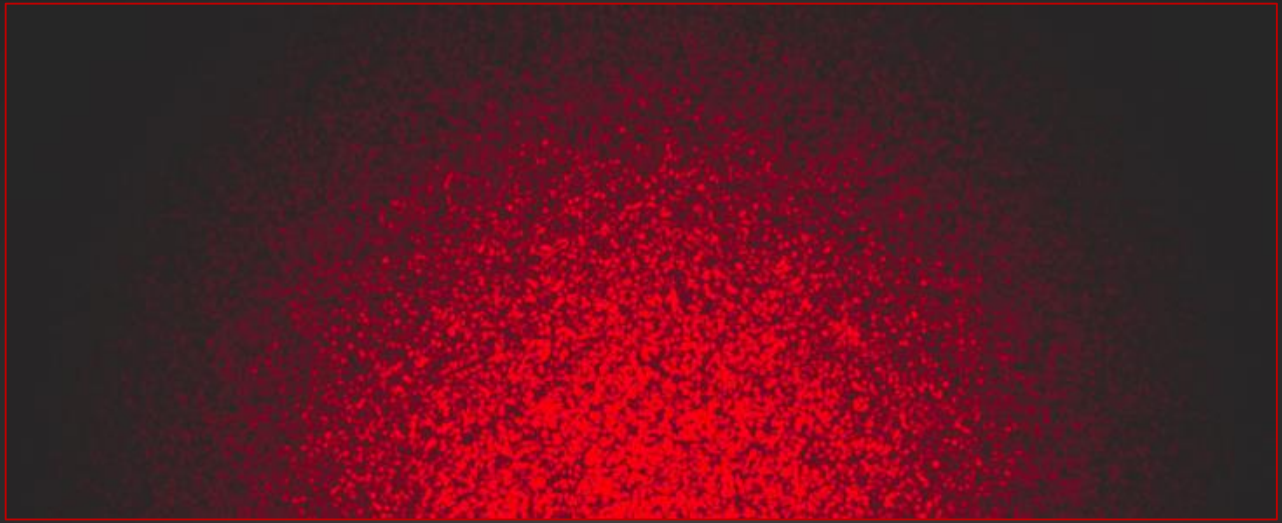

A Phenomenological Approach to Integrating Gaussian Beam Properties and Speckle into a Physically-Based Renderer

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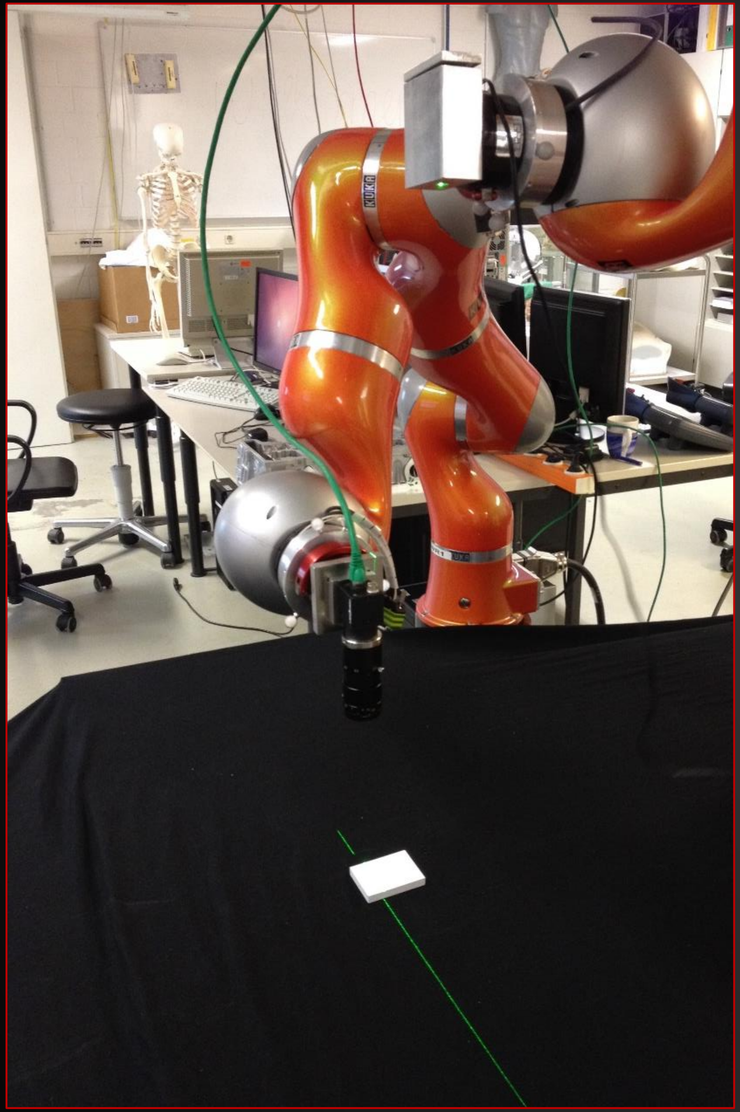
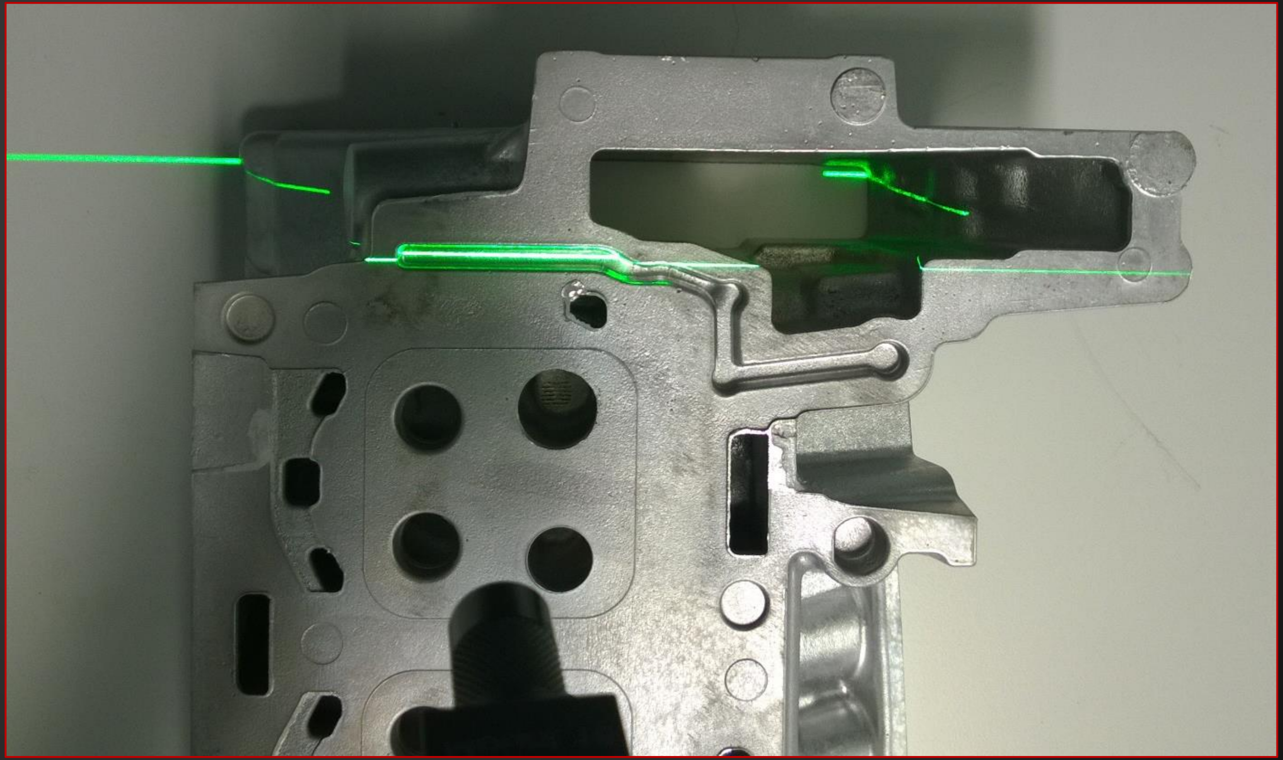
Motivation & Goals

