

A camera-based approach for digitizing a large-scale photographic negative collection

Abstract

The University Archives at Texas State University contains an estimated 1.8 million photographic negatives. In 2017, the University Libraries were awarded a TexTreasures Grant, funded by the U.S. Institute of Museum and Library Services, from the Texas State Library and Archives Commission, to research and build custom capture stations and digitize an initial 6,000 negatives from the collection. In this comparative analysis, the authors present evidence that their camera-based system surpasses traditional scanners for photographic negative digitization. Major factors affecting equipment and workflow decisions are discussed.

Biographies

Jeremy D Moore is the Digital Media Specialist in the University Libraries' Digital & Web Services department and Lecturer in Photography in the School of Art & Design at Texas State University. Mr. Moore has over 20 years' experience in photography and a decade managing digitization labs and grant projects. Previously, he was the Digital Imaging Lab Manager in the University of North Texas's Digital Projects Unit.

Alkek Library, Texas State University, San Marcos, TX 78666 USA

Tel: +001 512 245 3719 E-mail: jeremy.moore@txstate.edu

Todd C Peters is Head of Digital & Web Services at Texas State University. In this capacity he manages digitization projects and his unit manages digital services such as Ezproxy, ILLiad, Dataverse, Dspace, Archivematica, and Sierra. In previous positions at Texas State he has managed overall technology for the library and provided reference services. Previously, he was the Assistant Government Documents & Electronic Resources Librarian at the University of Texas at Austin.

Alkek Library, Texas State University, San Marcos, TX 78666 USA

Keywords

digitization, photographic negatives, digital cameras, sampling efficiency, digital workflows

Background

Texas State University (TXST) is an Emerging Research University in San Marcos, Texas established in 1899. Located in central Texas within the Austin Metropolitan Area, TXST serves a diverse population of 38,694 students and offers 97 bachelor's, 92 master's, and 14 doctoral degree programs. The University Libraries' mission is to advance the teaching and research mission of the University and support students, faculty, staff, and the greater community. The Alkek Library is the main library on campus, contains more than 1.5 million printed volumes, and houses two special collections, the Wittliff Collections and the University Archives. The Wittliff Collections is home to the major papers of such notable authors as Cormac McCarthy and Sam Shepard, the *King of the Hill* archives, the *Lonesome Dove* miniseries collection, and the largest repository of modern and contemporary Mexican photography in the United States. The University Archives preserves and makes available unique sources of information about TXST and the surrounding communities.

In 2013, the University Libraries created a new Digital & Web Services (DWS) unit to focus on digitization. Initially focusing on material in the Wittliff Collections and the University Archives, the unit has digitized more than 378,000 objects. Completed projects include digitizing the complete 100-year run of the student yearbook and digitizing a 1555 copy of *La Relación*, Cabeza de Vaca's account of his years in the Americas. The unit also began digitizing some of the over 1 million negatives in the University Archives that were transferred from the University Marketing department and consist mostly of photographs from university athletics and photographs taken during production of the yearbook. The University Libraries joined Flickr Commons and began uploading images for public access¹, bringing attention to the capabilities of DWS and the University Archives.

In January 2016, the San Marcos Daily Record (SMDR) donated its archive of photographic negatives to the University Archives with permission to digitize and make available to the public. The collection spans approximately 70 years, from the mid 1930s to 2000s, and initial estimates place it at more than 800,000 negatives. Established in 1912, the SMDR has been the major chronicler of events for San Marcos and surrounding counties. The SMDR photographic negatives include photos published with news stories, as well as unpublished photos documenting both local history and regional news events and items of statewide and national interest. These photographic negatives are of interest to historians, researchers, and genealogists.

Problems During Large-Scale Negative Digitization

Initially, University Marketing negatives were scanned with a Nikon Super Coolscan 5000 ED slide scanner and an Epson 10000XL flatbed scanner, but facing a collection now over 1.8 million negatives, DWS decided to investigate other equipment and methods for digitization that would increase efficiency. To put this in perspective, digitizing 1 million negatives at a rate of 50,000 per year would take twenty years. Broken down on a frame-per-frame basis, efficiency is paramount at this scale; ten seconds per frame times 1 million frames is 2,778 hours, a total exceeding the hours worked by one full-time staff member in a single year. It was decided to build capture stations using cameras based on the experience of project staff and the collective advice of members of the professional imaging association ImageMuse². In 2017, the University Libraries were awarded a TexTreasures Grant, funded by the U.S. Institute of Museum and Library Services, from the Texas State Library and Archives Commission (TSLAC), to research and build custom capture stations and digitize an initial 6,000 negatives from the collection.

