Co-axial depth map sensor with an extended depth range

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INTRODUCTION & MOTIVATION

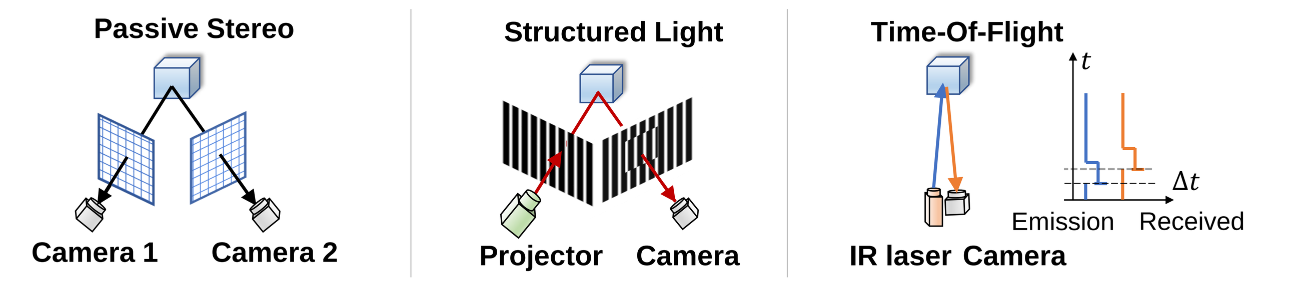
- VR/AR consumer electronics powered by depth sensors
  - Scan and digitalize a user's the environment in the real time
  - VR input
  - HCI