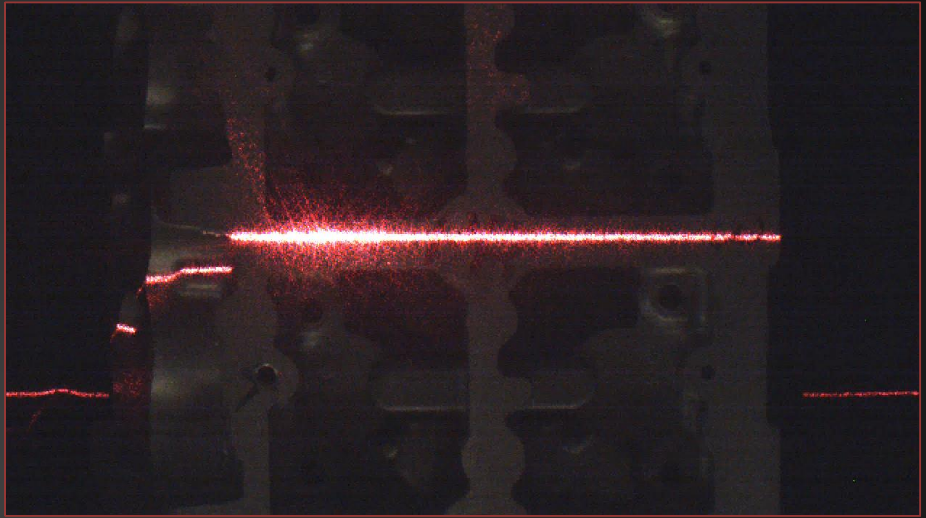


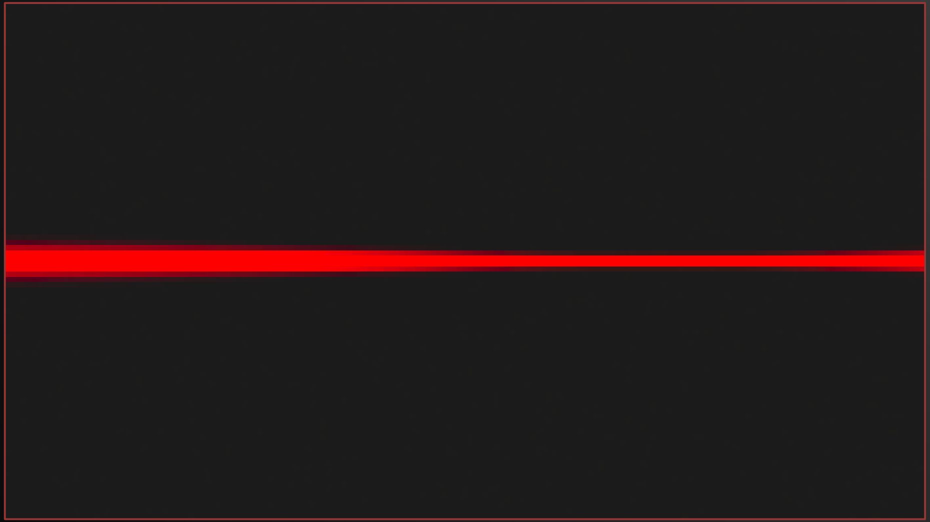
- Automated optical inspection
  - Laser triangulation
- Synthesize sensor data