The authors report the successful completion of four goals set at the beginning of the year-long grant process. The first goal was the digitization of the 6,000 oldest negatives from the SMDR collection as they were considered most at-risk by the University Archives. These 6,000 negatives were more challenging to digitize than modern negatives due to larger variations in exposure and chemical processing on a frame-by-frame and roll-by-roll basis. The second goal was breaking the digitization process down into discrete steps so work could

be separated into batches, technicians trained in stages, and focus maintained on what is most important during each step. For example, prioritizing the safe handling of physical film over digital manipulations during capture and performing tonal adjustments separately from digital dirt and scratches removal.

The third goal, making the digitization process more active and engaging to increase job satisfaction, is closely connected to the fourth goal, increasing the rate of capture at the same level of quality compared to DWS's scanners. While researching various film negative digitization methods, DWS technicians were informally surveyed and reported the most frustrating part of the digitization process to be waiting more than 30 seconds for a computer or scanner to complete a step that could not be batched together because of its impact on workflow rhythm. When work can be batched together, technicians can schedule and take breaks when they run these longer processes. The legacy equipment's extended scan times meant technicians spent most of their time watching a progress bar fill up on a computer monitor, therefore decreasing the time to capture each negative would increase overall throughput and staff morale.

Traditional Film Scanner Technology

As background, there are three types of traditional scanners that can capture film negatives: drum scanners, slide scanners, and flatbed scanners. With a drum scanner, the negative is wet-mounted to a drum using oil then spun around a central light while the scanner's photomultiplier tube reads the light levels. Because each negative must be soaked in oil and spun at high speeds, these scanners are better used to scan individual frames at exceedingly high-quality by an experienced technician and are not conducive to a production environment staffed with novices. With a slide scanner, the negative is placed in a film holder that is loaded into the machine then mechanically moved between a light and a charge-coupled device, or CCD. The CCD contains 3 rows of sensors, each with a color filter red, green, or blue. A slide scanner can only scan film sizes allowed by the size of its sensor and film holders; Hasselblad is the only manufacturer who currently makes a slide scanner that will scan negative sizes up to and including 4x5 in. film. With a flatbed scanner, the negative is loaded into a film holder, this holder is placed onto a glass platen, and a scanner lid with a light in it

is closed over the holder. Under the film carrier, below the glass platen, a CCD moves to capture the light being shined through the negative from the light in the lid above. A flatbed scanner, like a slide scanner, is limited by the size of its sensor and the film holders available, though simple film holders can often be made for flatbed scanners out of acid-free board and glass, if necessary.

Camera-Based Film Scanning Considerations

In comparison, a camera-based station will require, at the minimum, a light source, film support, digital camera, camera lens, and camera support. The light source must evenly illuminate the largest film size it will be used to digitize. Film does not naturally lie flat and this curl increases when heated³ so less heat per lumen is better. The film holders must hold the film flat during exposure and be compatible with the sizes being digitized. The most common films in the University Archives' collection are modern 35mm and 6x6 cm roll films, but the oldest negatives also include much larger 4x5 in. sheet film, obsolete formats, such as 4x4 cm and 3.25x4.25 in., and even frames that were physically cut down to non-standard shapes and sizes. The variety of sizes is important because glassless holders are traditionally made for a specific film size and one will be necessary for each size being digitized. Without glass to compress the film, glassless holders can only squeeze at the edges so the film will bow in the center. A glass holder will keep film flatter and can be used with any size film that physically fits, but this increased flatness and flexibility come at the expense of added fragility and additional surfaces to clean, plus the possibility of a phenomenon known as Newton's rings occurring. Newton's rings are interference patterns caused by the reflection of light between two surfaces, in this case, film and glass, that appear as an unsightly series of irregularly-shaped concentric rings of alternating light and dark tones. Specially etched anti-Newton glass can be employed in contact with the shinier, base side of the film to reduce the probability of rings appearing⁴.

To capture a variety of sizes and output a preservation image in accordance with an organization's local standards, for example, at least 5,000 pixels on the longest side, a digital camera's sampling frequency must exceed the stated minimum pixel count and the lens must be focusable over a range of close-up distances that

the camera support can accommodate. Most lenses are not capable of focusing closely enough to capture a field-of-view on the image sensor at a reproduction ratio near 1:1, where 1 cm² of real subject area is captured by 1 cm² of the imaging sensor, so a specialized macro lens or bellows-system is necessary. The entire system must remain steady, without jars or vibrations, as the imaging sensor is exposed to light or fine details will blur and resolution will decrease. Sturdy camera, film, and overall system support (e.g. table or desk) plus a bright light source to shorten minimum exposure times can lessen the impact of vibrations. It should be noted that some locations and work schedules may not be suitable for capturing high-resolution images due to environmental and architectural factors such as proximity to heavily trafficked areas or building shake from construction or inclement weather⁵. Technicians also seem to be more aware of possible operator-induced movements, such as leaning on a desk or tapping their foot, when they are trained to physically move back from the capture station and use a foot pedal to remotely trigger the camera to take a picture.

