color Checker SG: front, back and legend

B. Target Sheet Composition and Sequence

All aspects are assessed by capturing images of a frame-filling white sheet of cardboard on top of which various technical targets are placed. The optical density of the white

Third target sheet: sharpness. Again, the target sheet is based on the first type, this time with five QA-62 slanted edge sharpness test targets (see Fig. 3) placed in the center and the four corners of the target sheet.

Fourth target sheet: optical distortion. The target sheet is constructed by placing a QA-2 metric test target (see Fig. 4) containing length markers in the center of the white cardboard.

For assessing microfilm scanning performance, a Microfilm target sheet is used. It contains all test targets from the four document scanning sheets placed on a single cardboard base. All aspects are evaluated by studying the scanned image of the target sheet captured on microfilm.

For every individual image, it must be possible to assess tonal reproduction and color accuracy in relation to the original. Therefore a Kodak Gray Scale Q-13 or Q-14 and a mini GretagMacbeth Color Checker Rendition Chart must be captured together with every single original [2]. Both technical targets must be positioned side by side, and clearly visible, centered at the bottom of the frame.

How to enable assessment of color cast for each individual image is still being investigated [3]. A possible solution might be to use a target with a number of neutral gray patches, placed in a relevant position. This target could be positioned in each corner, and captured with each image.

The following sections discuss the methodology of evaluating each aspect in the scanning process. Please note that a valid range of [0-255] for all pixel channel values is considered, since all targets are acquired as 8-BPP or 24-BPP images.

III. TONAL REPRODUCTION AND ILLUMINATION

Measured on the basis of the Kodak Gray Scale (Q13 or Q14) all patches of the Kodak Gray Scale should be distinguishable from each other. For noise test acceptance within the pixel values of the Kodak Gray Scale (or equivalent) a maximum standard deviation of 10 is allowed. After the noise check is performed a noise reduction [4] may be employed in order to improve the accuracy of pixels values measurements. The pixel value of patch A has to be between 250-230. The pixel value of patch 19 must be above 10. The pixel value should be measured with a 5x5 average window.

IV. COLOR CAST AND COLOR ACCURACY

The color cast is determined by measuring the grayscale patches of the GretagMacbeth Color Checker within a 5x5 average window. The patches must be neutral. The maximum deviation allowed is -4 or +4 pixel point difference between the RGB channels for every patch, when taking the middle RGB-value as a starting point.

V. IMAGE SHARPNESS ASSESMENT

The sharpness of a photographic imaging system or of a component of the system (lens, film, image sensor, scanner, enlarging lens, etc.) is a quality factor that determines the amount of detail that can be reproduced. It is characterized by a parameter called Modulation Transfer Function (MTF), also known as spatial frequency response, which is a measure of the response of an optical system to varying intensities of light. The MTF is strictly the response to parallel lines whose

brightness varies from minimum to maximum in a sinusoidal function.

Traditional methods for MTF measurements were initially designed for devices forming continuous images and can produce erroneous results, because the sampling of digital devices is not properly taken into consideration [5]. Additionally, MTF results can depend on the chosen technique (sine target or bar target utilization, slit or knife-edge technique).

The proposed method is an improved version of the slanted edge method described in the ISO 12233 methodology and the SAFECOM methods [6]. The slanted edge method involves the analysis of a portion of an image containing an edge slightly tilted with respect to the detector and, compared to other methods, has the advantage of requiring a small number of pixels from a single image to be processed.

VI. SHARPNESS VALIDATION METHODOLOGY

This section details a methodology suitable for calibrating document or microfilm scanning equipment with respect to the image sharpness quality factor.

A. Initial Setup

For measuring image sharpness, a special target shall be constructed, containing five calibration targets (four near the corners and one in the center) such as the QA-62 target (presented in Fig. 6) with four slanted edges as sides of a rectangle. The target must be scanned and validated at regular intervals (e.g. at the beginning of the day) or after any change in scanning parameters (e.g. resolution, scaling factor for microfilms, etc.).

