Range finding using a masked annular folded optic imager

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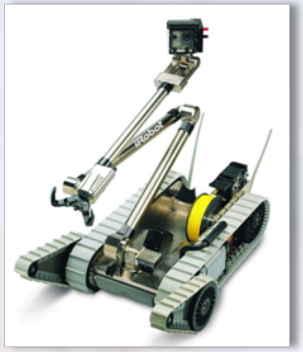
Photo: Kevin Walsh, OLR

Range finding is application driven

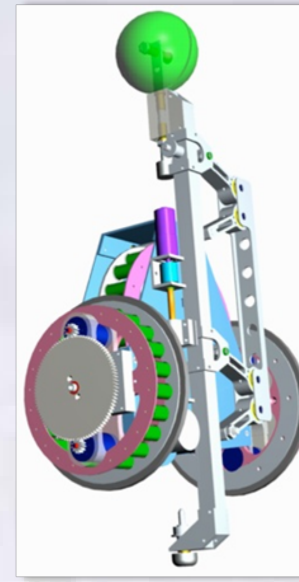
Modern robotic platforms

- small, mobile, and interact with their environment
- require navigation and vision



Packbot Scout
(iRobot)

Pointman SUGV
(Applied Research Associates)



iceCube (left) and iHop (right) demonstrate unique maneuverability with small size and low power*

*** Coordinated Robotics Lab, robotics.ucsd.edu**

Design goal

- compact ranging and onboard imaging

Requirements

- small volume
- low power
- minimum cost
- telephoto imaging
- ranging for obstacle avoidance and observation

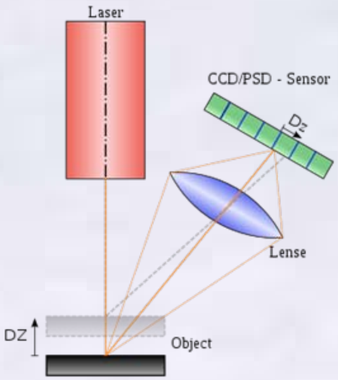
Do commercial options exist that satisfy these requirements?

Current range finding solutions

Numerous range finding methods available

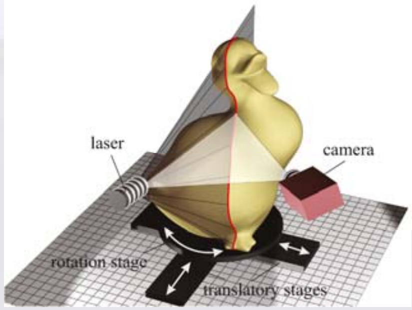
[Blais (2003) “Review of 20 years of range sensor development”]

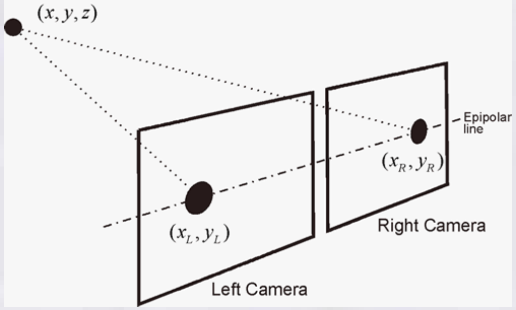
- Optical ranging
    - triangulation
    - time-of-flight
    - slit scanners
    - interferometry



The optical solutions offer ranging without synchronization with imaging

- Imaging and ranging
    - aperture/mask
    - photogrammetry
    - stereo vision
    - Moiré
    - pattern projection/structured illumination



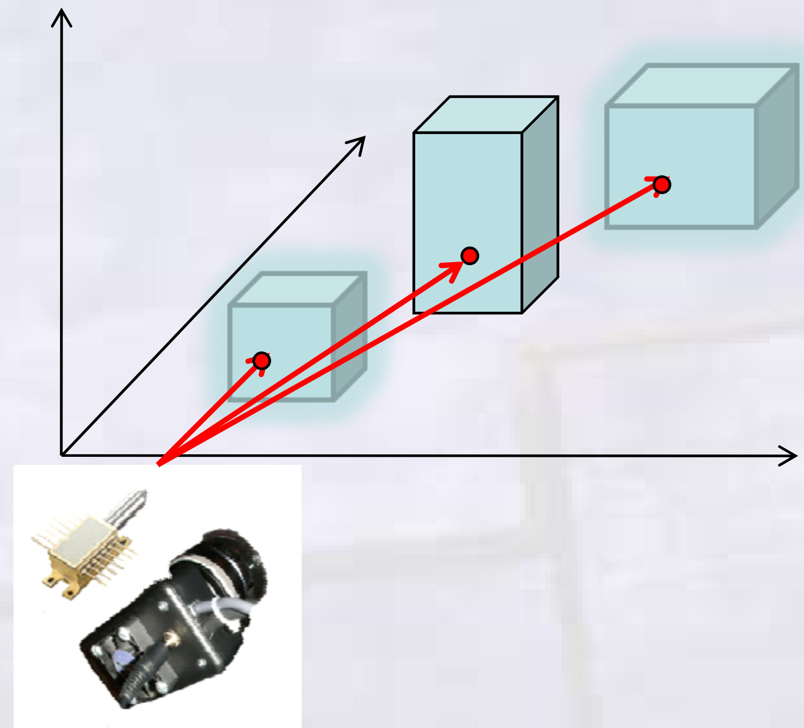


- Considering range, cost, computational requirements and size eliminates commercial options
- However, combination of ranging methods with size appropriate lens would work