While most modern digital cameras can take and save many pictures for download to a computer later, not all makes and models can be tethered, or connected, to a computer during capture, which can greatly improve the digitization experience. When a picture is taken, instead of being saved to the camera, the image file is downloaded over a wired or wireless connection to the computer where it can be viewed on a computer monitor and post-processed. Image quality is more quickly and easily verified with a large, color-accurate monitor and the tools provided by advanced capture software than using feedback from the camera alone, speeding both setup and production. Problems caught during production can be immediately fixed and a new capture made while the negative is still loaded in the film holder, increasing efficiency and reducing handling of the materials. Most camera settings can be adjusted from the computer resulting in less physical handling of the camera, which could knock the system out of alignment or introduce vibrations

Capture Station Equipment⁶

For their system, the authors mounted a Sony Alpha a7R II mirrorless digital camera with 42 megapixel Full-Frame 35mm Exmor R BSI CMOS Sensor and Sony FE 90mm f/2.8 Macro G OSS lens on a Kaiser RSD

motorized copy stand connected to a Dell Alienware computer tower. The Dell tower contains a 4+ GHz Intel i7 quad-processor with 32 GB of RAM, 8 GB NVIDIA graphic processing unit (GPU), and fast SSD hard drive alongside a slower, spinning-disk data drive for local backups. The Kaiser RSD motorized copy stand has a column height of 120 cm and supports a maximum payload of 8 kg. Its camera mounting arm is raised and lowered by electronic push-button, so technicians are not physically manipulating anything that could affect stability and the power can be turned off to avoid accidental changes in camera height. The Sony macro lens focuses closely enough to produce a 1:1 reproduction ratio, incorporates aspherical, ED, and Super ED glass elements to correctly focus color in a flat-field, and has a Nano AR lens coating to dramatically reduce contrast-robbing flare. It uses an electronic motor to focus that is unaffected by gravity so, once set, focus will not drift while the camera is mounted with the lens pointing straight down.

Camera Selection Rationale

The Sony Alpha a7R II mirrorless digital camera was selected because of its expected shutter life and ease-of-use on a copy stand for film digitization. Acknowledging the large number of negatives to digitize, the Sony's expected shutter life of 500,000 cycles⁷ more than triples that of comparable models, like the Canon 5Ds digital single lens (DSLR) camera rated at 150,000 cycles⁸. As a mirrorless camera, the a7R II lacks a physical mirror that must lift up and move out of the way as on the more common DSLR cameras, reducing vibration during exposure. While many advanced DSLR cameras feature a mode whereby the user can lock the mirror up and out of the way so they function much like a mirrorless camera, their capture systems are still more complex by necessity due to the mirror's presence possibly making them more prone to failure. The a7R II's focal plane shutter uses two mechanical shutter curtains to block the imaging sensor from light exposure, but an electronic front shutter curtain can be used instead so the only camera part moving during exposure is the rear mechanical curtain. Much like modern smartphones, the a7R II has a live view of the imaging sensor it displays on a high-resolution screen on the back of the camera. This LCD screen also articulates 90 degrees, so while the camera is mounted on the copy stand pointing straight down the screen can be flipped up and viewed from the front as seen in Figure 1. This view can then be zoomed from 1x to 5x to 12.5x on the LCD screen by pressing a button

on the camera to aid in setting up the system and verifying focus, as shown in Figures 2A, 2B, and 2C, respectively.

Using Zebra Stripes for Rapid Exposure Adjustment

The earliest SMDR negatives were incredibly varied in density necessitating significant adjustments by the technician for each frame. This conflicted with needing the system to be simple enough for a novice digital technician to successfully perform without an extensive background in digitization or photography. Thanks to the hybridization of digital cameras to shoot video in addition to still photographs, Sony included an exposure aid in the a7R II called zebra stripes (or zebra patterning) that has long been a feature on video cameras. After turning zebras on, blinking stripes appear on the camera's LCD screen overlaid on any area in the scene that is over-exposed according to menu settings. As the shutter speed is adjusted up or down, zebra stripes appear and disappear in relation to how the scene is exposed in real-time, providing a visual feedback loop to adjust exposure without needing to take a picture, inspect the digital file, tweak settings, and repeat. With the settings used by DWS, acceptable exposure for most negatives is when there are slight zebra stripes appearing in the live image, but there is a bit of latitude in the system. Figure 3A depicts an image with too many zebras as the image cannot be seen; the shutter speed is too slow and the camera is letting in too much light. In Figure 3B, zebras are not visible anywhere; the shutter speed is too fast so not enough light is hitting the sensor. In Figure 3C, zebras are beginning to appear in the image so $1/20^{\text{th}}$ of a second is an acceptable exposure for the displayed negative.

