Automatic Estimation of Modulation Transfer Functions

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Motivation

Lens Quality Assessment is expensive and time consuming...

simple/cheap ⟷ **complex/expensive**

- visual inspection of images
- MTF test charts, artificial stars
- wavefront sensor, MTF test station

qualitative ⟷ **quantitative**

... but every photographer has access to photographs captured with that lens

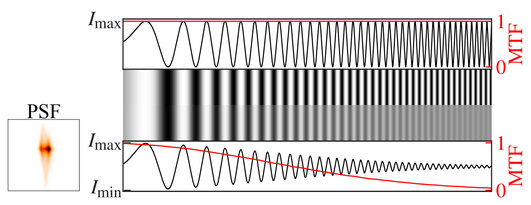
- Photographs contain ample information about lens properties
- This information is confounded with the statistics of the images
- Lens properties are the same for different motives

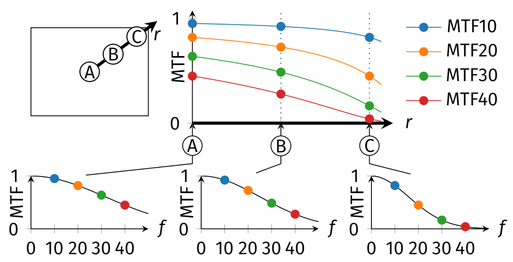
The Modulation Transfer Function (MTF) is a standard measure for camera lens quality.

What is the Modulation Transfer Function?

The MTF characterises how contrast is diminished by optical aberrations (blur)

$$\mathrm{MTF}(f) = \frac{C(f)}{C(0)}; \quad C(f) = \frac{I_{\max}(f) - I_{\min}(f)}{I_{\max}(f) + I_{\min}(f)}$$





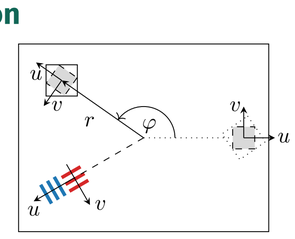
- **The Point Spread Function (PSF)** characterises the local blur and is spatially varying across the field of view. It is related to the MTF by a Fourier Transformation:

$$\mathrm{PSF}(x) \xrightarrow{\mathcal{FT}} \mathrm{OTF}(f) \propto \mathrm{MTF}(f)\, e^{i\,\mathrm{PhTF}(f)}$$

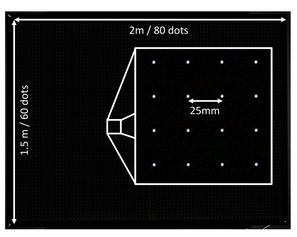
- **Global MTF charts** summarise the MTF for fixed frequencies (10 cy/mm, 20 cy/mm, etc.) over the entire field of view and **are typically provided by manufacturers**.

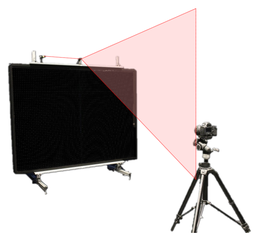
The MTF is measured locally in radial and tangential direction

Global coordinates (r, φ) indicate the patch location
Local patch coordinates (u, v) denote the radial (u) and tangential (v) direction within a patch
Meridional lines measure the *radial MTF*
Sagittal lines measure the *tangential MTF*



Ground Truth PSF/MTF Measurements





- Custom-built *pinhole array* of $2\,\mathrm{m} \times 1.5\,\mathrm{m}$ to record the point spread function (PSF) at $80 \times 60 = 4800$ locations over the entire field of view
- The image of a point light source is a local measurement of PSF

Set up a Supervised Training Task

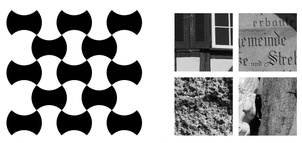
Inputs **Synthetically blurred patches**

