Analysis of PSF and Geometric Distortion of a Camera Lens

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Agenda

• Introductory Material

• Methods

• Results

• Conclusion
Point Spread Function

- Camera lenses have non-idealities that introduce noise into the captured image
- The PSF of a camera is a description of this noise – image of a point source blurred due to camera imaging system
- PSF is analogous to impulse response of imaging system – can deblur an image by deconvolving it with PSF
Geometric Distortion

• Another known degradation of images comes from geometric distortion.
• Geometric distortion is a type of optical distortion inherent to lens design that causes straight lines to appear bent or curved in the captured image.
• The two most common types of distortion are barrel distortion and pincushion distortion:
One methodology by Shih et al. [1] uses an iterative method to calculate the PSF of a camera lens.

Given a lens prescription, they employed ray tracing to determine the PSF.

They then used a feedback method to update the lens prescription until it produced a PSF that more closely matched the measured PSF.
Methods

- Monochrome Camera Lens
- Point Spread Function
- Shift Invariance
- Characterization of Geometric Distortion of Lens
Monochrome Camera Lens

• Camera lenses have different channel sensitivities to red, green and blue colors
• Creation of a monochrome camera lens was required
• A white field was placed on the display and a sensor image was captured
• The ratio of red vs. green and blue vs. green channel sensitivities was calculated to acquire the scaling factors
• Using scaling factors, all red and blue pixels in the image were scaled to generate a monochrome camera sampling at the sub pixel resolution
Point Spread Function

• To measure the PSFs accurately, we need to remove the artifacts of this collection process
  • Color channels
  • Background
• Use channel scaling to remove the color channel differences
• Subtract a blank image to remove the background
• Resulting image is a PSF of the camera system if it is shift invariant
Shift Invariance

• Take two images where they have been shifted by a known amount
  • 1 or 2 pixels right and down
• Remove all artifacts as previously discussed
• Compare the PSF results together by undoing the shift done on the original image
  • Translation ratio between image space and photo space is unknown - must sweep a region of values
  • Calculate cross correlation ratio and structural similarity index (SSIM) for each pair of images
  • Neither result can be 1 since time variant noise in camera system
Geometric Distortion

- Geometric distortion is radially symmetric around the center of image.
- The sensor image of the grid of white pixels was scaled using the red/green and blue/green scaling factors.
- The exact location of each white pixels was calculated.
Center of Image – Method 1

- Calculating $d_1$, $d_2$, $d_3$, and $d_4$
- $Distance_{total1} = d_1 + d_2 + d_3 + d_4$
- This process was repeated for all the points in the grid.
- The point with smallest $Distance_{total1}$ was selected as the center of the image.
Center of Image – Method 2

- Calculating $d_1$, $d_2$, $d_3$, and $d_4$
- $Distance_{total2} = |d_1 - d_2| + |d_1 - d_3| + |d_1 - d_4|$
- This process were repeated for all the points.
- The point with the lowest $Distance_{total2}$ is the center of image.
- Allocating more emphasis on center being equidistant from its adjacent points.
Results

- PSF Measurements
- Center of Image Calculation
### PSF Measurements

<table>
<thead>
<tr>
<th>Cross Correlation</th>
<th>Image 1</th>
<th>Image 2</th>
<th>Image 3</th>
<th>Image 4</th>
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- Image 1: original location
- Image 2: 1 pixel shifted to the right and down
- Image 3: 2 pixels shifted to the right and down
- Image 4: Repeat of image 3

**Generated PSFs are shift invariant**
PSF Measurement - Takeaways

- Translation ratio between image space and camera space: 1
- SSIM inappropriate for this type of image comparison
- Background removal introduces other noise
The center of the image was found to be very close to the actual center of the image for both methods.

Top five centers for both methods coincided for 4 out of 5 points.

Using both methods, percent difference between the center and the point with the worst distortion was 4%.

The image had very little distortion.

It was not necessary to estimate parameters for the radial distortion model, since there was little to no geometric distortion.
Conclusion & Next Steps

• Performing analyses based on the setup described above can yield very interesting properties of this camera system
  • PSF generation
  • Image centers
• If they are known, we can use these properties to improve the quality of images already taken with this camera system
  • Remove blurring caused by PSF
• We want to take a series of test images with this camera and then apply our preliminary PSF removal script to them
  • Understand the extent of the deblur
  • Calculate the image quality improvement based on measures such as the SSIM
References

References (cont’d)