Production Workflow

Building on this novel exposure method, the authors developed a production workflow using Capture One Pro and Adobe Photoshop. With the camera tethered to a computer running Capture One Pro, images are

made in a proprietary Sony .ARW raw image file format, tones are adjusted, and the image is cropped before final output. To adjust tones, an Auto-Levels algorithm is used in combination with custom Shadow and Highlight alert settings that make over-processed pixels turn bright green or red on the screen as white and black levels are manually adjusted until no green or red pixels exist in the image. In accordance with the United States government's Federal Agencies Digital Guidelines Initiative's (FADGI) 2016 guidelines for digitizing cultural heritage materials, the alerts were set to change when pixel values fall outside of the range 5 – 250, as measured in an 8-bit color space⁹. A properly captured and processed image will therefore not contain any areas of pure black or white ensuring image detail is not clipped in the shadows or highlights.

This semi-automated system has worked for the vast majority of images digitized so far, though many night photographs and heavily damaged or stained negatives have required time-intensive manual adjustments. After capture and post-processing, two image files are output for each negative. The first is a full-size, 16-bit, uncompressed TIFF and the second is a 1,500 pixels-on-the-longest-side, 8-bit, LZW-compressed TIFF; both images are in the Gray Gamma 2.2 color space. The full-size image is moved to a storage repository¹⁰ for preservation, while the smaller image will be lightly “cleaned” in Adobe Photoshop and converted to an sRGB color JPEG before delivery to University Archives for metadata and upload to a dedicated Flickr account¹¹. Because tethered negative capture, post-capture processing in Capture One Pro, and digitally cleaning a web-sized image in Adobe Photoshop are discrete steps, they can be split among multiple technicians using different computers and increase production.

Comparison of New and Old Methods

To measure the improvements of their camera-based system over legacy equipment, the authors compared them using three different methods and two different sizes of film. The first method looked at the average time per frame to load film, capture it, and save a full-size, preservation image to a network drive. The second was a visual comparison of the same negative digitized on new and old equipment. The final method

used MSCAN 3.2 Analysis software with scans of Image Science Associates' 35mm Preservation Microfilm Targets (PMT)¹² to determine a system's sampling efficiency.

35mm Film Scans Compared

Digital captures of 35mm film were made with the camera-based system, a Nikon Super Coolscan 5000 ED slide scanner, and an Epson 10000XL flatbed scanner at similar sampling frequencies for comparison. The Sony, at 66 seconds was the quickest capture method by far, performing at twice the speed of the Nikon at 135 seconds and over five times more quickly than the Epson flatbed, which clocked in at 352 seconds, or nearly six minutes. The white box in Figure 4-A depicts the location and size of the 2.54 mm² (0.1 in²) cropped areas compared in Figures 4-B, 4-C, and 4-D. The Nikon close-up shows how its collimated light source exacerbates dust and grain in black and white negatives. The Sony image is larger due to capturing 4,213 pixels per inch compared to 4,000 with the other two. The Epson's blurry results are due to scanning at a higher resolution than can be captured by the scanner's optics. The white box and arrow in Figure 5-A point out the location and size of the 1.27 mm² (0.05 in²) cropped areas compared in Figures 5-B, 5-C, and 5-D. The Nikon and Epson both show banding, in the vertical and horizontal axes respectively, due to the motion of the scanner during capture.

Table 1 contains the samplings on film, effective resolutions in the horizontal and vertical directions, average effective resolutions, and sampling efficiencies as calculated by MSCAN 3.2 Analysis software. Sampling frequency, as expressed in pixels per inch (ppi) specifies the quantity of data collected. The sampling efficiency is the ratio of the effective resolution to the sampling frequency. The camera-based system outperforms both the Nikon and Epson scanners. The vertical banding pointed out in Figure 5-B is reflected by the Nikon's drop in effective horizontal resolution (the PMT target is analyzed perpendicular to the orientation of the example negative). Same as the Nikon, the Epson exhibits a large dip in one axis of effective resolution due to banding.

3.25x4.25 in. Film Scans Compared

Because the Nikon scanner is limited to 35mm film, comparisons with 3.25x4.25 in. film were only made with the camera-based system and Epson 10000XL flatbed scanner. The Epson takes 3 minutes to scan 3.25x4.25 in. film at a sampling frequency comparable to that captured by the Sony a7R II; to be clear, 3 minutes is the time it takes the scanner to physically scan across the film at high resolution and does not include cleaning the scanner or film, loading or unloading the film, pre-scanning, or saving the scan. In comparison, a frame can be loaded, captured, and unloaded in an average of 2.5 minutes with the Sony a7R II. The white box in Figure 6-A shows the cropped area compared in Figures 6-B, 6-C, and 6-D. While closer in appearance than the 35mm scans, the Epson scan is still visibly softer than the Sony capture. Using Adobe Photoshop to apply an unsharp mask with settings of Amount 200%, Radius 1.3, and Threshold 3, the authors were able to improve the Epson's appearance of sharpness and increased its sampling efficiency to match the Sony's as seen in Table 2. The black arrow in Figure 7 points to where the Epson scan plus unsharp mask's SFR value exceeds 100%, which is indicative of excessive sharpening leading to haloes at dark and light transitions, in other words the sharpening introduces visual artifacts¹³. Finally, while glass was necessary to flatten the 3.25x4.25 in. negative on the Epson flatbed, doing so without Newton's rings was challenging as evidenced by Figure 8-A and details 8-B, 8-C, 8D, and 8-E (the glass used was specially etched anti-Newton glass).