Fixed-focus ranging

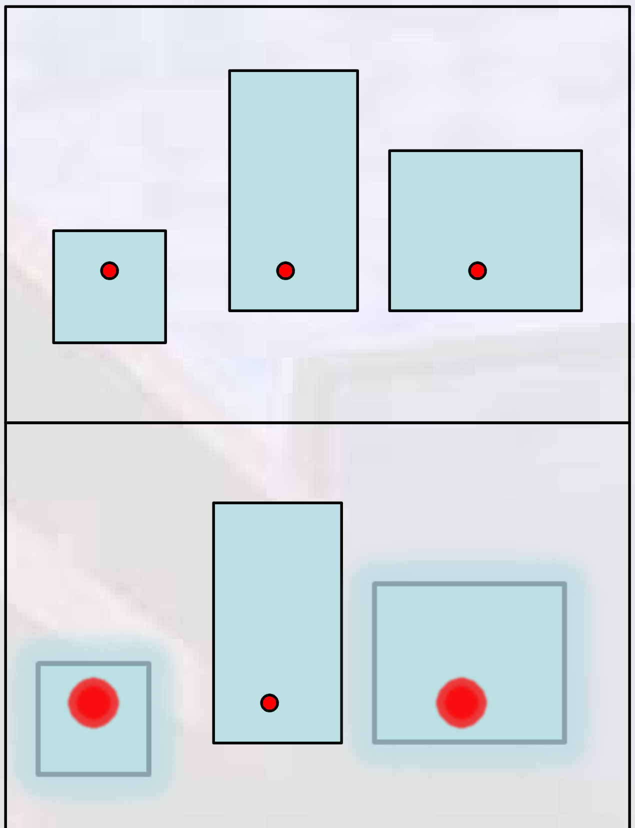
- Through-the-lens ranging minimizes number of detectors, total volume, power consumption
- A fixed-focus imager can use the focal length to determine range