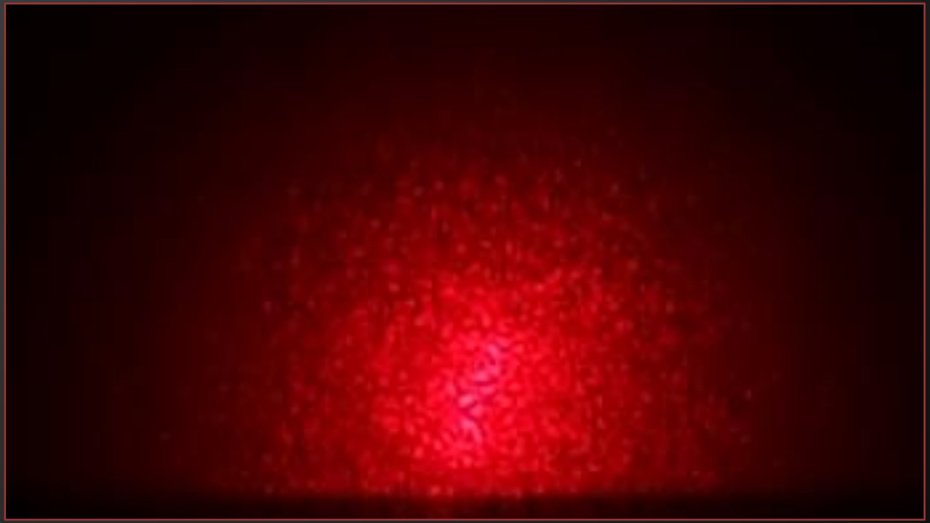


Motivation & Goals

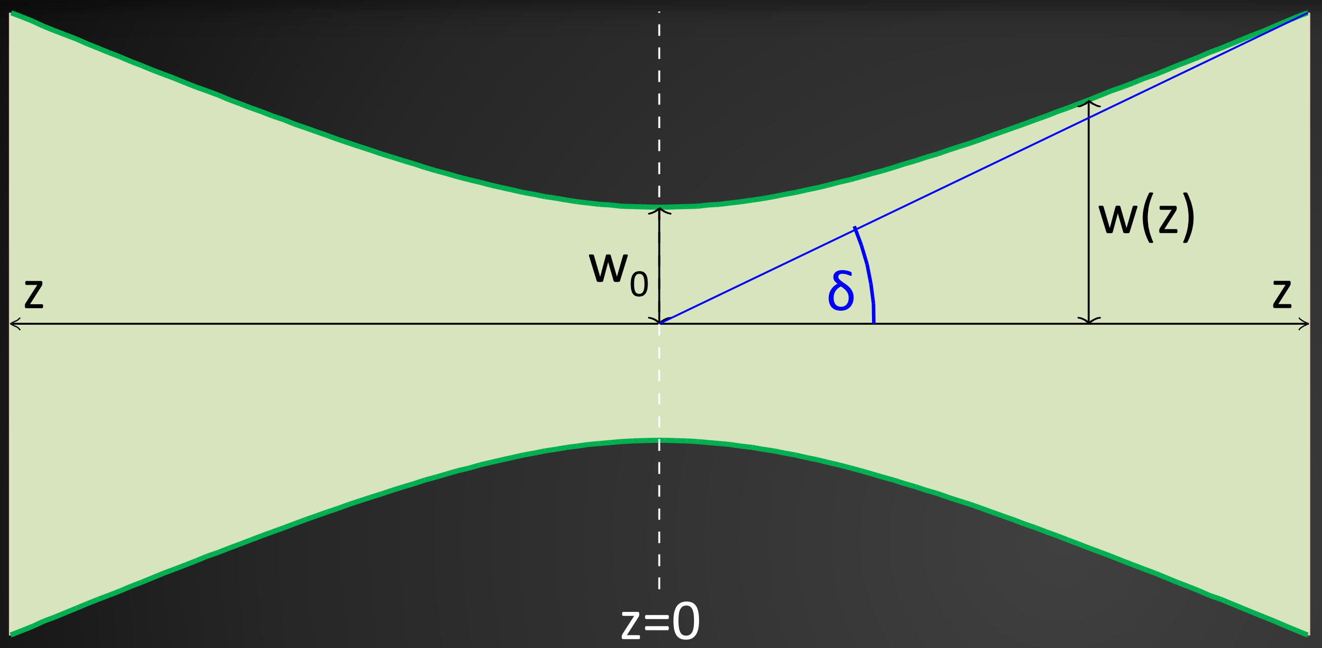
- Laser light exhibits wave optics effects
  - Limited focusability (of beams)
  - Speckles
- Measurement affected [DHH94]
- Limited time budget

