Sensing Increased Image Resolution Using Aperture Masks

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Supplemental Material
Contributions

• Achieve sub-pixel image shift using a mask in front of the lens

• Enhance effective sensor resolution without moving the camera or sensor.
We intentionally blur the image so that when the aperture is open, the blur is less than one pixel, $\Delta p$. 
Moving a pinhole in along the lens effectively moves the image in an out-of-focus sensor plane.
Moving a pinhole in along the lens is same moving the sensor by sub-pixel distances.
Moving a pinhole in along the lens is same *moving the sensor* by sub-pixel distances.
Moving the pinhole aperture with a slightly out of focus sensor…

…is equivalent to…

…translation based superresolution

But, aperture movement is in mm instead of \( \mu \text{m} \)
Pin holes are inefficient, collect little light, thus increasing exposure time. Instead, we use wider carefully chosen apertures.
Unique finite sized aperture positions
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Unique finite sized aperture positions
We capture multiple photos with out-of-focus sensor and unique finite sized aperture positions.
3x resolution enhancement: Capture 3 photos with aperture position $l_r, l_g, \text{ and } l_b$
Total blur size = one pixel size ($\Delta_p$)
Blur due to each partial aperture

= $\Delta_a = \Delta_p/3$
2x resolution enhancement for a 1D signal

Scene, $s(x)$
Capture 2 photos with complimentary apertures

Notice the phase shift between the two signals. For a total blur of one pixel, this corresponds to half pixel shift.
Anti-aliasing due to finite pixel size

Scene, $s(x)$

$\rightarrow l_0(x)$

$s(x) * l_0(x)$

$\rightarrow p(x)$

$s(x) * l_0(x) * p(x)$

$\rightarrow l_1(x)$

$s(x) * l_1(x)$

$\rightarrow p(x)$

$s(x) * l_1(x) * p(x)$
Discrete sampling due to pixels

Samples captured by the two photos are different.
Interleave samples from the two photos

\[ s(x) * l_0(x) \quad s(x) * l_0(x) * p(x) \quad f_0[x] \]

\[ s(x) * l_1(x) \quad s(x) * l_1(x) * p(x) \quad f_1[x] \]

Interleaved Samples
Deblur the effect of $p(x)$ and $l(x)$
Image Shifting without Moving Parts

Suggested Design:
Programmable Aperture with NO moving parts, eliminating expensive precision or cumbersome registration

Our Implementation:
Masks in a Holder
Prototype using a conventional SLR camera

- Cokin filter holder
- Slide mask in front of the lens
Aperture Masks
Result: Radial spoke chart

Mask size=12mm
Mask resolution=3x3
Image scale factor=1/1.7
Input image size=471x741
Output image size=1413x1413
Input images (3x3)
Cropped and bicubic interpolated input images (4 of 9 shown)

Observe the jaggies in the input images. In the result, details in high spatial frequencies closer to center of the spoke are maintained up to a limit.
Result: Barcode

Mask size=12mm
Mask resolution=4x1
Image scale factor=1/3
Input image size=171x416
Output image size=684x416
*Input Images (4x1)*

**Result:** 4x increase in horizontal resolution
Result: Sheets of paper

Mask size=12mm
Mask resolution=4x1
Image scale factor=1/8
Input image size=100x300
Output image size=400x300
Input images (4x1)
2 of the 4 input images

Result: 4x increase in horizontal resolution
Result: Carpet tile

Mask size=12mm
Mask resolution=2x2
Image scale factor=1/2
Input image size=256x256
Output image size=512x512