Pattern illumination on three objects



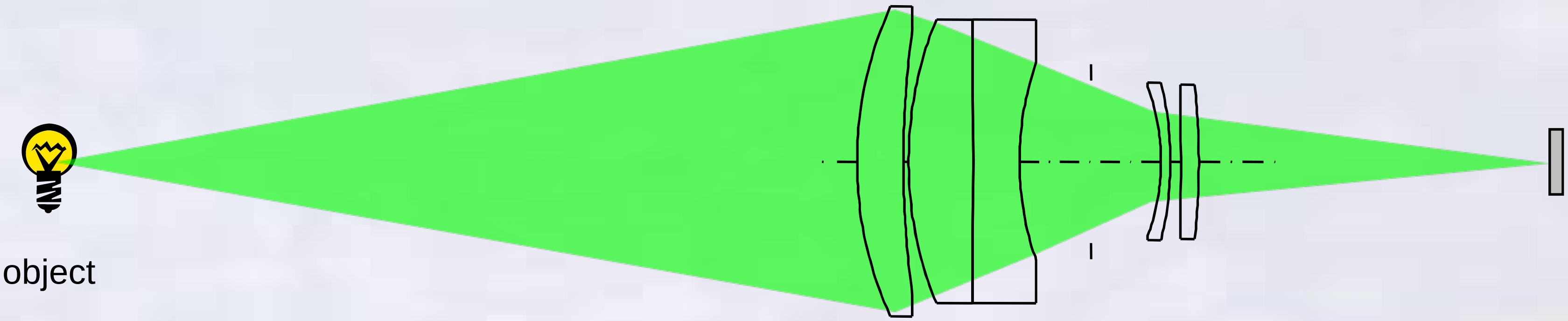
Deep depth of focus

Narrow depth of focus

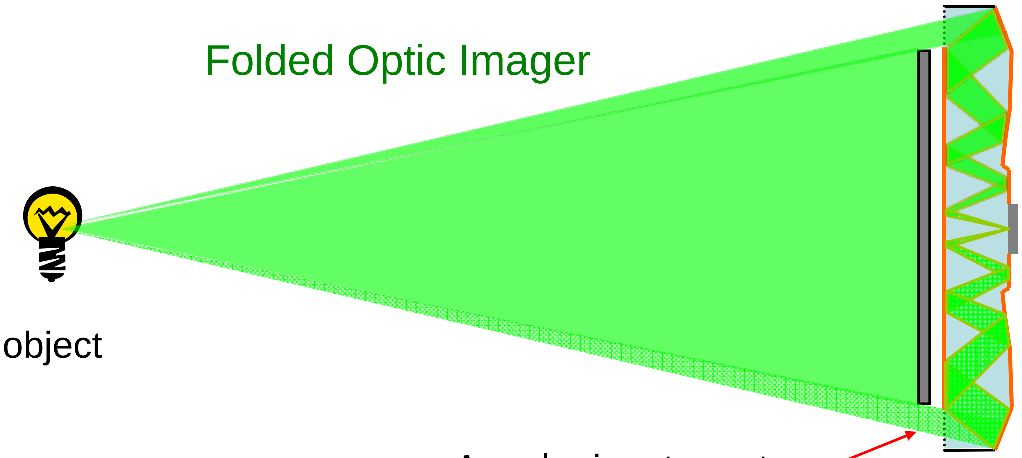


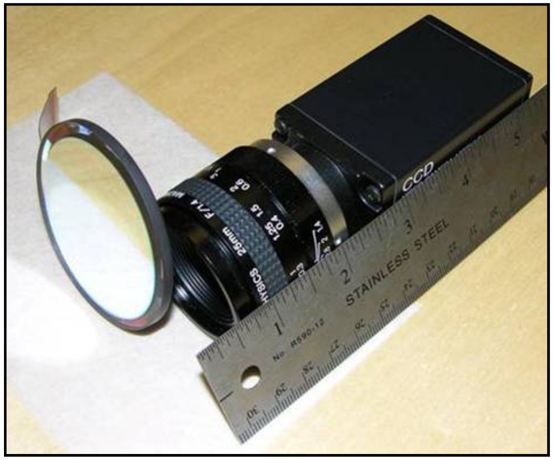
- Laser diode source collocated with imager
- Detector sends images to computer for visualization and analysis

Folded optic lens



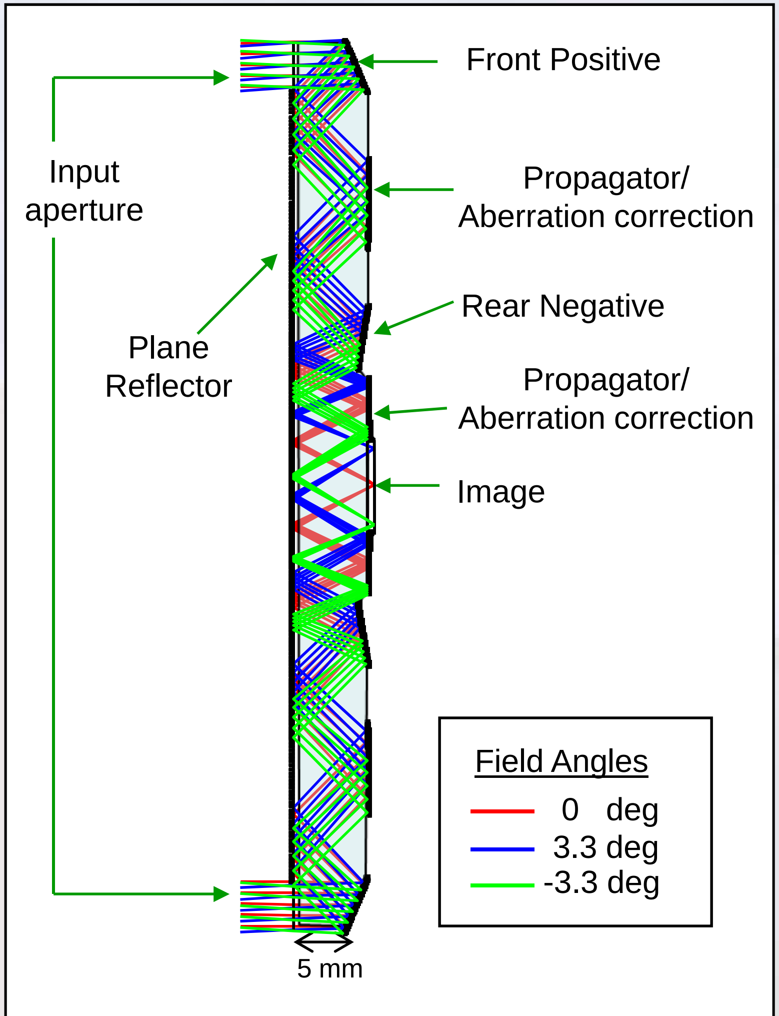
10x less length/weight/volume

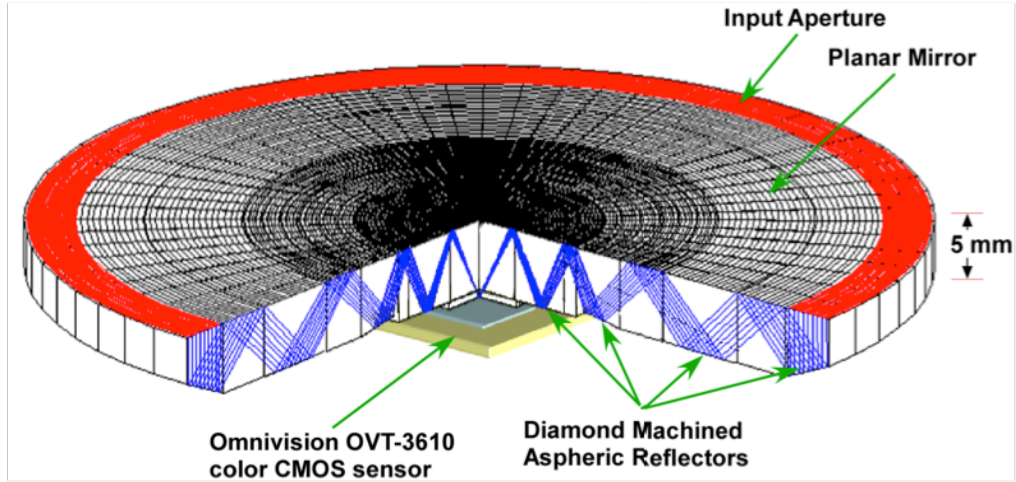




Thickness comparison with equivalent conventional camera

8-Fold Optic Design: Single Sided Structure





Imager specifications:

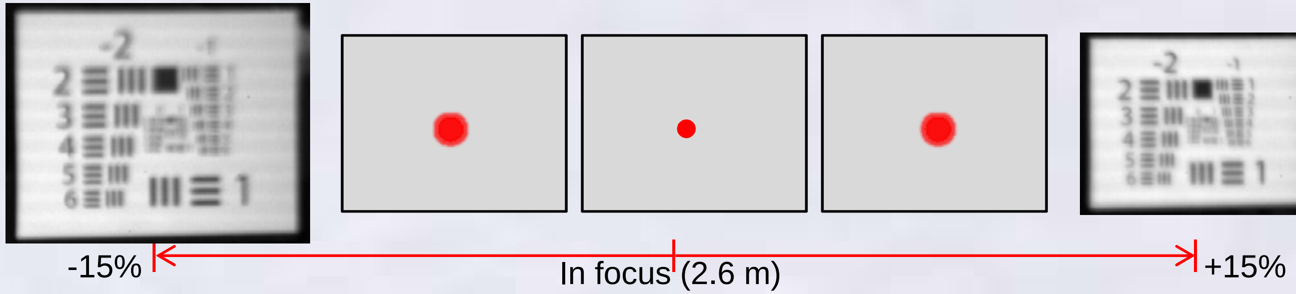
- 38 mm effective focal length folded into 5mm track
- 60mm diameter, effective circular aperture = 27.3 mm
- Image NA = 0.71
- Back focal length ~0.5mm
- FOV = 0.12 rad
- 1280 x 960 pixel
- F/$\#_{eff}$= 1.40

Fully-packaged prototype
Including USB interface to PC

[Tremblay (2007) “Ultrathin cameras using annular folded optics”]

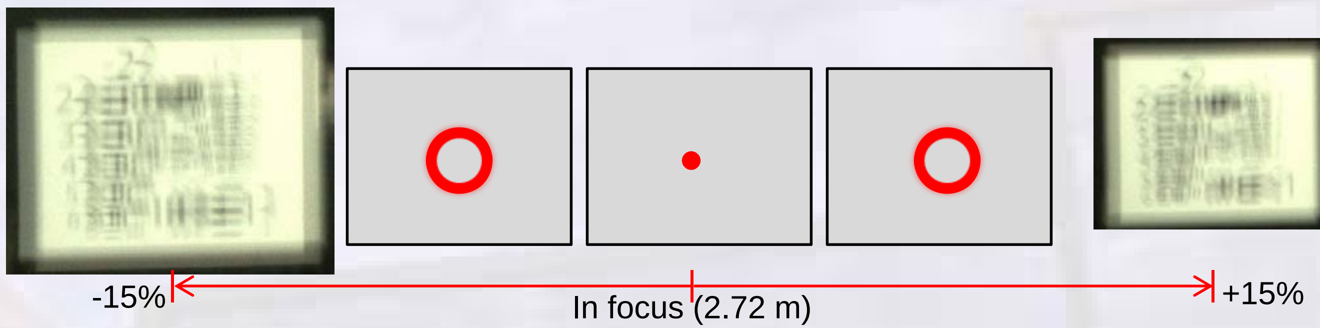
Improved ranging with folded optics

Conventional
Tokina NA=0.5



- Limited depth of field permits larger blur spots at comparable distances away from focus
- Folded optic demonstrates annular blur

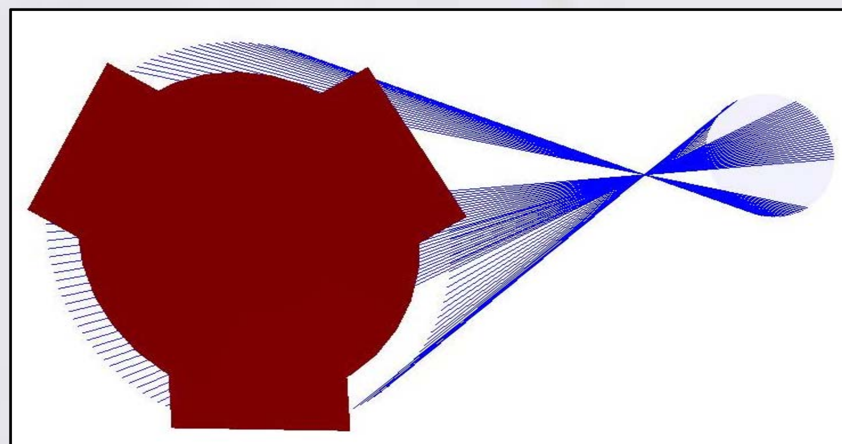
8-Fold
NA=0.71



How to assign polarity to blur image?