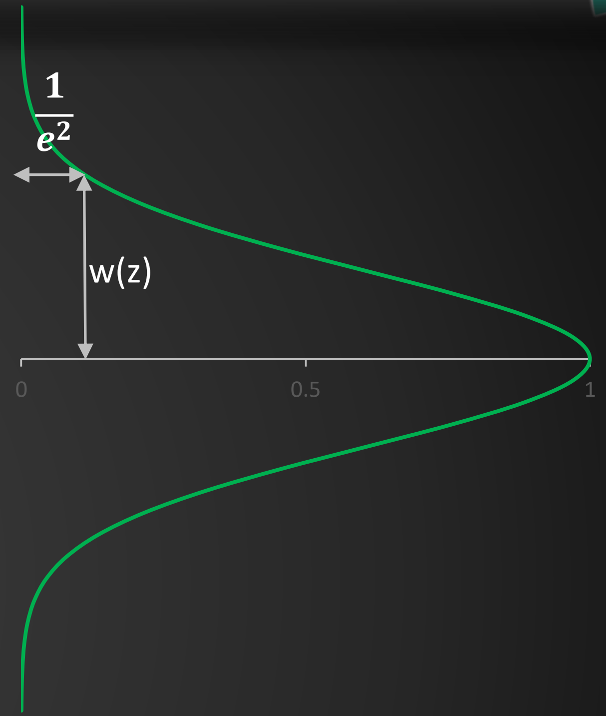






Properties of Gaussian Beams [Hec16]



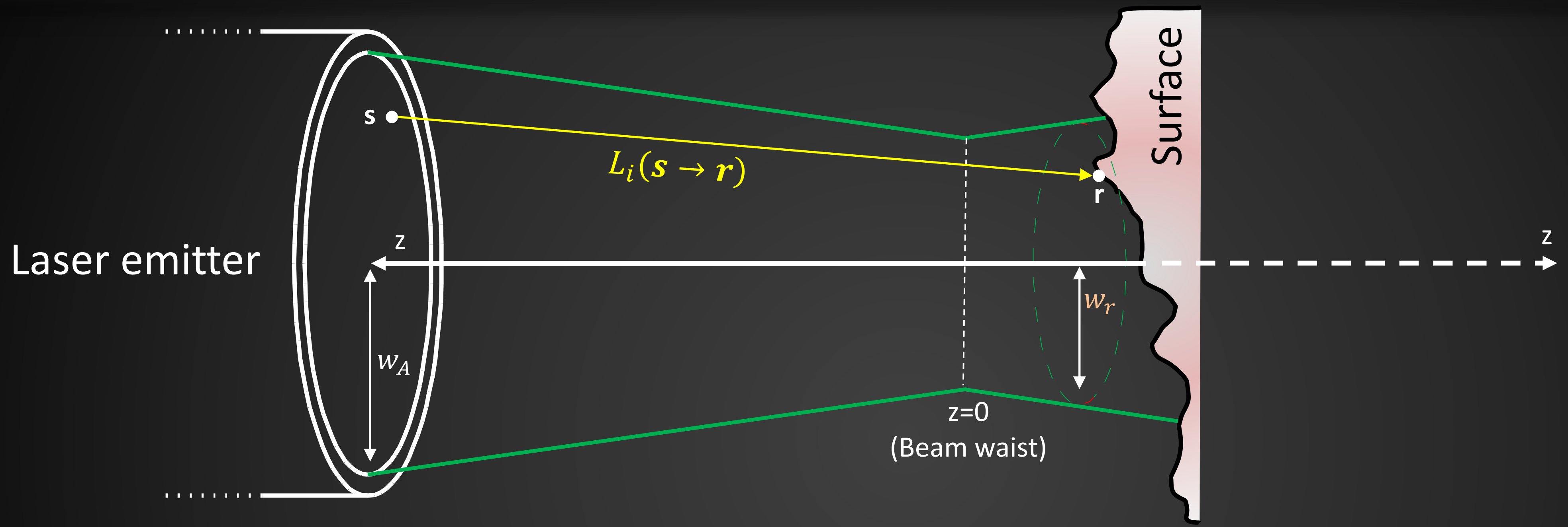


- Gaussian irradiance profile
- Non-linear relation between travelled distance and beam radius

$$w(z) = w_0 \sqrt{1 + \frac{z^2 \lambda^2}{w_0^4 \pi^2}}$$

- Non-negligible beam radius in focus (z=0)
  - Beam waist w_0 depends on wave length and divergence δ

Integration of Gaussian Beams



- Determine laser light arriving in point **r** on surface
  1. Determine beam radius w_r
  2. Determine point **s** on laser aperture
  3. Determine irradiance E(r) (with optical power P)
  4. Determine incoming radiance L_i(**s**→**r**)
     - Assumption: Irradiance from a single direction

$$E(\boldsymbol{r}) = \frac{2P}{\pi w^2(z)} e^{\frac{-2r^2}{w^2(z)}}$$

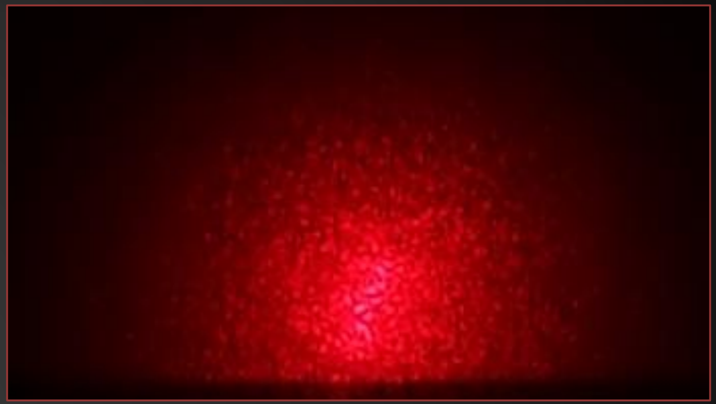
$$L_i(\boldsymbol{s} \rightarrow \boldsymbol{r}) = \frac{1}{\cos\theta_s} E(r)$$