Outputs **MTF values of the blur**

MTF10, MTF20
MTF30, MTF40

Ground truth training and validation data

① **Sharp image patches**



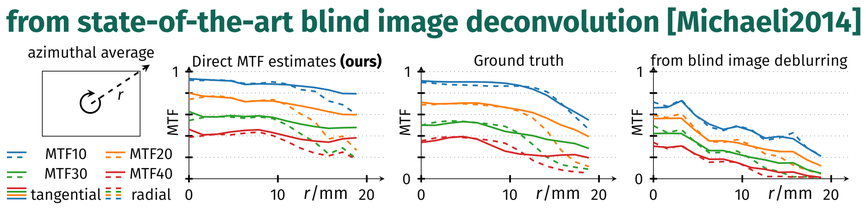
- regular patterns [Joshi2008]
- patches from photos in the wild

② **Lens blurs**

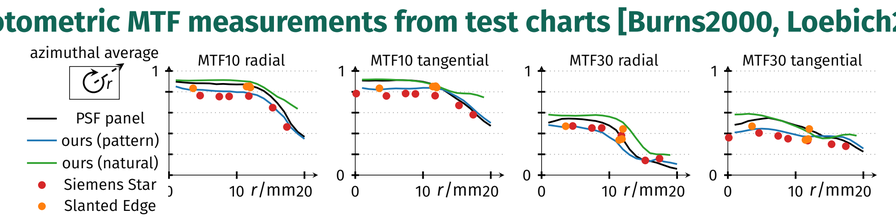
- real blurs from pinhole array
- artificial blurs (e.g. sum of Gaussian)

Comparison to other Methods

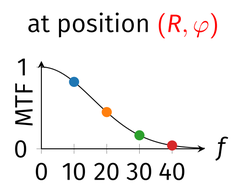
MTFs from state-of-the-art blind image deconvolution [Michaeli2014]

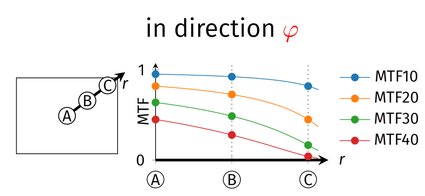


Photometric MTF measurements from test charts [Burns2000, Loebich2007]



Our work: MTF Estimation from a Batch of Photos

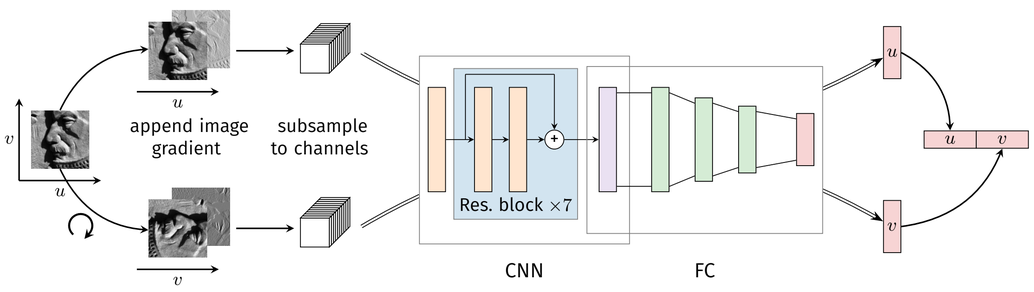




Patch extraction → **Local MTF estimation** → **Global MTF aggregation**

- Estimate entire global MTF charts from a batch of photographs within minutes
- Good qualitative and quantitative agreement with photometric measurements