Asymmetric Pupil Mask

- Pupil mask limits received light rays to a trefoil pattern
- Paraxial thin lens simulation verified concept
- Mask added to folded optic simulation



Improved ranging with folded optics

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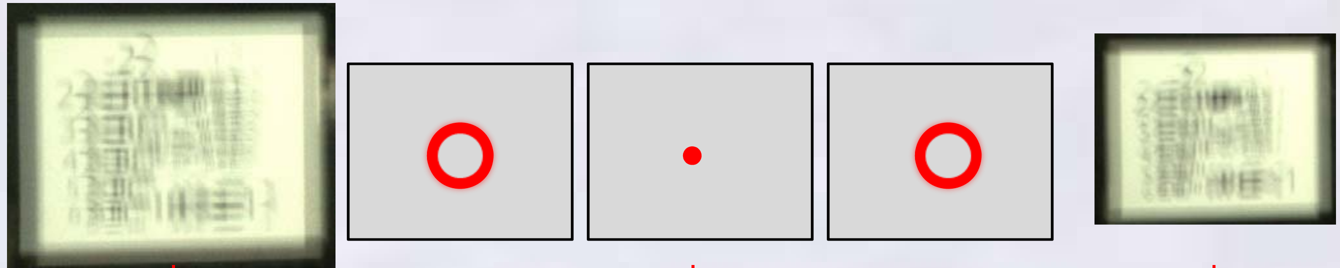
8-Fold
NA=0.71



-15% In focus (2.72 m) +15%

How to assign polarity to blur image?

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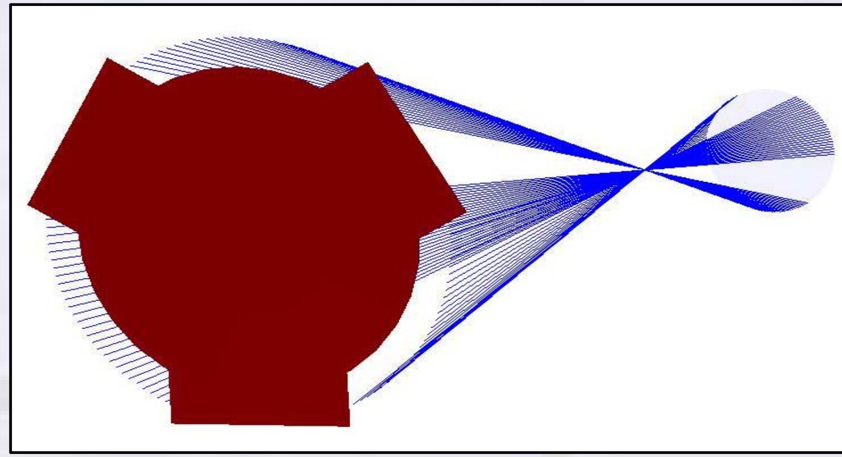
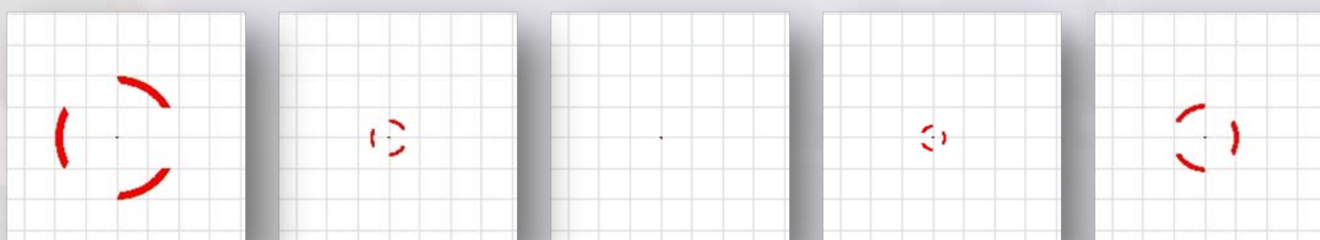


Resolution chart imaging demonstrates the small depth of field compared to paraxial lens

8-Fold Masked
NA=0.71



-53% In focus (2.72 m) +54%

Image processing steps

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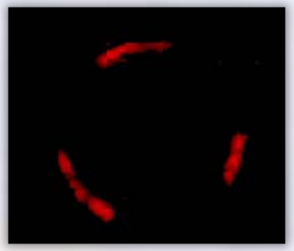
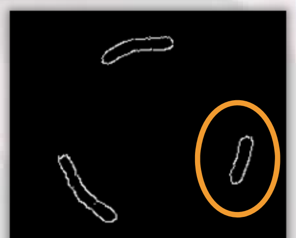
Raw image