Image: Courtesy of Microsoft

Image: Courtesy of Stereolabs

Image: Courtesy of Occipital Inc

- Current popular technologies

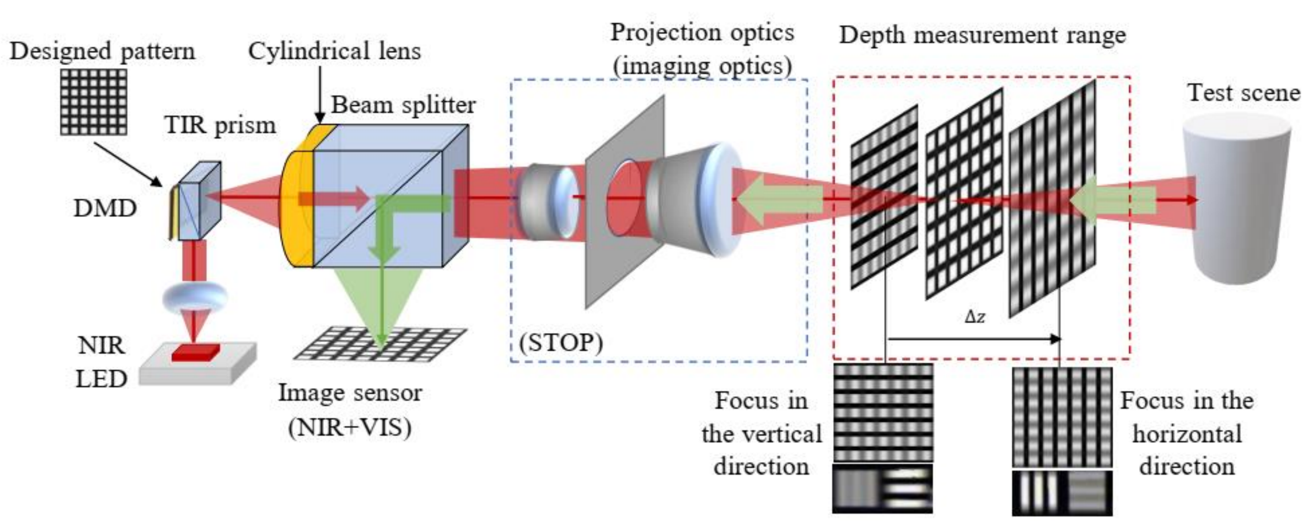


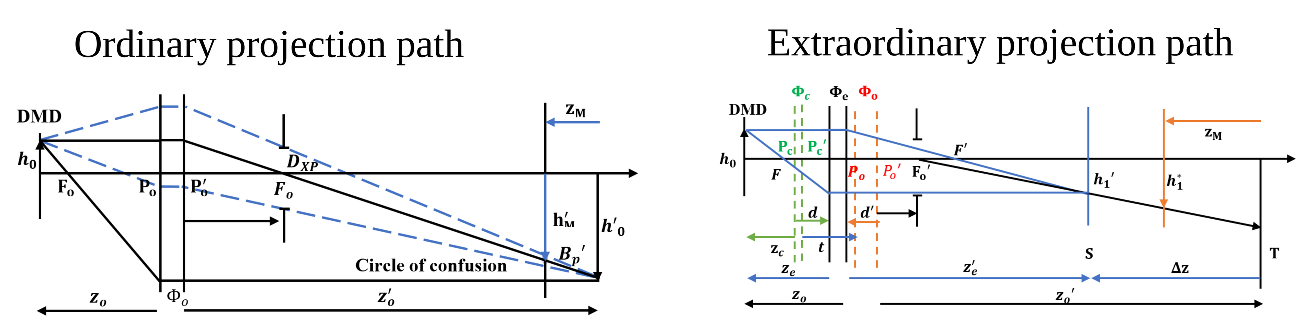
- Limitations:
  - ToF has the largest depth range but lower resolution and the interference problem.
  - Stereo and structured light have limited depth range and require the baseline separation.

CONTRIBUTIONS

- Extended depth range for measurement while maintaining the high depth map resolution
- Co-axial design for projection path and imaging path, potentially more compact and cost-effective than conventional structured light depth cameras.
- Provide a high-resolution 2D image along with a 3D depth map

CONCEPT

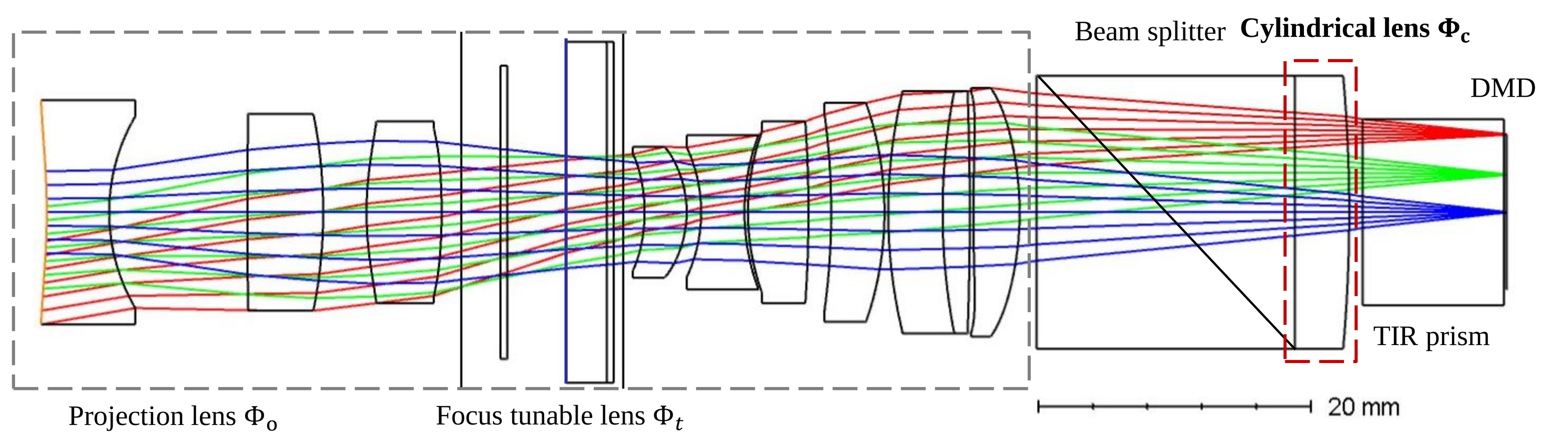




- A cylindrical lens is inserted in the projection path for the extra power in the extraordinary projection path.
- An electrically tunable lens is utilized to extend the depth measurement range.
- Based on the controlled aberration method [1], an astigmatic pattern is projected on the test scene and the contrast change of the reflected pattern image is measured in the tangential and sagittal directions for depth information.
- Co-axial design of projection path and imaging path is achieved by a beamsplitter.

EXTRAORDINARY PROJECTION PATH DESIGN

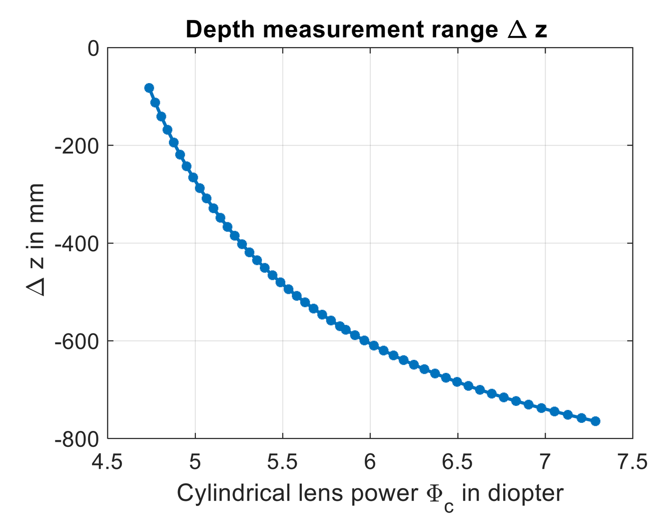
- The extraordinary projection path layout