Conclusions

In conclusion, this article has focused on the most essential factors and features credited for the successful development of a custom capture system to digitize black and white film negatives. While someone with little or no experience can be trained to operate a camera-based station, the authors want to caution that developing and maintaining such equipment will require substantial photographic expertise. With an eye to the future, the system is considered a work-in-progress and the authors are always looking for ways to tweak and improve its speed, quality, and utility, such as a current project combining it with LED light panels on light stands to photograph reflective documents. Other workflow additions include a geared tripod head used in concert with Capture One Pro's Focus Mask feature to assist the operator in aligning the system for maximum quality and a custom application to auto-crop captures and update a settings file so the crop is reflected in the

Sony .ARW raw file. In early August 2018, a recently trained student technician completed a patron request order for the University Archives in record time by digitizing 1,287 negatives in a single, 25-hour work week. As of August 2018, images created by DWS for the TXST University Archives from film negatives have been viewed over 1.7 million times on Flickr.

Acknowledgements

The authors want to thank the Texas State Library and Archives for their financial support and recognize the work of project staff Megan North, Jason Long, and Erin Mazzei, graduate research assistants Lindsey Waldenberg and Wenlan Cai, and student imaging technicians Grayson Ellsworth, Rebecca Jenson, Oscar Martinez, Vicente Rangel, Luke Sebree, Yosdy Valdivia, Austin Villacis, and Ashton Woodward.

References

1. University Archives. Texas State University Flickr Commons's albums | Flickr [Internet]. Yahoo!; 2015 Aug [cited 2018 Aug 1]. Available from: <https://www.flickr.com/photos/txstate-library/albums/>.
2. ImageMuse [Internet]. ImageMuse; 2007 Jun [cited 2018 Aug 1]. Available from: <http://imagemuse.org>.
3. Lambrecht, R, Woodhouse, C. Way Beyond Monochrome 2e. Focal Press; 2010.
4. Ibid.
5. The authors recently tested several potential sites for a relocation of the digital studio and reported their results on a departmental blog: <http://digitalcollections.wp.txstate.edu/2018/02/26/testing-long-exposures-in-different-environments/>.
6. Capture Station Equipment Mentioned in Article:
 - Kaiser RSD Motorized Copy Stand
 - Sony Alpha a7R II mirrorless digital camera
 - Sony FE 90mm f/2.8 Macro G OSS camera lens
 - Dell Alienware Aurora Desktop (Windows 10, 4.0+ GHz Intel i7 quad-core processor, 32 GB RAM, 0.5 – 1 TB SSD hard drive, 8 GB NVIDIA GPU)

- Capture One Pro 10 Software
 - Adobe PhotoShop CC 2015 Software
 - Image Science Associates' 35mm Preservation Microfilm Target with MSCAN 3.2 Analysis Software
7. ILCE-7RM2 Specifications | Cameras | Sony UK [Internet]. Sony Europe Limited; 2015 Jun [cited 2018 Aug 1]. Available from: <https://www.sony.co.uk/electronics/interchangeable-lens-cameras/ilce-7rm2/specifications#features>.
 8. Press Release Details [Internet]. Canon U.S.A., Inc.; 2015 Feb 5 [cited 2018 Aug 1]. Available from: https://www.usa.canon.com/internet/portal/us/home/about/newsroom/press-releases/press-release-details/2015/20150205_eos5dsr_pressreleasedata/20150205_eos5dsr_pressreleasedata.
 9. Rieger, T, editor. Technical Guidelines for Digitizing Cultural Heritage Materials: Creation of Raster Image Files [document from Internet]. Federal Agencies Digital Guidelines Initiative; 2016 Sep [cited 2018 Aug 1]. Available from: http://www.digitizationguidelines.gov/guidelines/FADGI%20Federal%20%20Agencies%20Digital%20Guidelines%20Initiative-2016%20Final_rev1.pdf.
 10. Preservation masters are saved to an Isilon storage array centrally managed by the university data center. The TXST library is currently implementing Archivematica which will become the final repository for preservation masters.
 11. University Archives. San Marcos Daily Record Negatives | Flickr [Internet]. Yahoo!; 2017 Sep [cited 2018 Aug 1]. Available from: <https://www.flickr.com/photos/txstate-smdr/>.
 12. Image Science Associates: Microfilm Preservation Targets [Internet]. Image Science Associates, LLC; 2010 Jan [cited 2018 Aug 1]. Available from: http://www.imagescienceassociates.com/mm5/merchant.mvc?Screen=PROD&Store_Code=ISA001&Product_Code=MPT&Category_Code=TARGETS.
 13. Burns, Peter. Preservation Microfilm Scanner Target and Imaging Performance Software (Mscan) User Guide Version 2.0 [document from Internet]. Image Science Associates, LLC; 2010 May 25

[cited 2018 Aug 1]. Available from:

<http://www.imagescienceassociates.com/mm5/software/PreservationMicrofilmUserGuide2.pdf>.