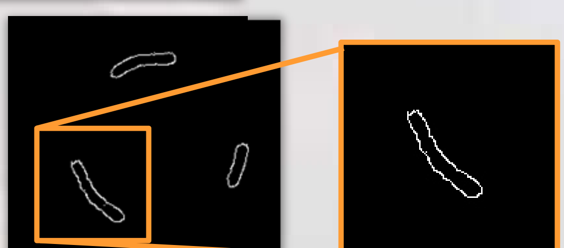


RGB filter, for red intensity and hue

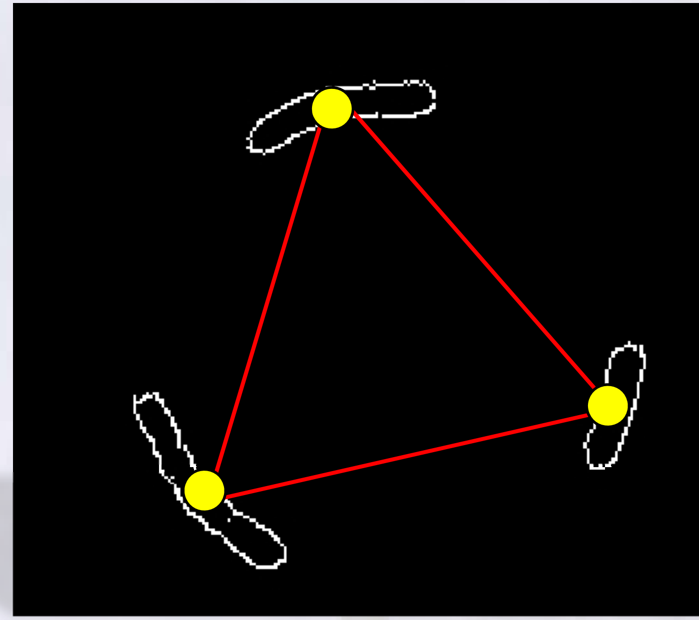
Mean filter, softens image by averaging with 10x10 pixel windows



Canny edge detector with low/high thresholds at 5/20



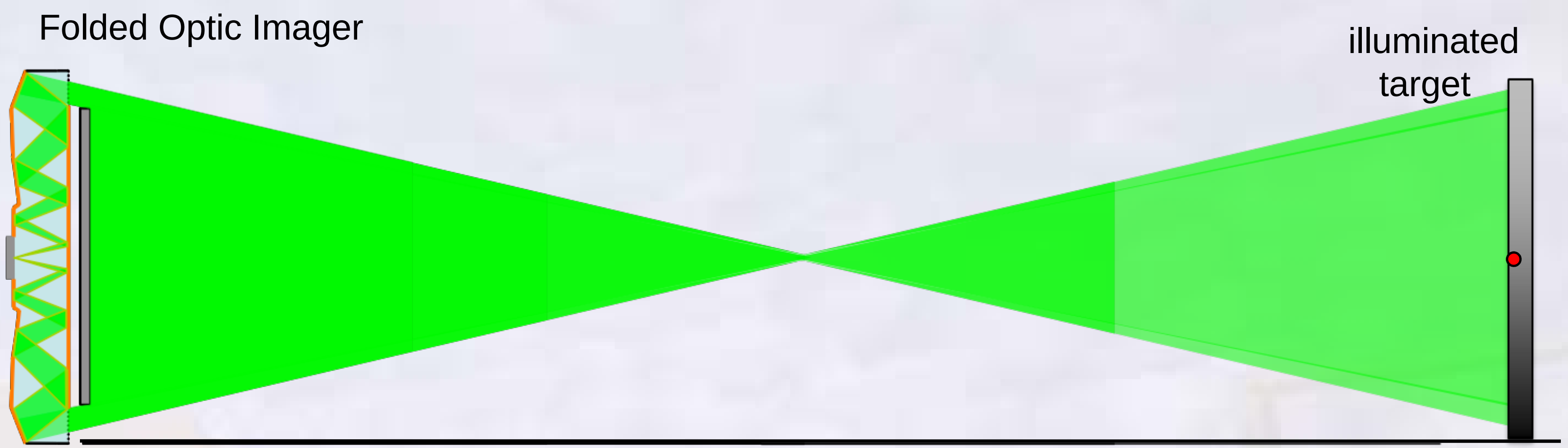
Center of gravity calculated for each blob