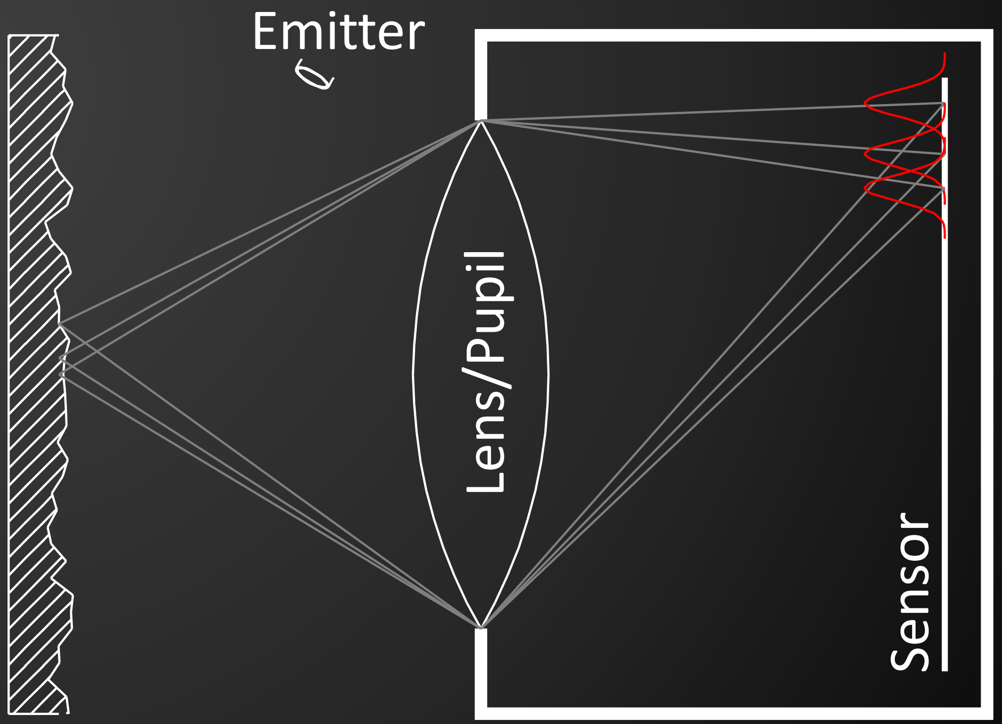
Integration of Gaussian Beams

Point laser nearly parallel to diffuse surface

Speckles – Properties [Goo75]

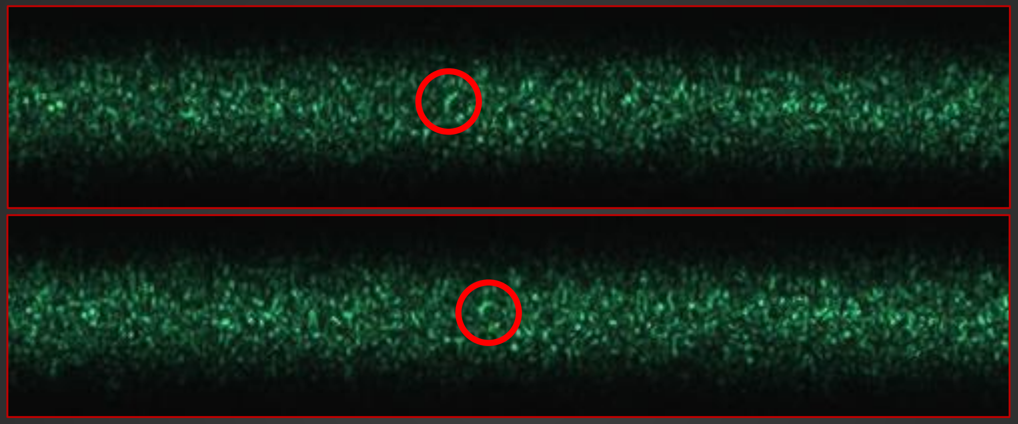
- Granular phenomenon caused by interference
  - Obvious in reflected coherent light
- Objective vs. subjective speckle pattern
- Statistics of patterns can be calculated (under certain assumptions)
  - Intensity distribution
  - Frequency distribution
  - …