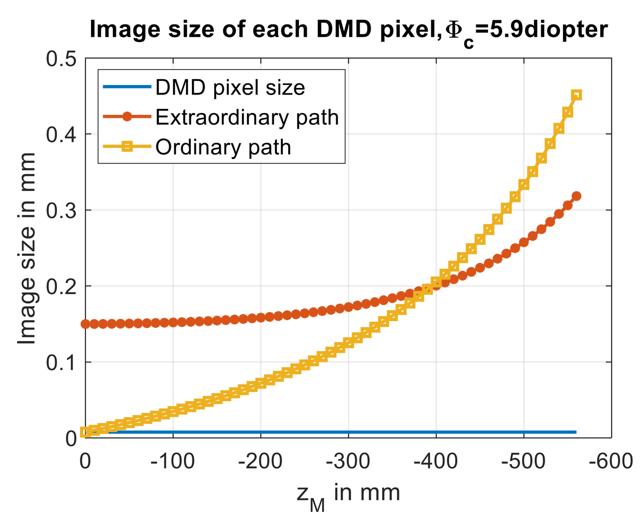


- The key is to choose the cylindrical lens power Φ_c
  - Determine the depth range Δz for measurement
  - Determine the depth map resolution for different distance

Table 1. The extraordinary projection path parameters

Φ_t	Φ_o	h_0 (DMD pixel pitch)	t	z_o
0	0.05158D	0.00768mm	0.46mm	-19.75mm



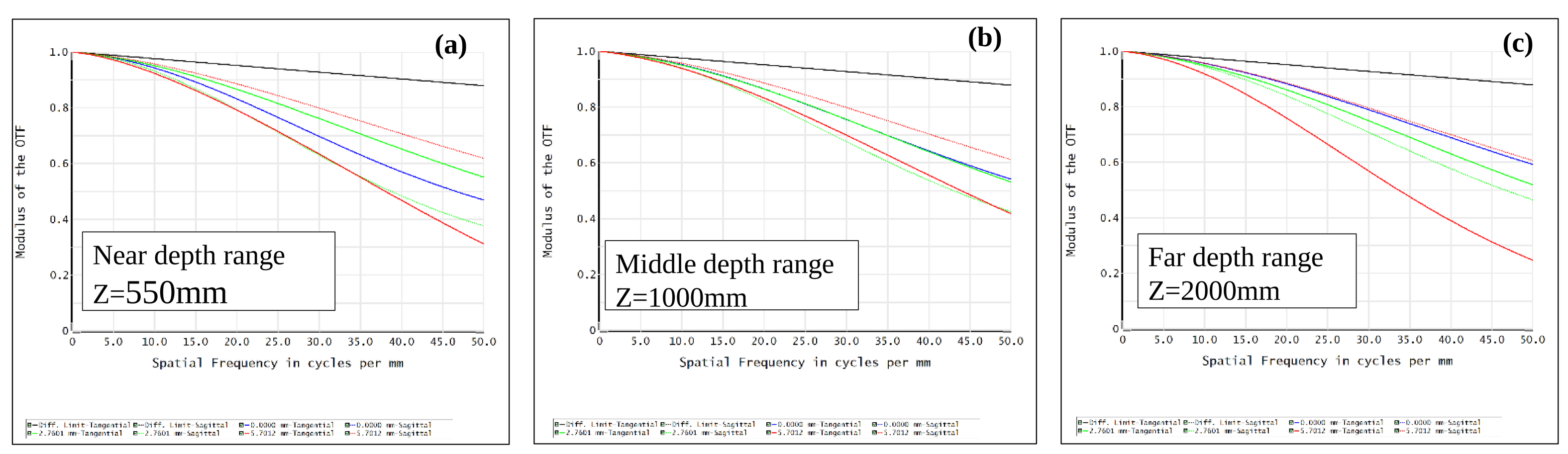


ORDINARY PROJECTION PATH DESIGN

- The ordinary projection path design(Reverse object and image for design)
  - Telecentric in the image space
  - Focus tunable lens at the stop
  - Optimization for the different focus tunable lens power