B. Detecting the Region of Interest

Automated sharpness validation techniques can be applied on the scanned target. To detect the five slanted rectangles in the target image, a conversion to black-and-white [7] followed by 4-connected (black) pixel detection can be applied. By analyzing the shape of the connected regions, the rectangles can be recognized and their slant angles can be checked to meet certain limits (e.g. between 2 and 5 degrees).

For each of the five rectangles, image sharpness shall be measured by processing the pixels contained in four regions of interest (RoI), corresponding to the slanted edges of the rectangle. The RoI is required to be of a minimum size of 80 by 60 pixels (see Fig. 5) and is normally selected by dividing

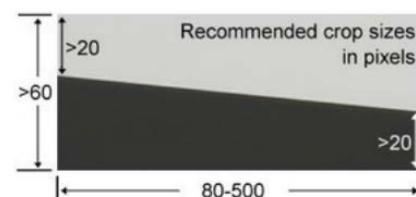


Fig. 5 Best minimum cropped region of slanted edge

the minimal non-slanted rectangle surrounding each slanted rectangle into 6 parts, both horizontally and vertically, and

extracting 4/6 by 1/6 portions (e.g. for the top edge, the RoI is situated in the top sixth and middle four sixths of the reference rectangle).

C. Modulation Transfer Function Computation

In the literature many approaches for MTF and MTF-related statistics computation are presented [8]-[10]. The currently used algorithm for computing the MTF and the associated frequency response graph is derived from the International Standard ISO 12233 [6]. The following steps are performed for each RoI of each QA-62 target and, depending on the employed scanning color space, for each RGB color channel plus combined luminance channel ($Y = 0.299 \times \text{Red} + 0.587 \times \text{Green} + 0.114 \times \text{Blue}$) for document scans, or just the gray channel for grayscale microfilm scans.

For each pixel column in the RoI (which is rotated to the position corresponding to the top edge RoI, for reference purposes) the position of the separation line between the background and the slanted rectangle is determined by maximizing the difference of the sum of weighted pixel values on the two sides of a triangle filter of predefined width (e.g. 10 pixels) sliding over the pixels in the column.

The least-squares fit line through the coordinates found is determined and is used to approximate the separation border between the background and the slanted rectangle.

Pixels in the RoI no further than a predetermined distance (normally 1mm, around 12 pixels at 300DPI) from the fitted line, on both sides, are projected along the edge transition, resulting in distance-color tuples. These values represent the Edge Spread Function (ESF) which is the system response to the input of an ideal edge [11]. The ESF is super-sampled because of the slanted edge which induces differences in the sub-pixel location of the projected pixels onto the perpendicular. A vertically oriented edge would only allow obtaining the horizontal Spatial Frequency Response (SFR) of the detector.

The ESF must be resampled to a fixed interval by accumulating the projected pixels into "bins" having the width a fraction of the pixel pitch. This can be achieved by filtering the pixel values with a triangle filter of unit height and the width of a bin. Thus, the value associated to each bin is the weighted average of the pixels filtered by the triangle function centered in the bin. This allows analysis of spatial frequencies

beyond the normal Nyquist frequency [6]. The number of bins per pixel distance is usually chosen as 4. Higher values may lead to insufficiently populated or empty bins.

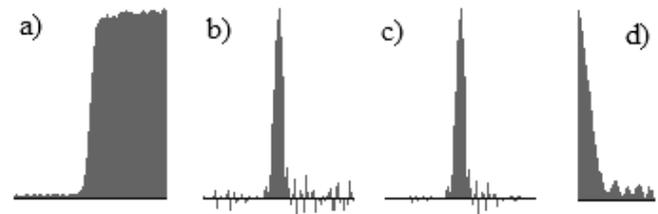


Fig. 7 (a) ESF, (b) LSF, (c) Hamming LSF, (d) MTF plots

The equally spaced ESF samples obtained are derived ($\frac{\partial}{\partial x}$) in order to obtain the Line Spread Function (LSF). A Hamming windowing function is applied to force the derivative to zero at the endpoints [6], reducing the effects of the Gibbs phenomenon that results from truncation of an infinite series [5].

