Evaluation of 3D-Projection Image Capture

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Abstract

It is now common practice to monitor imaging performance prior to, and during, image acquisition for digital collections. Important image characteristics include the influence of lighting, lens focus, and several aspects of general imaging practice. While these methods have been applied to near-flat objects and documents, less attention has been given to developing reliable corresponding methods for two-dimensional perspective images of three-dimensional objects, where optical depth-of-field can be critical. Focusing on the evaluation of image resolution over the macro depth/extent of the scene, we describe results of our effort to adapt standard methods to this new application. Cameras using simple, fixed lens and a tilted lens were evaluated.

Introduction

The monitoring of imaging performance is often part of image acquisition efforts for libraries and museums.[1,2] Several methods have been adopted as guidelines,[3,4] with the aim of reducing variation that can occur, e.g., from day-to-day during an extended project. Important image characteristics include the influence of lighting, lens focus, and several aspects of general imaging practice. While these methods have been applied to near-flat objects and documents, less attention has been given to developing reliable corresponding methods for two-dimensional perspective images of three-dimensional objects. We include single-camera, and two-camera stereoscopic applications. Our focus is on two aspects of imaging performance; image resolution,[5,6] and uniformity of illumination over the scene/object space.

Imaging Performance Evaluation

The design and selection of photographic optical systems has long considered the specification and control of optical depth-of-field to be important. The term refers to the distance in the scene between the nearest and farthest objects that is acceptably sharp in the captured image. Depth-of-field is influenced by several factors, including the optical material, its manufacture, and the setting of lens relative aperture, or f-number.

The performance of cultural heritage imaging systems, of course, is influenced by more than the lens. Factors such as the illumination, detector and electronics, and the image processing combine to determine the delivered digital collection. The need to measure this performance and its variation has led to the common practice of including test charts (reference objects) as either image-level or object-level targets.[3]

The consistent capture of object details in digital images is often of prime importance in digital collections. It is natural, therefore, to address this attribute, with the view to developing straightforward methods to evaluate this attribute over the range of object-space to be captured.

Consider the scene of Fig.1. Near the bottom of the scene is an object-level test target that is used to evaluate scanner and camera imaging performance. Corresponding analysis software can compute image-quality measure as part of system set-up, or a quality assurance program.

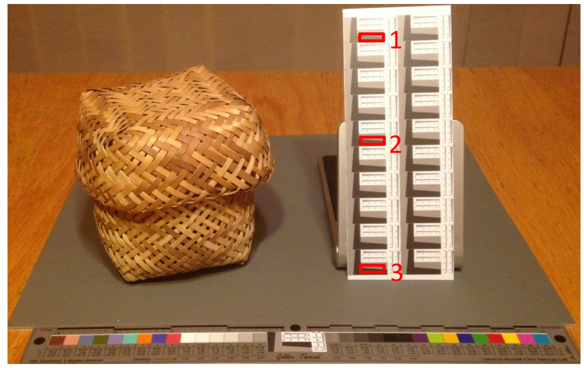

Figure 1: *Example image capture setup with two test charts*

We are often interested in the maintenance of consistent imaging characteristics over the object. For flat objects, the location within the digital image corresponds to the relative location on a (flat) plane in the scene. This is as true for a document scanner as for a camera that is used in a copy stand. As an example of the two-dimensional imaging of three-dimensional object we have the wicker basket of Fig. 1. Here we would like to measure the imaging performance over a range of distances from the camera.

An initial experiment to measure the image resolution involved the placing of the test chart as shown on the right-hand-side of Fig. 1. This chart has ten sets of edge features that are commonly used to measure the spatial frequency response (SFR) of the image capture. When the chart is positioned so that it spans the depth of the object, as it does here, then it serves as an object-level test target. We can compute the SFR for the three edges identified by the red rectangles labelled 1, 2 and 3. The SFR results indicate imaging-resolution performance at three distances in the scene. We are sampling imaging performance over the scene/object depth.

Test Chart Holder

Previous targeting tools to evaluate optics depth of field assume a vertical (*i.e.* 90°) positioning of the camera (lens axis) to the horizontal, and rely on subjective evaluation of focus depth through repeating vertical and horizontal lines. One such commercially available tool[7] is shown in Fig. 2. The test object presents the target at a fixed angle of 45°, with two sets of line rulings that are interpreted visually from the captured image.

The more realistic and general imaging application is one where the camera is positioned above the base or table at an oblique angle to the horizontal. This is shown in a side view in Fig. 3. To accommodate differing imaging angles while maintaining a consistent depth evaluation, we align the lower arm of the chart-support in a direction normal to the camera lens. Once the camera position has been chosen, the test chart holder can be placed either in the center of the object area (for an image-level evaluation), or beside the object (for an object-level evaluation).

