Measuring and Correcting Distortions

Keith T. Knox

*Early Manuscripts Electronic Library (EMEL)*

19 June 2017
• **MegaVision Cultural Heritage Imaging System**
  – High resolution, panchromatic camera
  – LED lights, narrowband lights, ultraviolet to infrared
  – Spectral images in perfect registration

• **Registration Issues**
  – Filters can introduce lateral shifts when tilted
  – Filters can also magnify an image
  – The lens introduces a wavelength-dependent magnification

• **Measurement and Correction**
  – Graph paper used initially
  – Registration now measured from image data
Multispectral Imaging System (MegaVision)

(Spectral lens that transmits and is in-focus over UV + Visible + IR)
**LED Illumination Panels**

- **15 LED bands in reflection:**
  - 365nm (near UV)
  - 420nm (violet)
  - 450nm (blue)
  - 470nm (long blue)
  - 505nm (cyan)
  - 535nm (green)
  - 590nm (yellow-orange)
  - 615nm (orange-red)
  - 630nm (red)
  - 655nm (dark red)
  - 700nm (red-infrared)
  - 735nm (near-infrared)
  - 780nm (infrared)
  - 850nm (infrared)
  - 940nm (infrared)

- **3 LED bands for fluorescence + 6 bandpass filters**
  - 365nm (UV)
  - 385nm (near UV)
  - 400nm (violet)

  Wratten Filters:
  - B47
  - G58
  - O22
  - R25
  - UV Pass
  - UV Block

- **4 LED bands in transmission using Lightsheet illuminator**
  - 500nm (green)
  - 580nm (yellow)
  - 735nm (near-infrared)
  - 940nm (infrared)

*Bill Christens-Barry (Built prototype LED Illumination System)*
Image Registration between Wavelengths

Narrowband Light Sources
(light-emitting diodes = LEDs)

Sensor

Lens

Object (Manuscript)

Illumination with narrowband LEDs of a still document and camera, should give perfect registration between images.
Illustration of the Problem: Misregistration

Ultraviolet image:
No filter
Illustration of the Problem: Misregistration

Ultraviolet image:
Glass filter - UV Pass
Embossed Appearance from Misregistration

Ratio image: Ratio of two images
Three Types of Images

**Reflectance Images**
- Sensor
- Lens
- Manuscript
- Light Sheet
- UV
- VIS
- IR

**Transmission Images**
- Sensor
- Lens
- Manuscript
- Light Sheet
- VIS
- IR

**Filtered Fluorescence Images**
- Sensor
- Lens
- Filter
- Manuscript
- Light Sheet
- UV
- VIS
- IR
- UV
Use of Filters Causes Registration Issues

Tilted thick glass filter can cause image shifts

Thick glass filter can magnify an image with slight defocus

Imaged a grid to investigate registration

Filter wheel rotation may shake filters, changing the tilts of the filters
Magnification is evident in radial edge enhancement.

Divide open filter image by glass filter image.
Measured Grid Point Shifts

Radial deviation between “no filter” and “glass filter” images, 0.1%
### Grid Point Analysis

**(x, y) pairs**

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</tbody>
</table>

**Least Squares Fit**

\[
\begin{align*}
    x &= mu + a \\
    y &= mv + b
\end{align*}
\]

**Distance Measure**

\[
d = \sqrt{(x - u)^2 + (y - v)^2}
\]

With the coordinates of the distorted and undistorted images, one can compute the “magnification” and the “distance” between the corresponding points.
Unexplained Image Magnification with no Filter

Divide no filter UV image by no filter visible image

No shift on the left. Slight shift on the right.

Amount of shift is function of wavelength
Analysis of Reflectance Graph Paper Images
Variability of Center Location, Reflectance

Locations of Reflectance Centers seems to vary with setup
Variability of Center Locations, Reflectance

Measurements were made during three separate sessions

Black outline is boundaries of manuscript

Graph paper – circles
Red (Enoch, Berlin),
Green (Sythica, Vienna),
Blue (Jubilees, Milan)

Image Data – plus signs
Red (Jubilees, Milan)

Variation in center locations likely due to noisy fit
Image Demagnification vs. Wavelength

Graph paper measurements for three different imaging sessions.
Use Graph Paper Measurements to Correct?