The normalized magnitude of a linear Fast Fourier Transform performed on the LSF yields the MTF (see Fig. 7).

Care must be taken in selecting the number of points calculated along the ESF with respect to the sampling rate in order to obtain the desired number of points in the resulting MTF. The frequency axis of the MTF must be scaled to represent the calculated MTF in terms of the Nyquist frequency of the imaging system, defined as the highest sinusoidal frequency that can be represented by a sampled signal and is equal to one half the sampling rate of the system [11] – always 0.5 cycles per pixel.

For maximum precision in sharpness measurement, the steps in the MTF computation algorithm can be repeated for the interpolated line rotated by slight angles in steps of ± 0.1 degrees, taking into consideration only the MTF curve with the highest values.

D. Sharpness Specification

For a scanning system to pass sharpness validation certain criteria must be defined. Relevant indications are found by checking the frequency at which the MTF graph drops to 10% of its initial, zero frequency value. Values above 70% of the Nyquist frequency are desirable. The frequency corresponding to half the maximum MTF value (MTF50P) is also a good sharpness metric. Furthermore, internal sharpening (performed by firmware in scanning equipment) can be detected by comparing the peak MTF value with the initial value. A ratio below 1.2 is acceptable [2].

VII. OPTICAL DISTORTIONS

Because of the great variety in the optical distortion marker's placement across all target types, their actual position is determined by employing basic line-detection algorithms [12] and is validated by comparing to the marker's expected length.

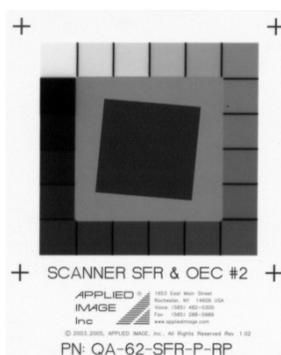


Fig. 6 Quality Assurance 62 sharpness calibration target

The allowed deviation is a change in length or height of 1% at the most. The Image Evaluation Test Target (QA-2) is recommended. The size of this target is A3. To measure larger sizes, a larger test target must be used.

VIII. TARGET VALIDATION AND IMAGE COLOR CALIBRATION

The presented techniques and the proposed methodology were validated in an automatic content conversion system (see Fig. 8 and Fig. 9), in the image acquisition phase.

In respect to color calibration, in Fig. 8 are presented the acquired image before and after a color calibration and correction process. The color reference was deducted by employing a GretagMacbeth Color Checker like the one in Fig. 2.