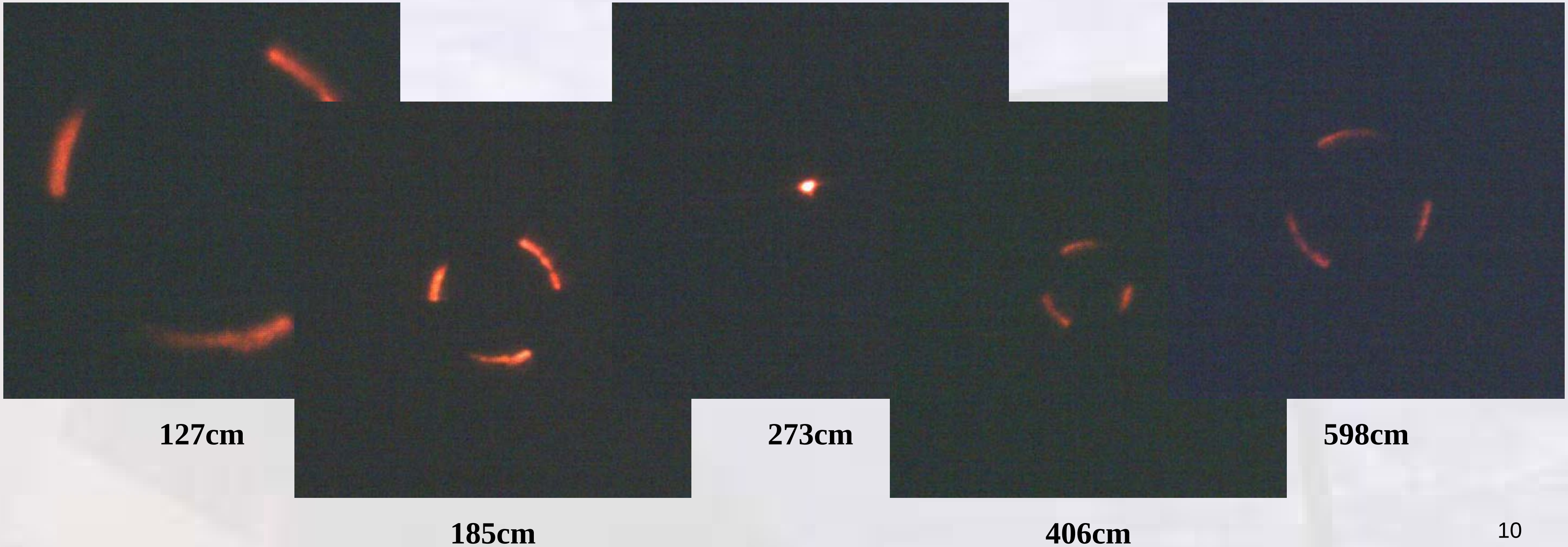


Radius calculation:

1. CGs are vertices of equilateral triangle
2. Measure the pixel distance between two CGs

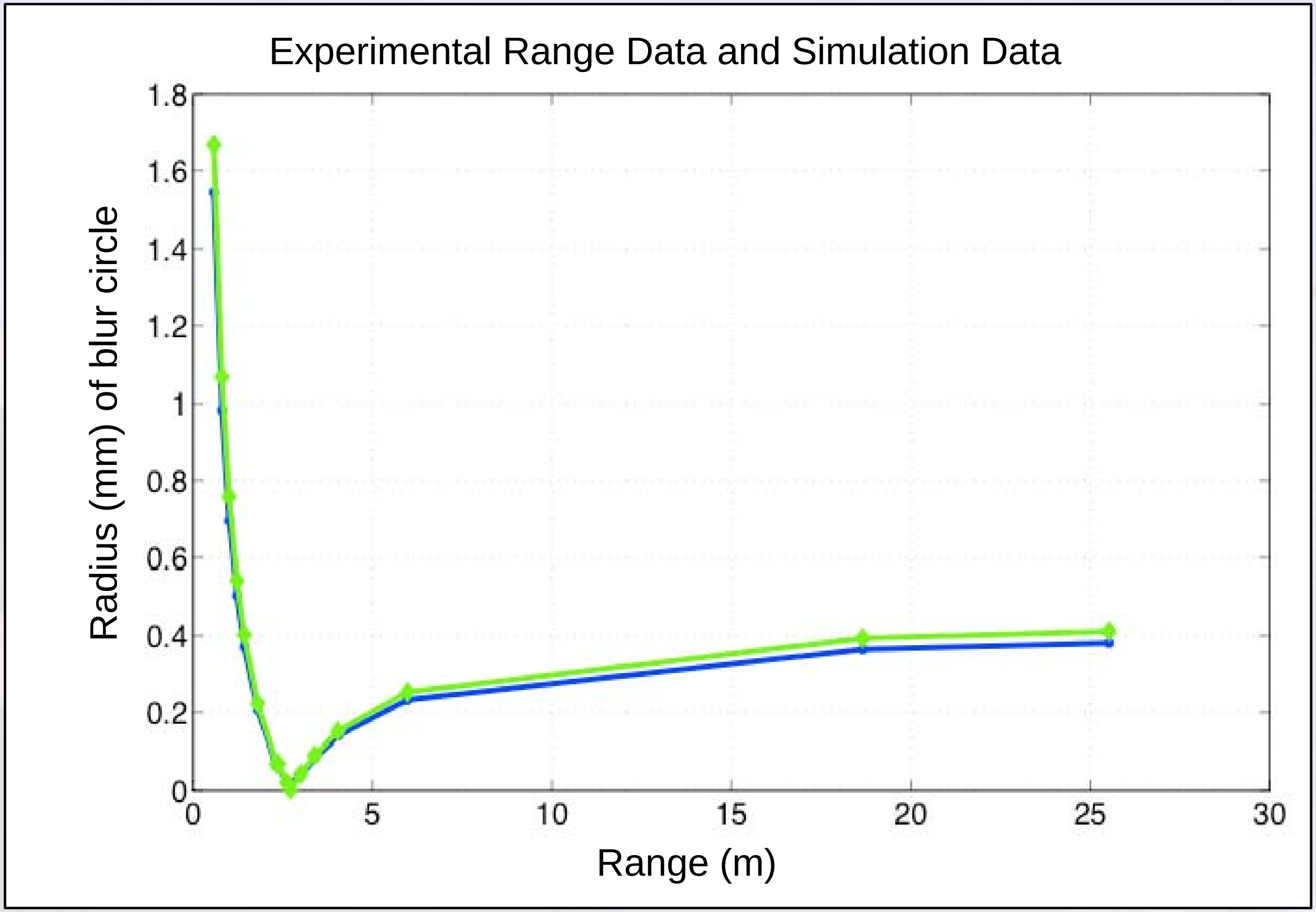
Images taken with structured illumination





Calibration curve and output comparison

Experimental curve matches closely with the numerical simulation performed in Zemax



