

Automating 35mm Photographic Film Digitization: X-Y Table Capture System Design and Assessment

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Abstract

35mm still image formats are some of the most abundant photographic film types in cultural heritage collections. However, their special handling needs coupled with high resolution digital capture requirements have traditionally posed logistical constraints with regard to the formats' digitization at scale. Through the use of a programmable X-Y table camera capture system, both slide and strip 35mm photographic film can be digitized in an automated fashion following Federal Agencies Digitization Guidelines (FADGI).

Introduction

35mm film is one of the most commonly collected formats in cultural heritage archives. These collections can range into the hundreds of thousands of images and span multiple types of institutions [1] [2] [3] [4]. Two of the main hurdles that have challenged imaging studios and labs in digitizing such formats at scale have been the film's careful, deliberate handling needs coupled with more rigorous digital imaging guidelines over time [5]. In turn, increasing acceptance thresholds for resolution and tightening tolerances for image quality metrics such as SFR, noise, and sharpening ranges can slow throughput rates considerably in traditional capture workflows.

Automated System Design

One option to increase capture speed while maintaining high image quality metrics is to use a medium-sized programmable X-Y copy table. Working with designer, Ulsaker Studio, the University of Connecticut Library's Digital Imaging Lab put its automated system into production during the summer of 2019.



Figure 1. University of Connecticut Library Digital Imaging Lab X-Y Table.

Together the camera and table system can operate in three modes based upon the physical format in need of digitization and its condition. These modes include fully automatic, semi-automatic, and manual. Table movements are belt-driven by two OpenBuilds High Torque Series stepper motors. These are programmed by a single Cognysis Stackshot 3X controller which also automates synchronized camera triggering.

Currently the system employs a Kaiser Prolite light source, custom film holder mount, and Canon EOS 5DsR 50MP camera. Mated to the camera is either a Canon EF 100mm f/2.8 Macro or Zeiss Milvus 100mm F/2M lens depending upon the operator's chosen shooting mode. However, because the system is consciously modular and open in its basic design, elements such as camera, optics, and film holders can all be easily swapped out and replaced over time as new imaging technologies evolve and additional funding becomes available. Among other applications besides film work, the system can also shoot oversized flat objects as large as 30" x 40" in size and capture them at high resolutions through automated photo merging.

Throughput Speed Comparisons

Soon after the X-Y system was configured and made operational, capture speed tests were conducted that compared the table's full auto and semi-auto modes with that of an Epson V500 photo scanner. Tests were conducted on 35mm mounted slide film captured at 3,500 ppi in color.

Capture Method	Average Capture Time Per Slide	Capture Rate
X-Y Table Full Auto	9 seconds	6.7 slides/min.
X-Y Table Semi-Auto	18 seconds	3.3 slides/min.
X-Y Table Manual	24 seconds	2.5 slides/min.
Epson V-500 Scanner	163 seconds	.37 slides/min.

Figure 2. Capture throughput comparison among various X-Y Table System modes and Epson V-500 Film Scanner. 35mm mounted slide film sampled at 3,500 ppi, color.

The X-Y table system's automatic and semi-automatic mode timings were conducted with the Canon 5DsR and Canon EF 100mm f/2.8 Macro lens set to autofocus. For manual mode table testing, the Zeiss Milvus 100mm F/2M's manual focus lens was utilized.

In full auto mode, the X-Y system, once programmed and started by the operator, automatically moves the table to the center of the first slide in the carrier. It then locks the camera mirror in the up position, autofocuses the lens, trips the shutter, and then moves the table to the next slide's center where the entire process repeats itself until all 15 slides are shot in a grid pattern.

Semi-auto mode requires the operator to incrementally re-start the table so it may move to its next pre-programmed X/Y address through the Cognysis controller. From there, the photographer initiates auto focus using camera tethering software and live view display at the workstation before each subsequent shot in the pre-programmed sequence [6].