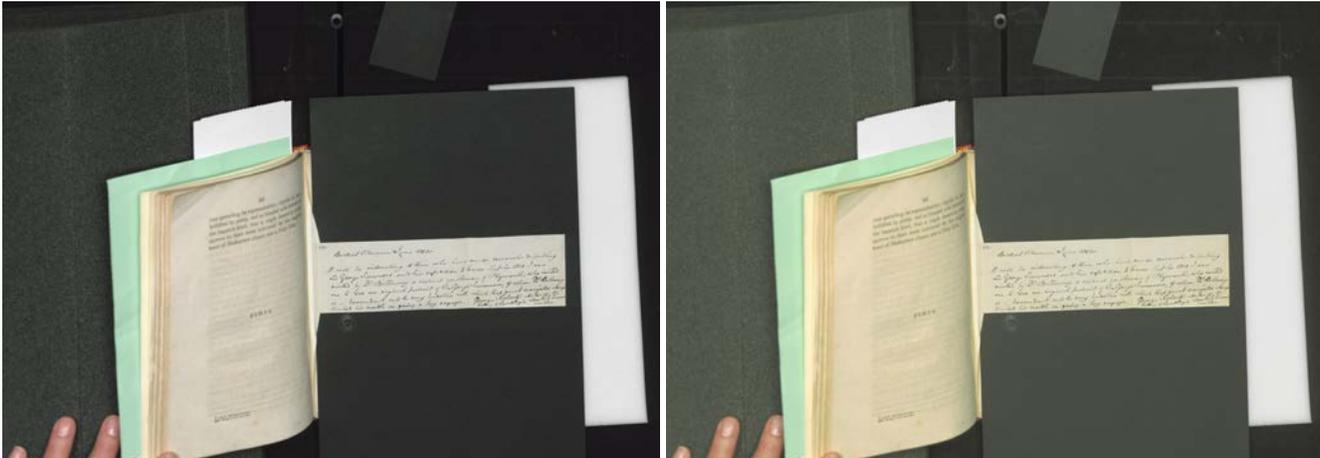


Fig. 8. The process of image color calibration and correction. Left image is the image directly acquired from a scanning device; right image is the resulted color-corrected one

After the sharpness target image has been scanned, sections of the resulted image containing slanted edges are cut out from various locations. The validation test should be run on slanted vertical and horizontal edges near the center of the image and in the far corner of the image. For some equipment, the resolution may vary significantly, depending upon the location in the image (i.e., center vs. edge) and the direction (i.e., horizontal vs. vertical).

Although the cropped region can be as small as 20 by 20 pixels in order for a MTF plotting to function with a minimal quality it's best to ensure the cropped region is at least 60 pixels wide and 80 pixels long to attain the most accurate and consistent results. (Note that the edge is approximately centered in the cropped image.) The horizontal slant edge in Fig. 10 is used for measuring the resolution in the vertical

direction, while a vertical slant edge (from another part of the chart) is used for measuring the resolution in the horizontal direction.

There have been used two sharpness metrics:

- MTF50: The frequency where MTF drops to 50 percent of its low frequency value is a widely used sharpness metric. Should be used for equipment having (internal) software which does not automatically apply sharpening, because would strongly affect the result producing unrealistic values.
- MTF50P: The frequency where MTF is half (50 percent) of its peak value is a measurement that is sometimes preferred over the MTF50 due to its more predictable behavior when measuring MTF-related statistics over a large number of imaging devices.