Reflectance Images

Location of center of demagnification is dependent on the alignment of camera and tabletop at setup.

Location of center of magnification is an indication of tilt of filter in the filter wheel.

Filtered Fluorescence Images

Does not change from leaf to leaf.

May change from leaf to leaf as filter wheel turns.
Measure shifts at 400 regions of 301x301 pixels around the manuscript.

Cross-correlations between the different separations are computed for each square.

Shifts at each region are fitted to a magnification model using a robust least squares fit method.
Measure Shifts at Each Location

- **Image Sequence**
  - Each image at different wavelength or filter
  - Lateral shifts between images

- **Measuring the shifts**
  - Assume first image is centered
  - Measure the difference in position between every image pair
  - Use cross-correlation to measure shifts
    \[ r_{i,j}(\Delta x, \Delta y) = \iint f_i(u,v) f_j(u + \Delta x, v + \Delta y) dudv \]
  - Least squares fit of correlation pairs to determine shifts between first image (UV 365) and each other image (filtered fluorescence images, or reflectance images 420 nm to 940 nm)
Determining the Magnification

Measured shifts from 400 locations around the manuscript

\[(u,v) \quad \text{coordinates undistorted image}\]

\[(x,y) \quad \text{coordinates distorted image}\]

A least squares fit of all of the shifts between two images of different wavelengths can determine a single magnification factor and a \(x, y\) location of the center of the magnification.

Least Squares Fit

\[x = mu + a\]

\[y = mv + b\]
Robust Least Squares Fit

Measuring the shift from data is much noisier than graph paper

Measurements from some locations are outliers

A robust least squares fit was used to minimize the effects of the outliers and measure better values for magnification factor and center location

Reflectance Images – 3D, 450 nm - 590 nm
Reflectance Images – 3D, 615 nm - 940 nm
Reflectance Images – Top, 450 nm - 590 nm
Reflectance Images – Top, 615 nm - 940 nm
Variability of Center Locations, Reflectance

Variation in center locations likely due to noisy fit
Variability of Magnifications

Jubilees image data demagnification higher than graph paper measurement
Filtered Fluorescence Images – 3D
Filtered Fluorescence Images – top view
Variability of Center Locations

Measurements were made on five separate leaves of this manuscript.

Black outline is boundaries of manuscript.

Wratten filters – circles
Red (R25), Green (G58), Blue (B47), Black (O22)

Glass filters – plus signs
Red (pass), Blue (block)

Centers locations for Wratten filters are much more variable than glass filters.
Variability of Magnifications

Magnification of Wratten filters is much smaller than glass filters

Magnification decreases with wavelength
Correction of Magnification Distortions

Equations define where to draw from original to place in output

\[ x = mu + a \]
\[ y = mv + b \]
Results for B47 Filter

Uncorrected images bottom, Corrected image top
Results for G58 Filter

Uncorrected images bottom, Corrected image top
Results for O22 Filter

Uncorrected images bottom, Corrected image top
Results for R25 Filter

Uncorrected images bottom, Corrected image top
Results for UVB Filter

Uncorrected images bottom, Corrected image top
Results for UVP Filter

Uncorrected images bottom, Corrected image top
Summary

• Filters
  – Cause magnification changes
  – Tilts causes shift of center of magnification
  – Glass filters cause 10s of pixel shift
  – Wratten filters cause single digit pixel shifts
  – Lightweight filters jostled by filter wheel movement

• Reflectance Images
  – Lens demagnifies as a function of wavelength
  – No de-magnification in blue, maximum in infrared
  – Maximum pixel shift is 2 or 3 pixels
  – Center of magnification may indicate alignment