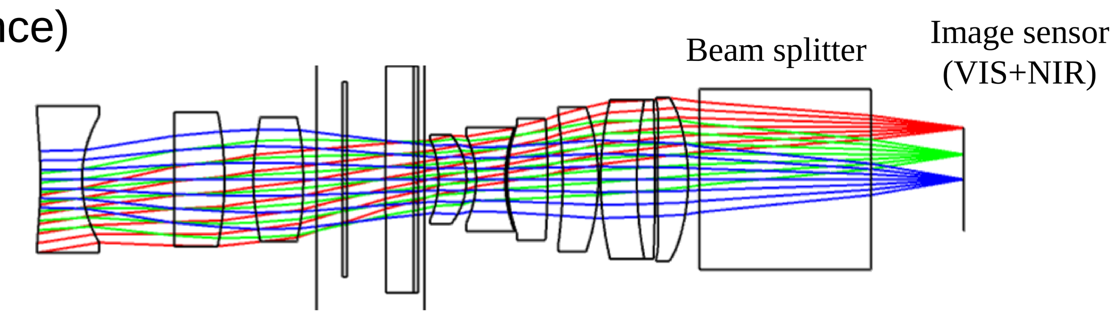
Table 2. The ordinary projection path parameters

	FOV	Image space F/#	Wavelengths
	±15.6°	3	0.810um (NIR)
Parameters change with tunable lens (TL)			
Depth Range	Near	Middle	Far
TL CVR (1/mm)	1.709×10^{-3}	0	-0.0012
TL power (diopter)	0.5	0	-0.35
Object distance (mm)	550	1000	2000
XP position (mm)	1.4e+5	1e+10	-1.7e+5
Paraxial Magnification	-0.034	-0.019	-0.0096



IMAGING PATH DESIGN

- The imaging path is the same as the ordinary projection path without cylindrical lens and TIR prism (unfold the reflection at beamsplitter for convenience)

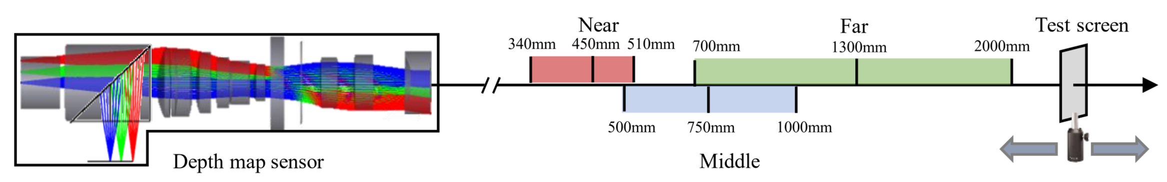


SIMULATION SETUP

- Take three different depth ranges based on the cylindrical lens power for simulation
- Use USAF resolution target as the projection pattern