Figures

Figure 1: Camera-based negative capture station

Figure 2: Focus verification **A.** 1X zoom **B.** 5X zoom **C.** 12.5X zoom

Figure 3: Exposure verification with zebra stripes **A.** Too much light exposure **B.** Not enough light exposure **C.** Acceptable exposure

Figure 4: Visual comparison of capture methods at 100% **A.** location of cropped sample **B.** Nikon Super Coolscan 5000 ED **C.** Sony a7R II **D.** Epson 10000XL

Figure 5: Visual comparison of capture methods at 200% and 100% **A.** location of cropped sample **B.** Nikon Super Coolscan 5000 ED **C.** Sony a7R II **D.** Epson 10000XL

Figure 6: Visual comparison of capture methods at 100% **A.** location of cropped sample **B.** Epson 10000XL **C.** Sony a7R II **D.** Epson 10000XL with sharpening applied

Figure 7: Spatial Frequency Response (SFR) for Epson 10000XL flatbed scanner with unsharp mask exceeds 100%

Figure 8: Newton's rings evident on Epson 10000XL with flattening, anti-Newton glass **A.** full image **B – E.** details with contrast increased for easier visibility

Tables

Table 1: Sampling efficiencies for 35mm film determined by MSCAN 3.2 software analysis of Preservation Microfilm Targets

Capture Method	Sampling Frequency (ppi)	Effective Horizontal Resolution (ppi)	Effective Vertical Resolution (ppi)	Effective Average Resolution (ppi)	Sampling Efficiency
Nikon	3987.2	2600.2	3410.1	3000.6	75%
Sony	4213.0	4100.4	4123.6	4112.0	96.5%
Epson	3996.3	2000.4	1679.8	1840.1	46.0%

Table 2: Sampling efficiencies for 3.25x4.25 in. film determined by MSCAN 3.2 software analysis of Preservation Microfilm Targets

Capture Method	Sampling Frequency (ppi)	Effective Horizontal Resolution (ppi)	Effective Vertical Resolution (ppi)	Effective Average Resolution (ppi)	Sampling Efficiency
Epson	1588.2	1454.5	1338.4	1396.5	87.3%
Sony	1586.2	1581.3	1591.0	1586.2	100.0%
Epson + unsharp mask*	1589.5	1588.0	1591.0	1589.5	100.0%

* Unsharp mask done in Adobe Photoshop CC 2015 with settings Amount 200%, Radius 1.3, and Threshold 3

Figure 1.

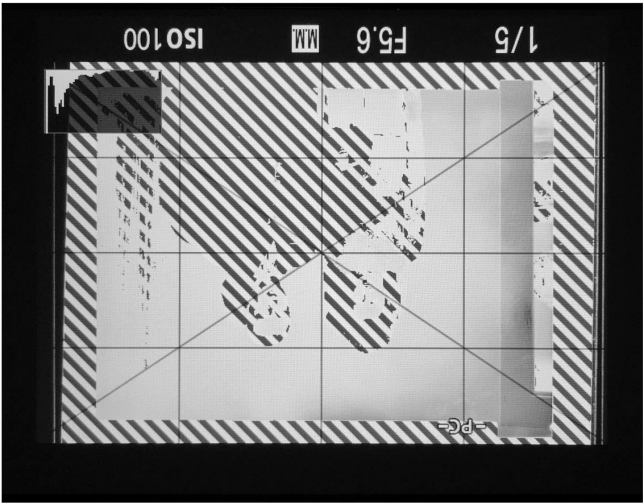


Figure 2.

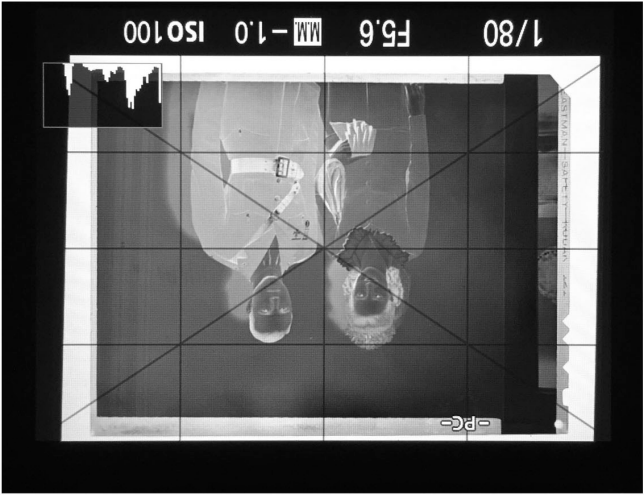


Figure 3.