***Figure 2**: Example of commercially available test object (courtesy of Edmunds Optics)*

The next step is to rotate the right-angled holder assembly so that the lower arm points toward the camera. Note that when the test chart is in place on the holder, the object depth spanned by the test chart is independent of the camera angle.

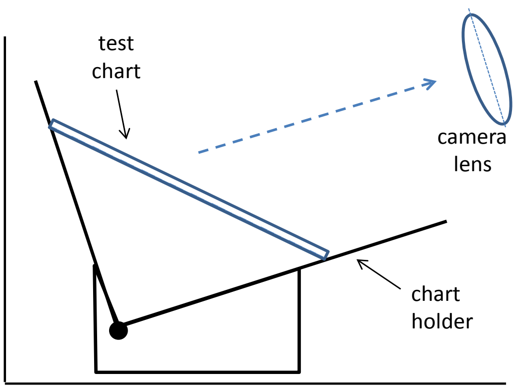

***Figure 3**: Layout of test chart and adjustable holder, where the lower arm is directed normal to the (taking) camera lens front surface*

Based on the above design, a practical chart holder was constructed of aircraft-grade anodised aluminium, weighing 1.7 kg. The chart holder is shown in the foreground of Fig. 4, alongside a Number 1A Pocket Kodak camera, ca.1930. Each holder arm is 18 cm long, supporting a 10 cm x 20 cm test chart. The chart holder angle and the positioning of the flat test object on the holder are adjustable to any angle required. Using rulings on both the target itself and on the target holder, depth dimensions along the optical axis are easily calculated to give an analytical and objective measure of focus depth.

Results

The test chart with multiple edge features was used in the above configuration as part of an institutional imaging project. The imaging workstation included a digital view camera. This type of camera can be operated with the lens tilted so as to remove the influence of both the perspective (not extreme in this case) and the variation in best-focus. This is shown in Fig. 5. Within the field of optics, this correction is based on the Scheimpflug principle. Adjusting the camera in this way is often done for architectural photography, when we desire a camera view that is not practical, e.g., due to height from the ground.

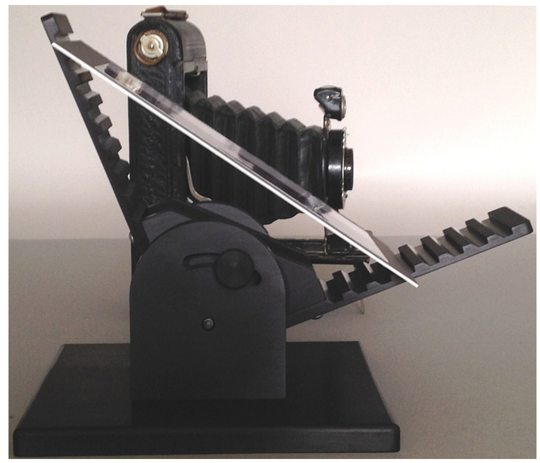

***Figure 4**: Test chart with adjustable holder in use (courtesy of Image Science Associates)*

The camera was first operated with a fixed position (not tilted) lens. Results of the slanted-edge analysis,[5] are show in Fig. 6 in the form of the spatial frequency response (SFR). As we can see, the camera was focused at the center of the test target, region 2, with a fall-off in performance either side (in position and distance).

The same camera was then used with the lens tilted to provide the impression that the camera angle was normal to (facing) the test target. The results of the edge-SFR analysis are plotted in Fig 7. For this camera setting, the measured SFRs are much closer for the three image field positions. This is as we would expect, and the use of the test chart and analysis software provides an evaluation of the camera resolution in the studio.

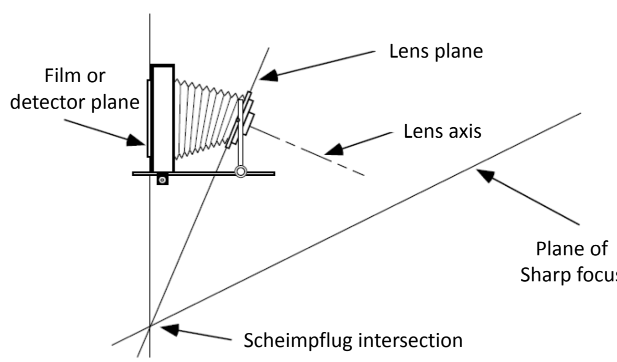

***Figure 5**: A view camera with tilted lens, adapted from Fig. 39 of reference 8.*

We should note that tilting the camera lens resulted in the best-focus being in the plane of the test target, for which it was adjusted. This does not mean that imaging performance was improved for all of the object-space. Our adjustable test target support and analysis software, however, provide the method and means for measuring the imaging resolution in a straightforward and consistent way.