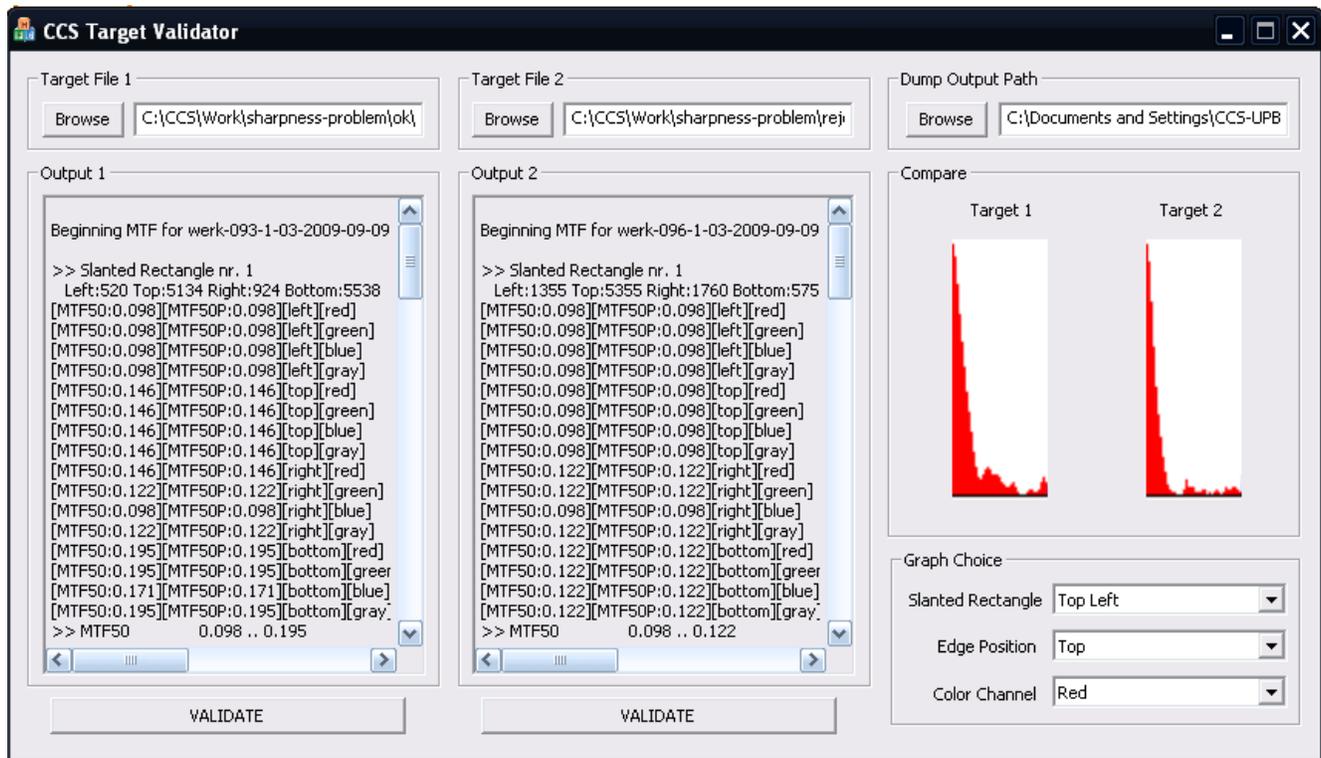


Fig. 9 Screen dump from a target validation tool, currently displaying a visual and numerical comparison of the results obtained by running on the sharpness target, showing for two different rectangles the computed MTF50 and MTF50P across all edges (left, top, right, bottom) and across all color channels (red, green, blue and gray)

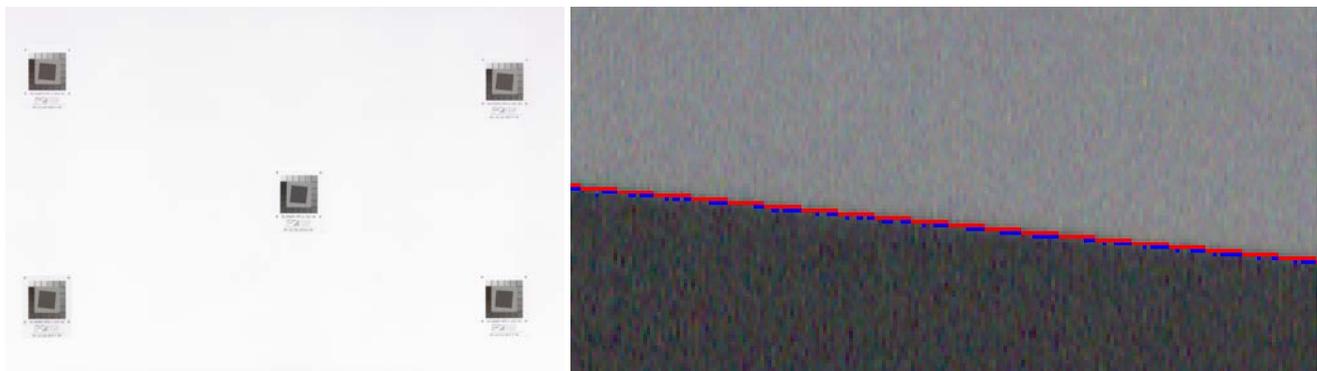


Fig. 10 The sharpness validation target image used for the comparison in Fig 8 and a zoom of the top slanted edge from one of the slanted rectangles (edge location centers from step 1 are marked in blue and the least squares fit from step 2 in red)

IX. CONCLUSIONS

Digitalization is the future for the preservation of information contained in decaying paper prints. Detailed methodologies for calibration of scanning equipment are required to avoid geometric and color distortions, as well as ensuring a level of high image sharpness. The paper presented a methodology for complete target validation in respect to tonal reproduction and illumination, color cast and color accuracy, geometrical/optical distortions, and an algorithm to

assess sharpness based on the Modulation Transfer Function of the scanning system.

All the proposed scenarios were tested in a large content-conversion automatic system, thus successfully validating the consistency of the acquired images over a huge range of input documents from all categories.

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