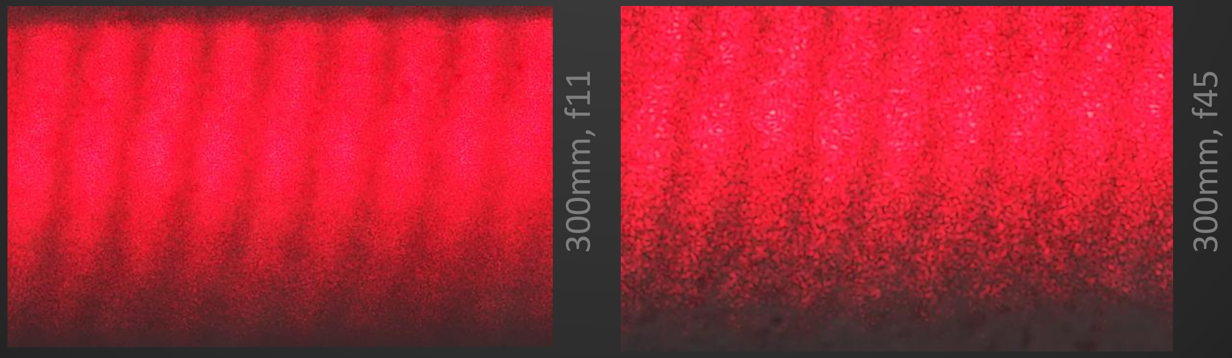
Speckles - Properties

- Speckle pattern translation
- Gradual decorrelation on movement



Surface translation

- Speckle size depends on aperture



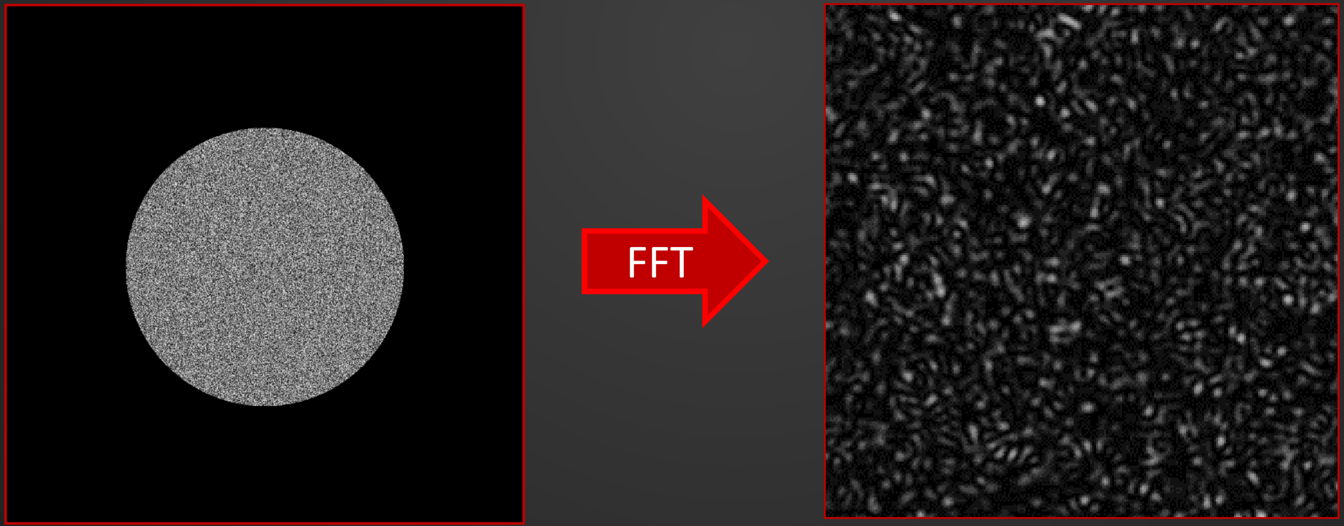
Integration of speckles

- Goals
  - Reproduce speckle properties
  - Low runtime impact

- Approach
  - Preprocessing:
    - Compute and store speckle patterns
  - During rendering:
    - Calculate pattern coordinate and read pattern
    - Multiple with coherent light contributions

Pattern generation

- Generation of speckle patterns according to Duncan and Kirkpatrick [DK08]
  - Generate complex-valued i.i.d. circular random field
  - Perform Fourier transformation to generate speckle pattern