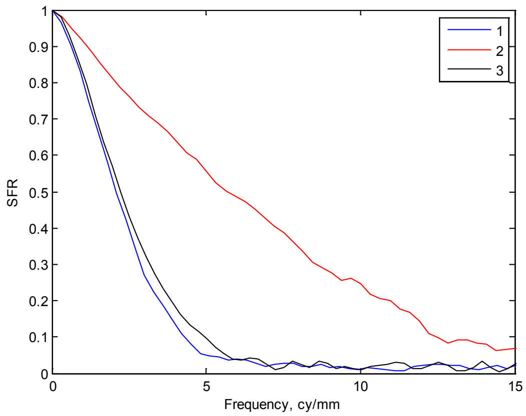

Figure 6*: SFR results for top, middle and bottom test-target edges from a view camera without perspective (focused on center edge)*

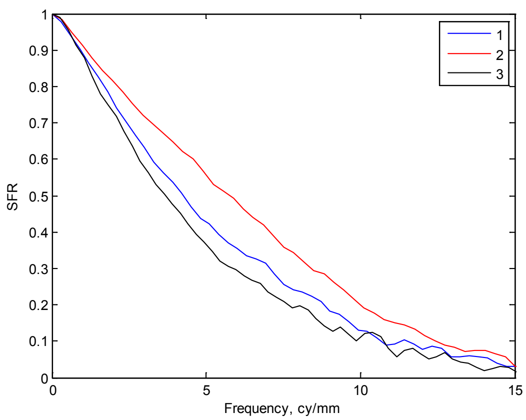

Figure 7*: SFR results for top, middle and bottom edges from the camera using perspective correction by lens tilting*

The resolution test chart also provides a visual understanding of the imaging performance, by including sets of converging lines and characters. In Fig. 8 we show three cropped image regions that correspond to the three edges used for the edge-SFR analysis. Inspection of the three sets of converging lines indicates similar visual resolution. This is consistent with the SFR results of Fig. 7.

Simplified Edge Target

The test charts used in the previous evaluations were originally developed for the evaluation of image scanners and, as we have seen, include elements that are easy to interpret visually. The edge-SFR analysis, however, can be applied to simpler test charts, since it only requires edge features. With this in mind, we investigated the use of a simplified test chart comprising a single extended edge, as shown in Fig. 9, next to the decorative mask. This test chart was used to evaluate a DSLR camera (Nikon D3000). As shown in Fig. 9 we use a single-edge (photographic) chart for the SFR analysis. Also shown is a narrower 1x Object-level Target (Image Science Associates) which includes color patches.

The advantage of the single-edge test chart is that it is easier to produce and can generally be formatted for larger objects. In addition the edge region selection, either by the human user or automated algorithm, is more reliable for the single edge than for the multiple-edge target previously used. The red rectangle of Fig 7 indicates the region used for the edge-SFR analysis.

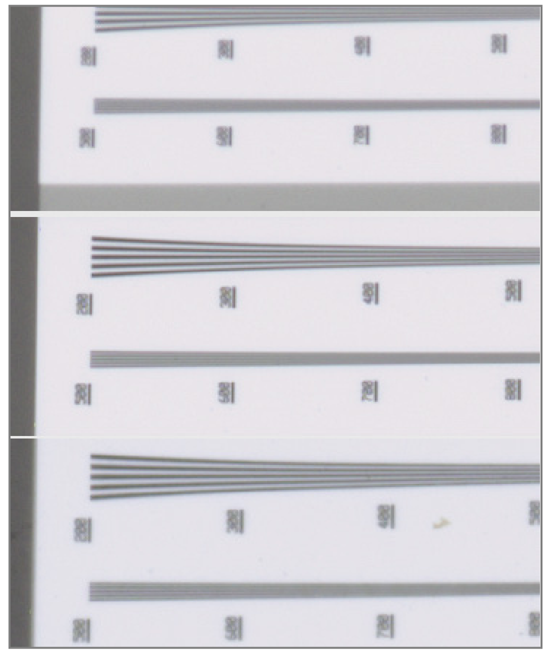

Figure 8*: Cropped test chart three regions corresponding to the edge-SFR result of Fig. 7. Top, center and bottom are from regions 1, 2 and 3, respectively.*

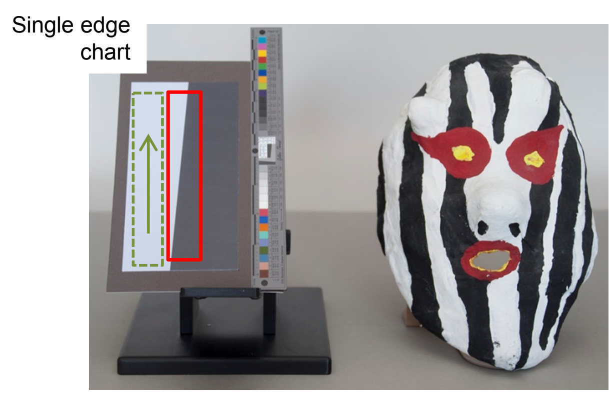

Figure 9*: Capture of a larger object using a single edge chart on left, for resolution and illumination evaluation*

This simplified test chart can also be used to evaluate the effective illumination variation. While it is often undesirable to have completely uniform, flat, illumination, it is important to have consistent illumination. This is particularly important for extended acquisition projects, and those with several imaging workstations.