A



B



C

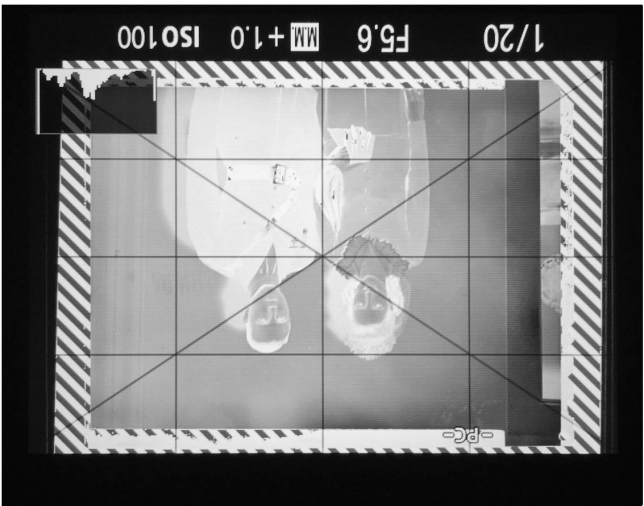


Figure 4.

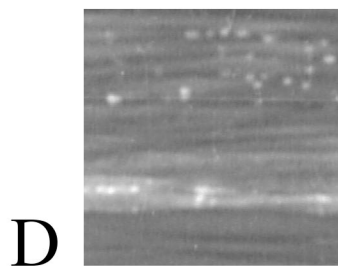
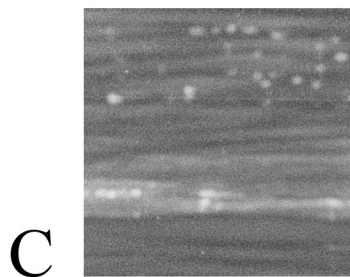
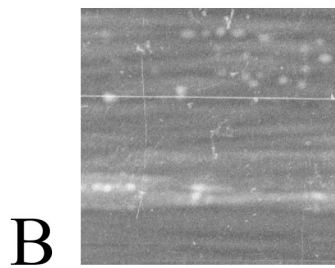


Figure 5.

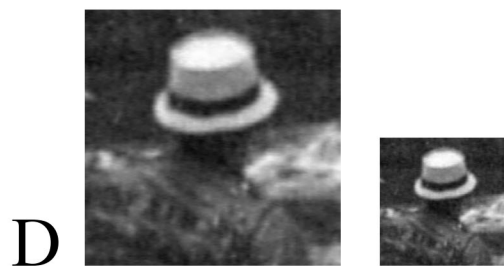
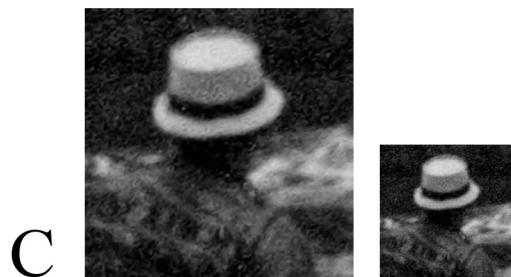
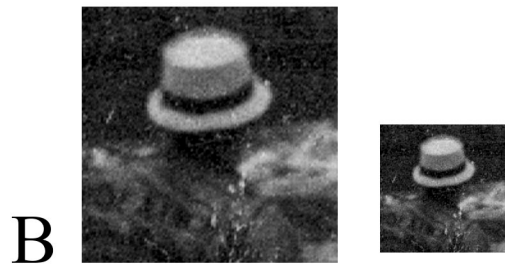


Figure 6.

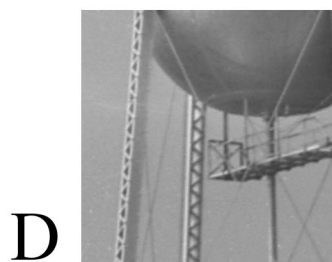
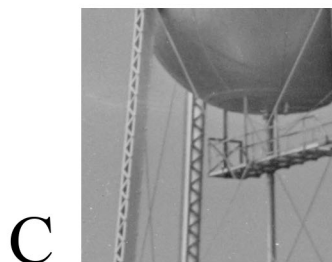
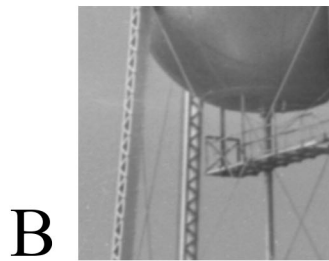


Figure 7.