The X-Y system's manual mode eliminates the autofocus step and instead requires the operator to manually focus using live view, then incrementally re-starting the table to its next position. Finally, during similar trials, the Epson V-500 was run with VueScan scanner software which was set to automatically autofocus before each scanned slide.

The X-Y system's capture speed per slide was calculated by dividing the total time taken for a full capture run by the total capacity of a device's given film carrier. As a result, these rates represent the entire system's speed which includes all of the steps previously described. A 15 slide carrier was used with the X-Y system (Fig 1), while a 4 slide carrier was used with the Epson V-500 (its maximum capacity). The Epson 10000 XL scanner was also considered for testing since it can also accommodate a 15 slide carrier. However, this device can only sample at a maximum rate of 2,400 ppi. The current FADGI 4 star acceptance level for limiting resolution for 35mm film format capture is 4,000 ppi.

General System Performance

Image quality evaluations were made of the Canon EF 100mm f/2.8 Macro and Zeiss Milvus 100mm F/2M lenses to compare each on overall X-Y system performance. The Canon lens offers autofocus capability and currently retails for \$599 USD [7]. The Zeiss is manual-focus-only and at present sells for \$1,850 USD [8]. Image Science Associates' 35mm standard black and white film target and GoldenThread v.6.14.0 software were used in objective data gathering and analysis.

Both lenses were set at near infinity focus while focusing on the film target's center region. Shooting distance, measured from the lens' front element to the subject, was 6.75 inches and 7.25 inches for the Zeiss and Canon respectively. Unlike the true 1:1 Canon macro, the 1:2 Zeiss lens was fitted with two stacked Canon EF 12 II extension tubes to allow for comparable close focus and captured pixel dimensions to the Canon.

Test images were single shot with the Canon 5DsR 50MP camera at 1/13 second shutter speed, f/9.0 aperture, ISO 100. Resulting Canon .cr2 raw files were first processed as black and white positives and cropped to the same 3,674 px x 5,669 px dimensions in Adobe Lightroom v.7.5 (Win 10). Uncompressed TIFF files were then exported from the application using individual tone curve and sharpening adjustments that followed tolerance ranges as defined in the FADGI guidelines. Such refinements emulate similar processing used by the Library of Congress in acceptance testing of their own film capture systems [9].

With these capture parameters in place, it was anticipated that the X-Y system could capture single shots at roughly 3,500 ppi, which falls midway between 3 and 4 star FADGI performance levels for limiting resolution. Subsequent GoldenThread analysis of target images shot during trials confirmed that the system could indeed resolve 3,500 ppi on average across the image field with a sampling efficiency of 93% for each lens [10].

System Performance in Detail

Despite similarities between the two lenses in terms of their influence on averaged limiting resolution metrics, there were differences in some of the more granular details of image quality analysis. Image Science Associates' 35mm standard black and white film target includes horizontal and vertical slanted edge features not only in the center of the target but also closer to its four corners. With the target filling the test image field, slanted edge gradient analysis which is commonly used in calculating Signal Frequency Response (SFR) could be conducted not only in a given lens' center region but also towards its edges.

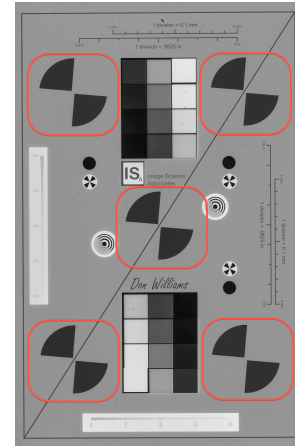


Figure 3. Image Science Associates 35mm Standard Black and White Film Target with slanted edge features outlined in red.

The Zeiss was found to out-perform the Canon with regard to maintaining consistently high optical resolution across the field of view. These findings corroborate previous independent MTF tests of the Canon and the older Zeiss Makro-Planar 100mm f/2.0 which shares its basic optical design with the newer Zeiss Milvus version used in this study [11] [12] [13].