Calibration curve and output comparison

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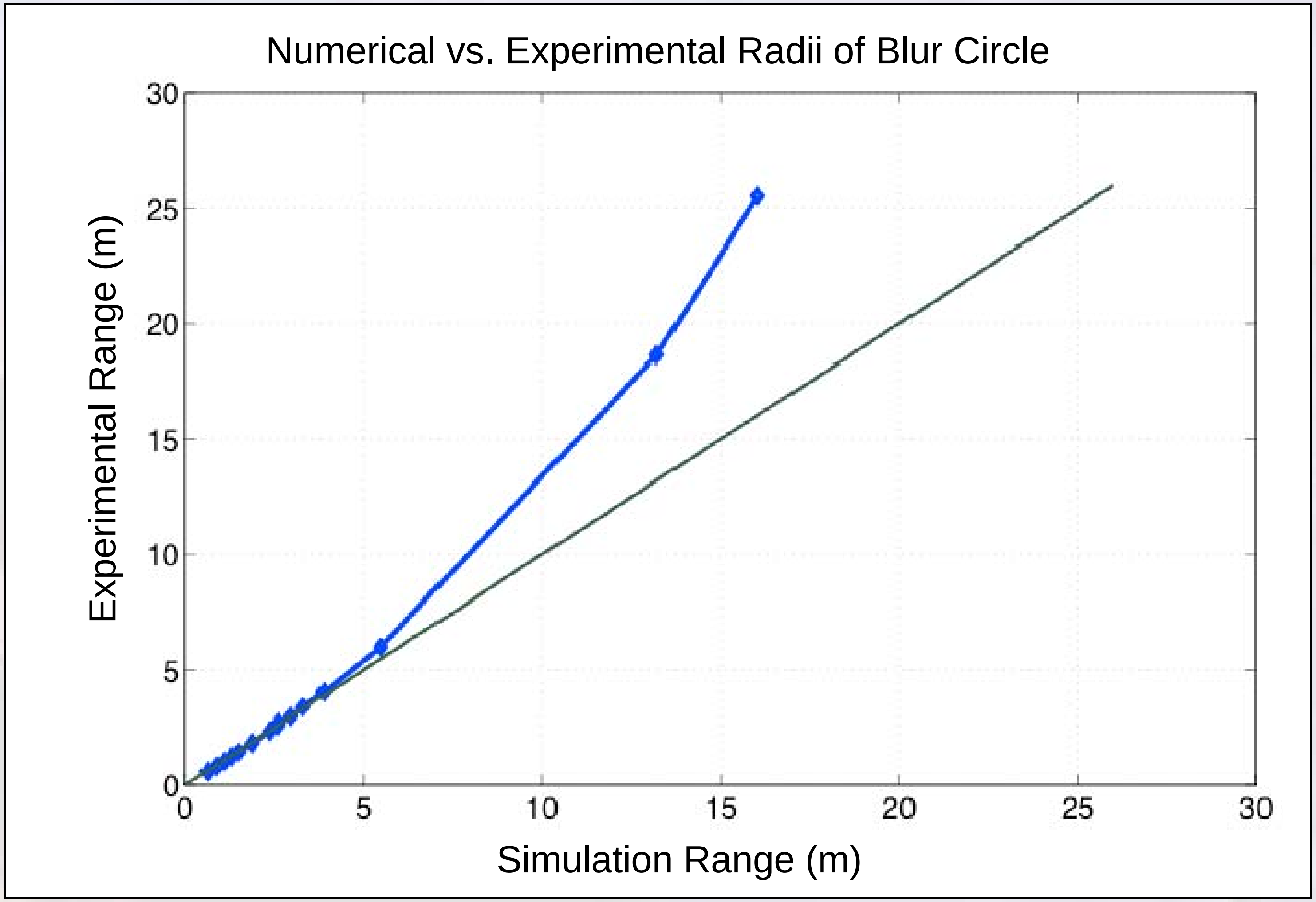
Further examination shows deviation of experimental data at large distances



Conclusion and future directions

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Conclusions

- The design goal was met.
    - integrated vision and ranging
    - low power and volume

- Experimental results followed theory except for drift at long ranges (10m+)

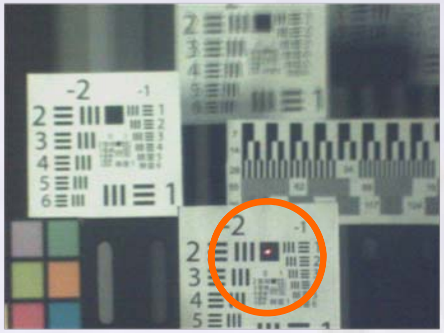
- Provides larger blur diameters between lens and focal length than paraxial thin lens

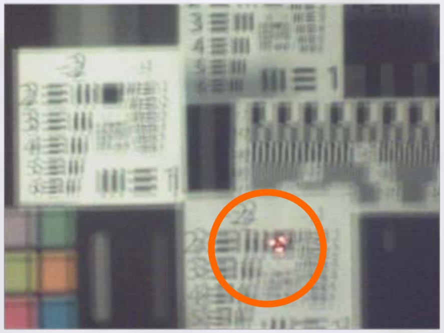
Future directions

- Variable focus lens
- Pupil mask modifications
    - Laser wavelength filtering
    - Alternative asymmetric mask shapes
- Pattern arrays
- Concentric imagers

Limitations

Real world demonstrations with ambient light caused anomalies in image processing





Range finding most accurate between minimum observable range and focal length

Thank You,

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