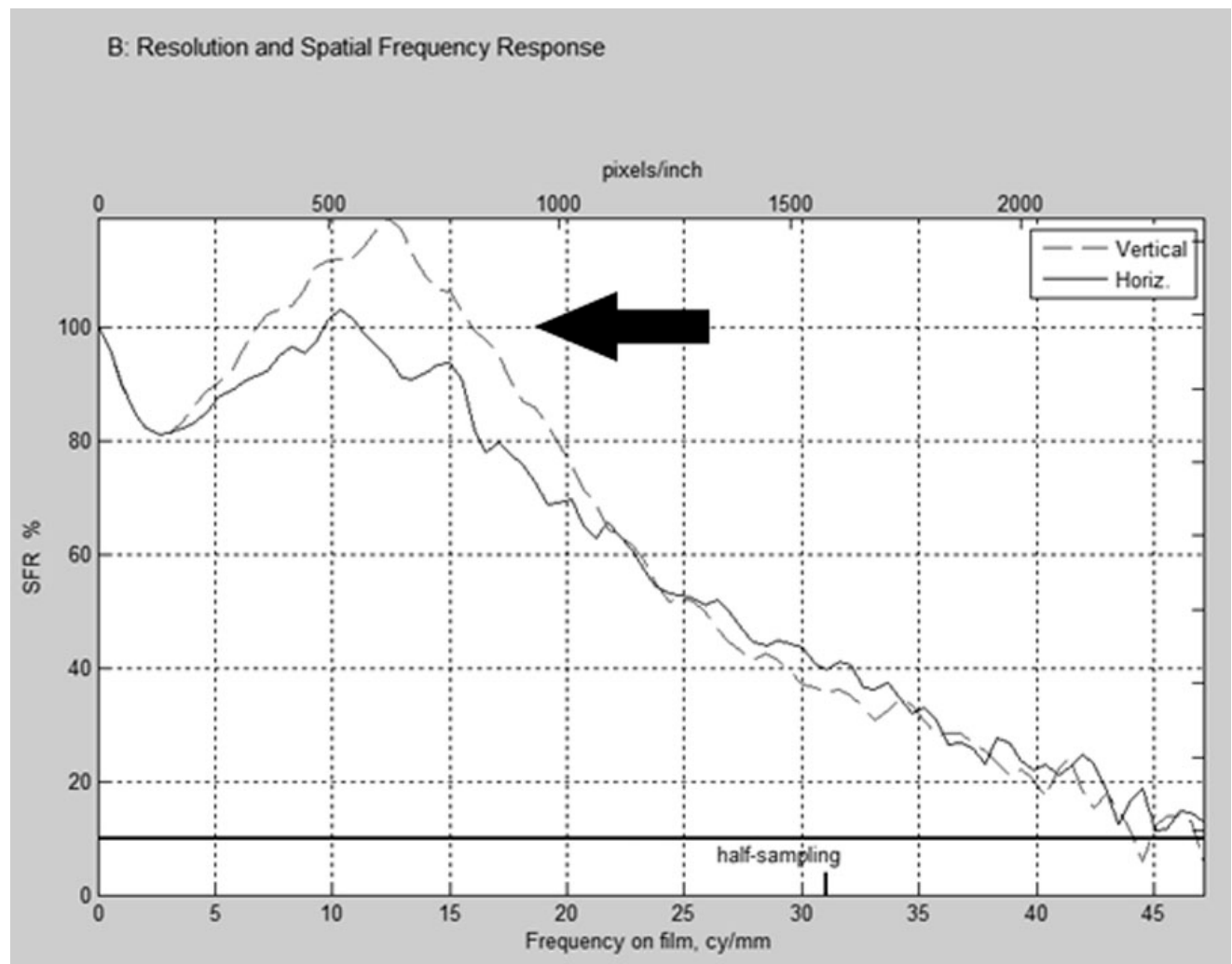


Figure 8.

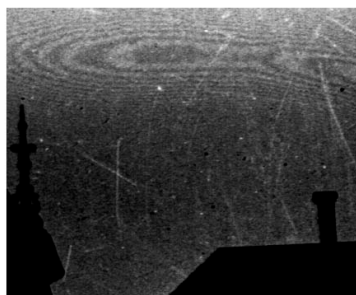
A



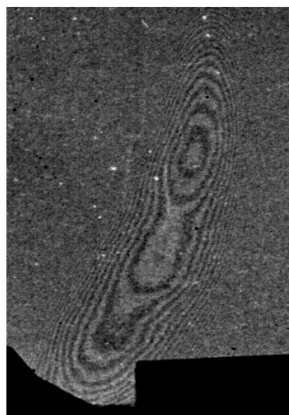
B



C



D



E