SFR is a fundamental resolution metric described in a number of international standards (e.g. ISO 12233, 15529). The spatial frequency associated with the 10% SFR response is considered a threshold value for limiting spatial resolution. It is also a powerful tool for identifying and quantifying additional imaging characteristics such as sharpening and flare through the 50% SFR level spatial frequency [14] [15].

A more detailed look at the 10% SFR results show that the Canon did well on average but was found to be 1% below the 3,500 ppi acceptance threshold in the bottom left corner of its field of view as measured against the horizontal slanted edge feature. 50% SFR values on the other hand all fell within the FADGI 4 star tolerance range. 50% SFR numbers that exceed the tolerance range's upper limit are indicators of over-sharpened images, while values less than the range's lower limit can signal the presence of flare.

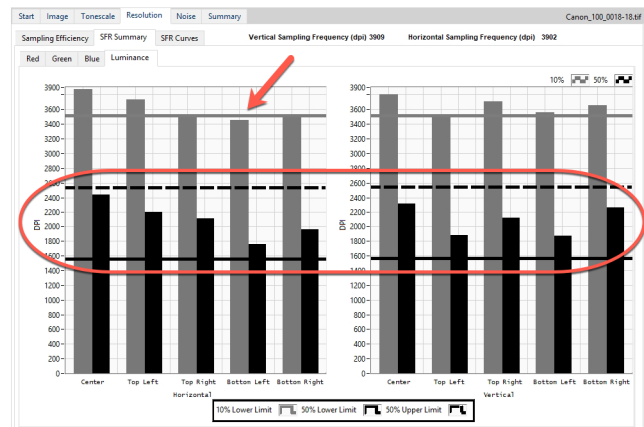


Figure 4. SFR summary of the Canon EF 100mm f/2.8 Macro. Red arrow points to SFR falling 1% below 3,500 ppi acceptance threshold in the lens' bottom left corner. Red outline indicates 50% SFR performance within FADGI 4 star range for all sampled locations.

The Zeiss showed minimal quality drop off in its corners and was more optically consistent overall than the Canon. 10% SFR results met the 3,500 ppi threshold throughout all sampled areas of the lens' field of view. Like the Canon, 50% SFR values all fell within the FADGI 4 star tolerance range.

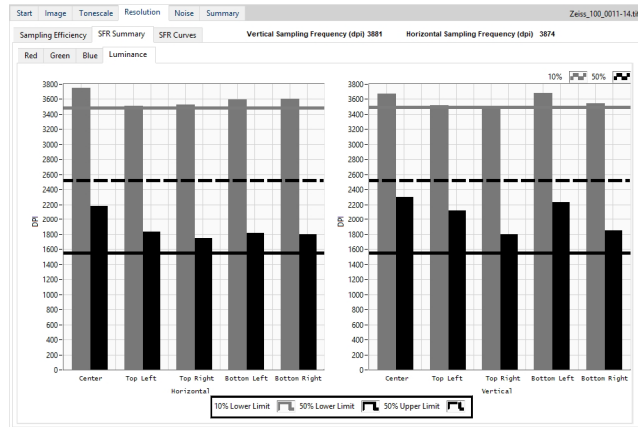


Figure 5. SFR summary of the Zeiss Milvus 100mm F/2M. Note 10% SFR consistency across all sampled image field coordinates and 3,500 ppi acceptance threshold being met. 50% SFR lens performance also within FADGI 4 star tolerance range.

Comparative SFR curves for each lens similarly represent these same findings, particularly with the Canon's somewhat wider spread among individual sample regions which point to its greater optical variability. In addition, the curves also illustrate how maximum SFR amplitude levels clearly remain ≤ 1 which meet FADGI 4 star acceptance for sharpening.