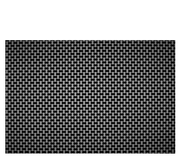
Neural Network for Local MTF Estimation

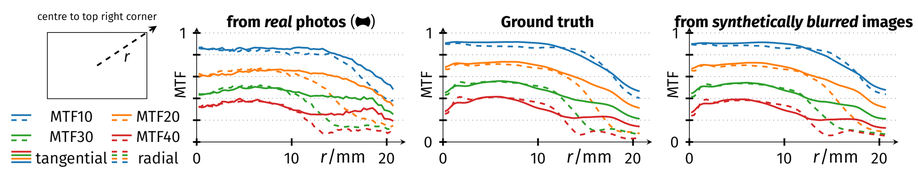


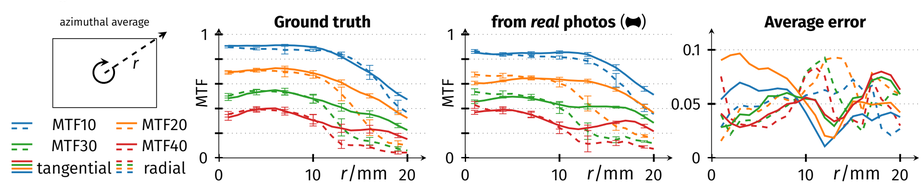
- **Inputs**: $192 \times 192 \times 1$ image patches
- **Outputs**: MTF10, MTF20, MTF30, MTF40 (tangential and radial)
- **Initial data processing**: Rotation, image gradient, subsampling into channels
- **DNN** with convolutional residual blocks and fully connected layers
- To **treat multiple input patches**, compute the feature representation separately and average them in feature space

Experimental Results

Results for a regular pattern [Joshi2008]

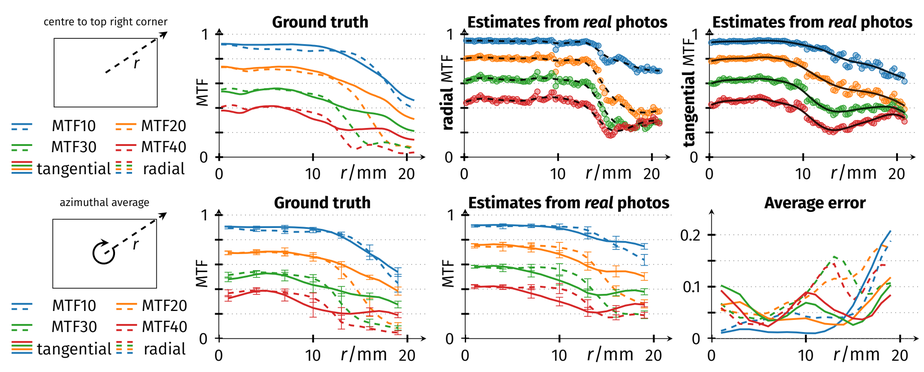






- Estimates from synthetically blurred patches are almost perfect (for all lenses)
- Very good quantitative and qualitative agreement (errors are similar for other lenses)

Results for photographs of natural scenes



- Typically, very good qualitative and good quantitative agreement

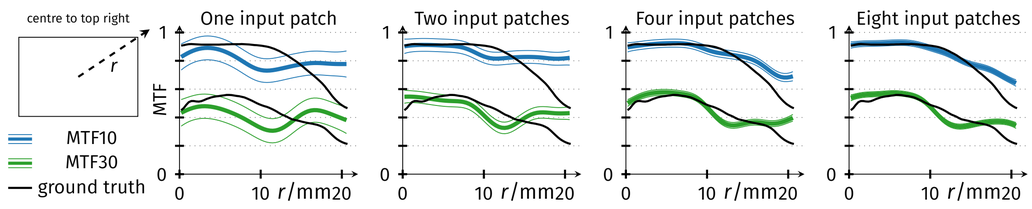
Limitations and explanation of discrepancies

Curvature of the focal plane. The PSF panel is completely flat, while natural scenes have depth variations; corners may appear sharper than PSF measurements

Not all patches are suitable. Objects not in focus (e.g. protruding objects); homogeneous/texture-less areas (e.g. sky); edges in only one direction

Mitigation strategy. Carefully select photos; *future work:* automatically select patches

Estimates improve with more images



References

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[Loebich2007] C. Loebich et al. "Digital camera resolution measurement using sinusodial Siemens stars" (Digital Photography III, 2007)
[Michaeli2014] T. Michaeli and M. Irani. "Blind Deblurring Using Internal Patch Recurrence" (ECCV 2014)