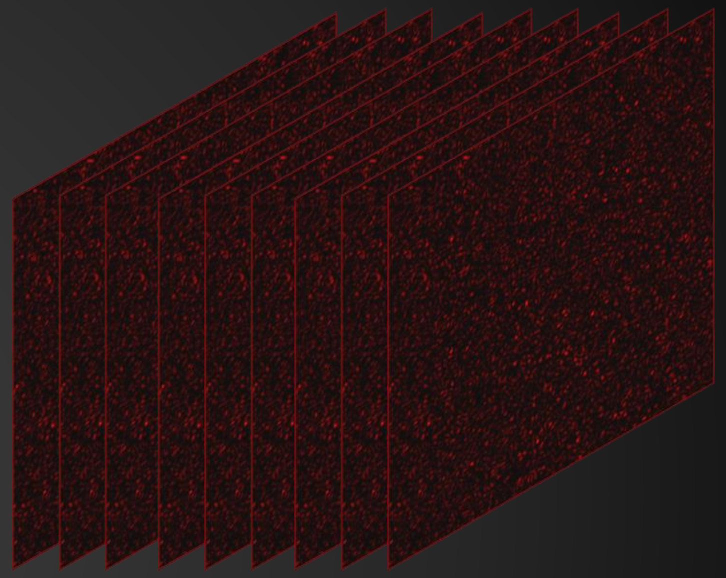


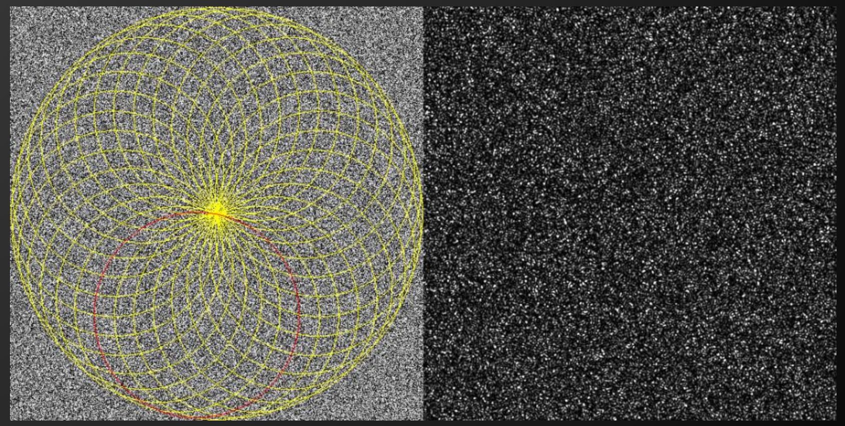
Magnitude 1, Random phase

Speckle pattern

Speckle decorrelation

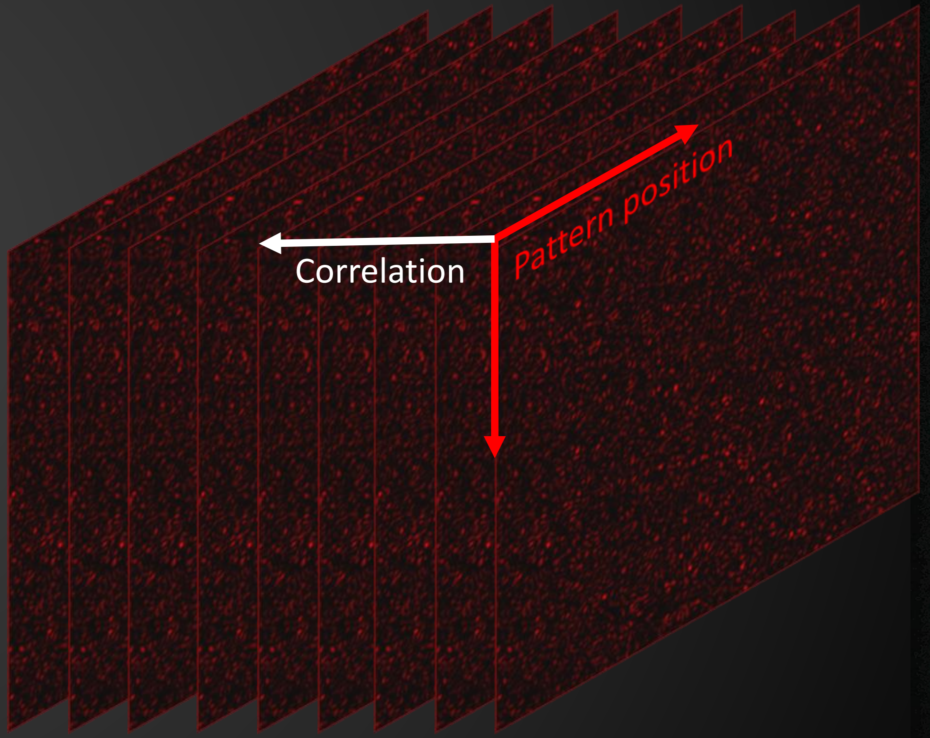
- Multiple pattern slices with gradually changing correlation
- During access
  - Select slices and interpolate pattern value (Trilinear filtering)
- Generation
  - Translate circular mask in random field
  - Generate circular correlation





- 3D access coordinate
  - 2D pattern position (s,t) and 1D correlation (u)
- Pattern position
  - Displacement on sensor $\boldsymbol{a_I}$ [Sjö95]
  - Screen coordinate $\boldsymbol{t}$

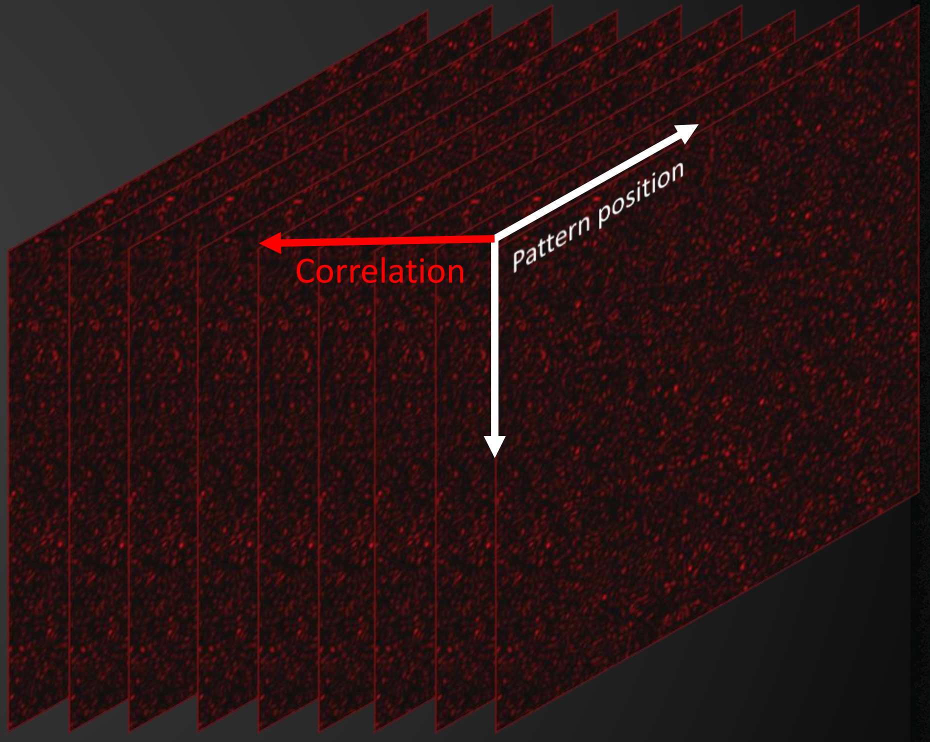
$$\begin{pmatrix} s \\ t \end{pmatrix} = \alpha_1 \boldsymbol{a}_I + \alpha_2 \boldsymbol{t}$$