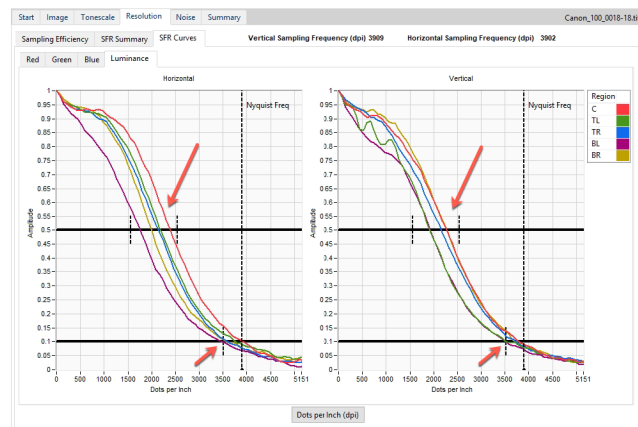


Figure 6. SFR curves for the Canon EF 100mm f/2.8 Macro. Top arrows point to 50% SFR tolerance range. Bottom arrows point to 10% SFR values (limiting spatial resolution). Amplitude levels remain ≤ 1 throughout the curves indicating 4 star FADGI acceptance level for sharpening.

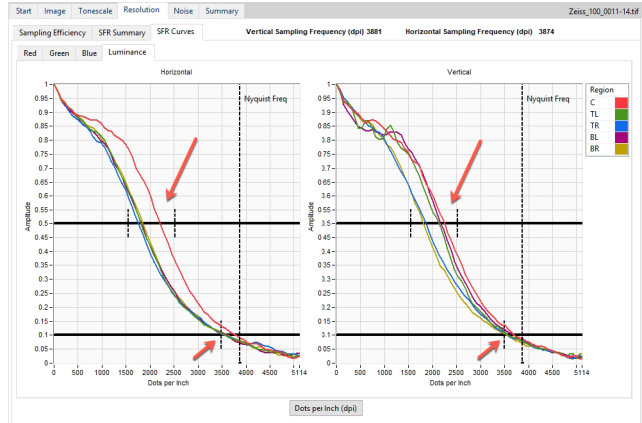


Figure 7. SFR curves for the Zeiss Milvus 100mm F/2M. Top arrows point to 50% SFR tolerance range. Bottom arrows point to 10% SFR values (limiting spatial resolution). Note how amplitude levels remain ≤ 1 indicating 4 star FADGI acceptance level for sharpening.

Summary

Through objective measurements of capture rates and image quality, a clearer picture can be drawn of the X-Y system's potential and how it can be best deployed for high volume, high performance 35mm film capture. To date it has successfully seen initial production use in both black and white slide and strip film digitization projects at scale [16].

Slide film mounted in slide carriers offers levels of consistent placement in geometric space that the capture system can leverage in full automatic mode. As tests have demonstrated, such film can be captured at 3,500 ppi limiting resolution at a rate of 6.7 slides per minute. This throughput is more than 18 times faster than a traditional film scanner and is accomplished to high FADGI performance levels.

The X-Y table's operational flexibility also allows it to adapt to the unique handling requirements of multiple film formats. When faced with situations such as unevenly cut 35mm strip film sections, the system can be programmed for semi-automatic or manual mode depending on the circumstance.

With its modular construction the device can also elegantly accommodate camera, lens and software upgrades as they become available. In this way, performance is not capped by monolithic design, and the system can act more like a springboard for future enhancements. Upcoming high megapixel mirrorless cameras, for instance, may be easily swapped in and offer not only greater capture resolution but also faster throughput based upon their mirrorless design. Mirror-based camera vibrations, and the additional workflow steps currently needed to mitigate their detrimental effects could potentially be eliminated. In addition, as tethering software matures, better implementations of focus peaking may evolve with crisp live view displays supported on large workstation monitors. In this way, more accurate and efficient use of high quality manual-focus-only optics such as the Zeiss Milvus 100mm F/2M may effectively be realized.

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