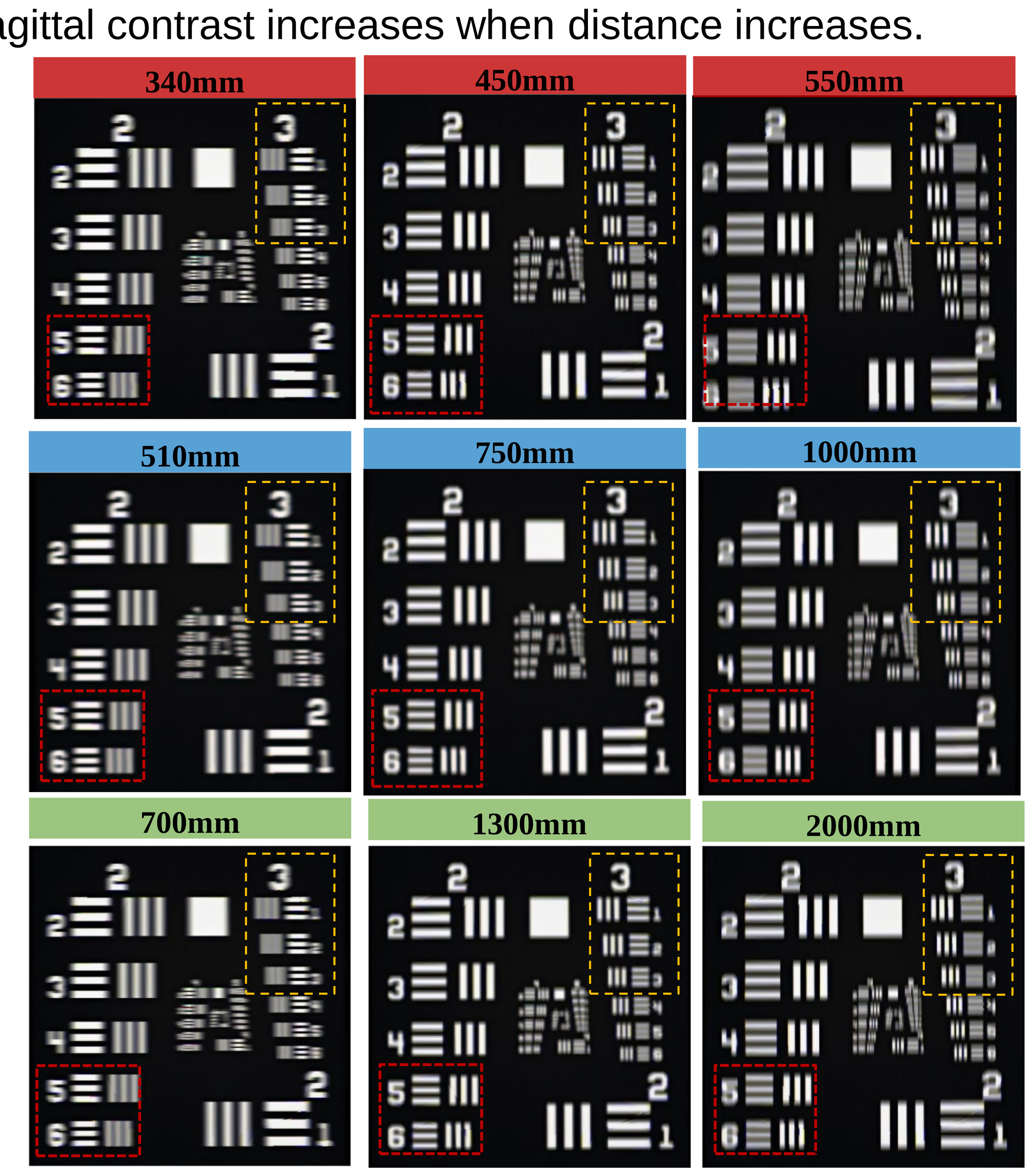
Table 3. Depth range for simulation

Cylinder lens power (diopter)	5.8846		
Depth range	Near	Middle	Far
Tunable lens power (diopter)	0.5	0	-0.35
Tangential focus distance (mm)	340	500	700
Sagittal focus distance (mm)	510	1000	2000



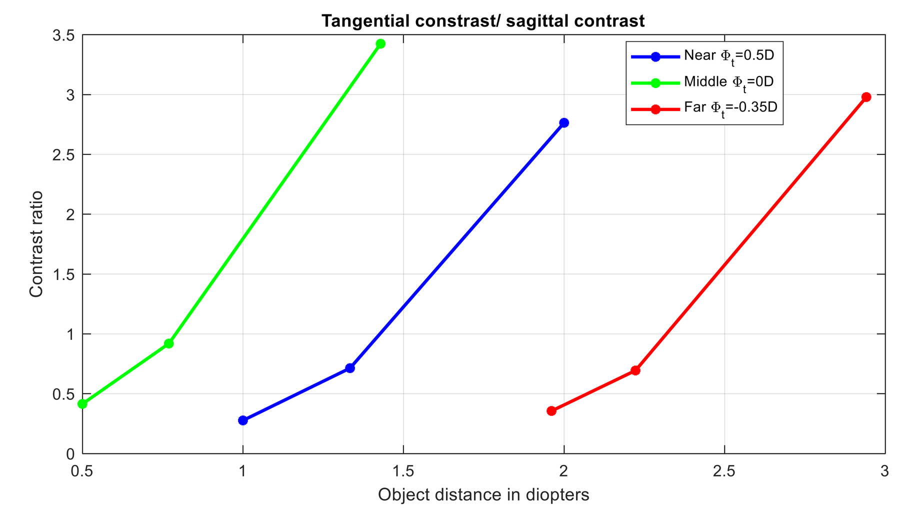
SIMULATION RESULT

- For each depth range, tangential contrast decreases monotonically when distance increases.
- sagittal contrast increases when distance increases.



ANALYSIS

- Contrast ratio vs. depth for calibration
- Measurement overlap in the sub ranges can increase the measurement accuracy



REFERENCE

[1] Birch, G. C., Tyo, J. S. and Schwiegerling, J., "Depth measurements through controlled aberrations of projected patterns," Optics express 20(6), 6561 (2012).

CONTACT