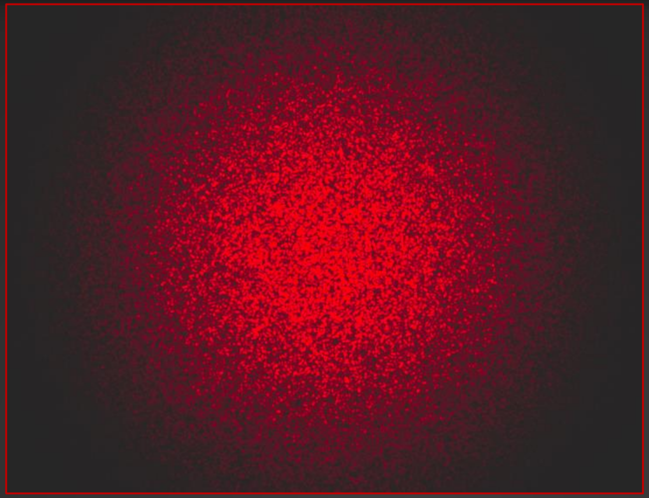
- α_1 and α_2 derived from minimal speckle size $h = \frac{\lambda d_{PI}}{D}$

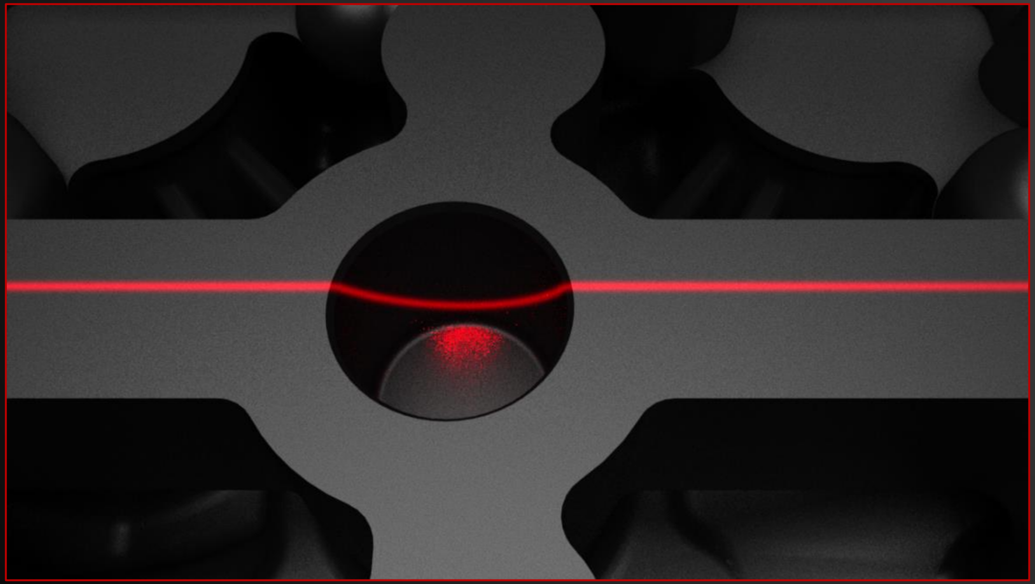
Pattern access

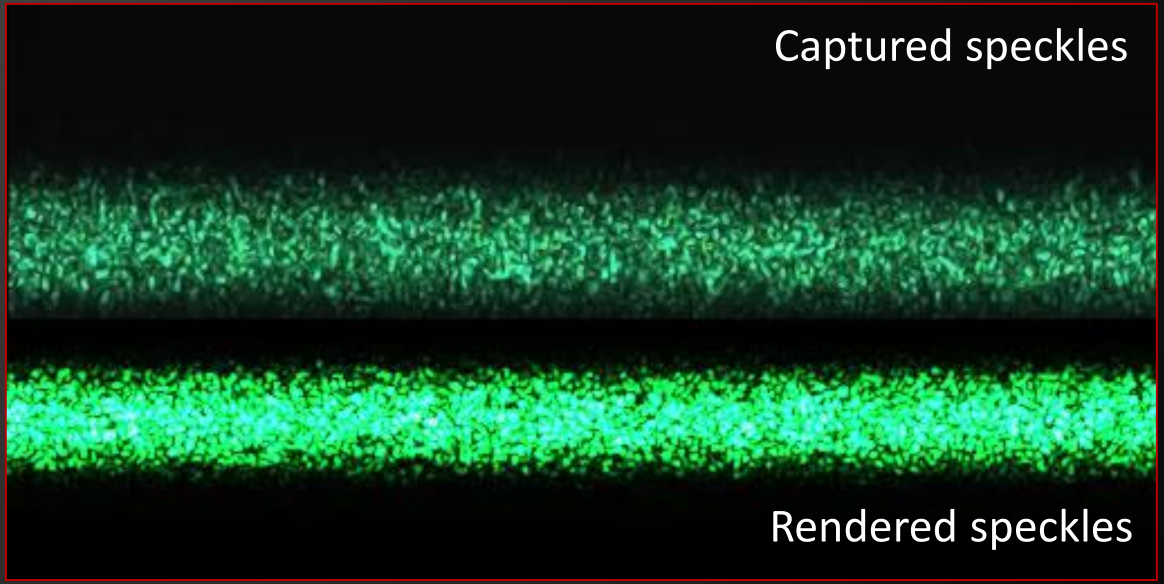
- Correlation
  - Analytically calculated according to Sjödahl & Li and Chiang [LC86]
    - In-plane camera movement → d_1
    - Surface movement → d_2
    - Distance change → d_3
  - $u = d_1 + d_2 + d_3$
- Access patterns with vector $\begin{pmatrix} s \\ t \\ u \end{pmatrix}$
  - Wrap-around, Interpolation



Results







Conclusion

- Reproduce limited focussing and speckle effects
- Small changes in renderer & small performance impact
  - Also usable in real-time context (access patterns in pixel shader)
- Limitations
  - No real 3d pattern generated
  - Constraints in displacement scenarios (e.g. no out-of-focus speckles)

- Acknowledgements
  - Work funded by DFG grant DA 1200/3-1.

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