The region indicated by the green, dashed-lined region of Fig. 9 was used to generate profile as a function of distance. The average image-signal level was computed for each pixel-row of the region. The resulting profile is show in Fig. 10, plotted versus object depth. Note that by simply plotting the profile as image pixel values, we can interpret the variation in the encoded color-space.

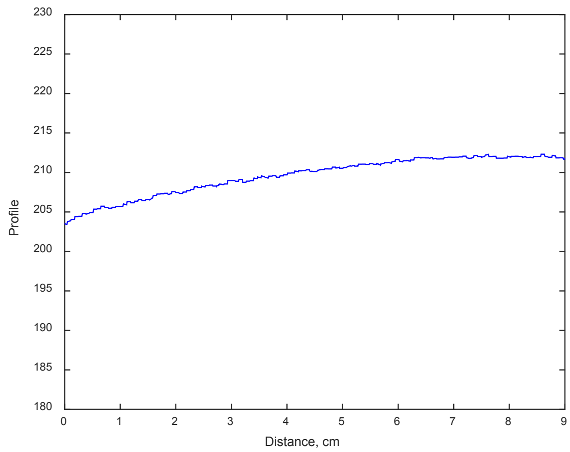

***Figure 10**: Illumination level profile measured from the left-hand side target region of Fig. 9, plotted versus object depth*

Conclusions

The monitoring of imaging performance is well-established and the subject of both imaging standards and guidelines for cultural heritage institutions. The emphasis has been on the imaging of flat objects. In this paper we address the task of automated imaging performance evaluation for digital collections where a perspective view is important. Our focus is on two aspects of imaging performance; image resolution, and uniformity of illumination over the scene/object space.

Using reference objects, such as test charts, it is possible to introduce both image- and object-level testing based in the three-dimensional space spanned by the objects to be photographed. We demonstrated the use of an adjustable test target holder. This can be introduced during normal operation of the imaging workstation, important for both system acceptance testing and quality assurance activities.

Our experience with both view- and DSLR cameras indicates that the evaluation and control of important characteristics, such as those tested, is achievable by adapting current methods. By adjusting and maintaining the location and orientation of test objects, the results of the corresponding analysis software can be interpreted similarly to those from near-flat collections.

Acknowledgements

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References

[1] M. Stelmach and D. Williams, When Good Scanning Goes Bad: A Case for Enabling Statistical Process Control in Image Digitizing Workflows, *Proc. Archiving Conf.,* IS&T, pg. 237-243, 2006
[2] P. D. Burns and D. Williams, Ten Tips for Maintaining Digital Image Quality, Proc. *Archiving 2007 Conf*., IS&T, 16-22, 2007
[3] Technical Guidelines for Digitizing Cultural Heritage Materials, Federal (US) Agencies Digital Guidelines Initiative, http://www.digitizationguidelines.gov/
[4] H. van Dormolen, Metamorfoze Preservation Imaging Guidelines, National Library of the Netherlands (KB), http://www.metamorfoze.nl/english/digitization
[5] P. D. Burns, Slanted-Edge MTF for Digital Camera and Scanner Analysis, *Proc. PICS Conf*., IS&T, pg. 135, 2000
[6] D. Williams and P. D. Burns, Evolution of Slanted Edge Gradient SFR Measurement*, Proc. SPIE Vol.* 9016, 901605*,* 2014
[7] Edmunds Optical Inc., DOF 5-15 Depth of Field Target, http://www.edmundoptics.com/
[8] H. M. Merklinger, Addendum to Focusing the View Camera, published by the author, Ottawa, Canada, 1993

Author Biographies

Peter Burns is a consultant supporting imaging system and service development, and related intellectual property efforts. Previously he worked for Carestream Health, Eastman Kodak and Xerox Corp. He is a frequent conference speaker, and teaches courses on these subjects.

Don Williams is founder of Image Science Associates, a digital imaging consulting and software group. Their work focuses on quantitative performance metrics for digital capture imaging devices, and imaging fidelity issues for the cultural heritage community. He has taught short courses for many years, contributes to several imaging standards activities, and is a member of the Advisory Board for the interagency US Federal Agencies Digitization Guidelines Initiative, FADGI.