High-speed fringe projection and real-time phase analysis for robot 3D vision applications

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3DMC 3D METROLOGY CONFERENCE

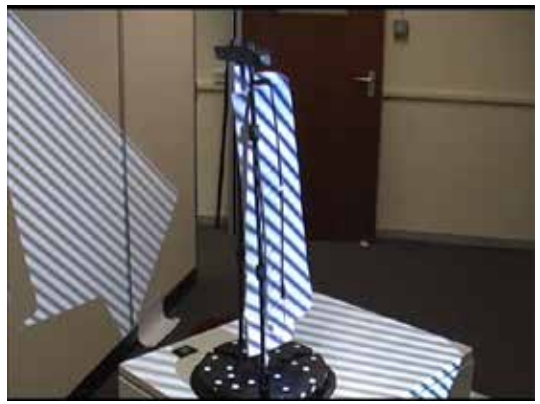
The Future Metrology Hub

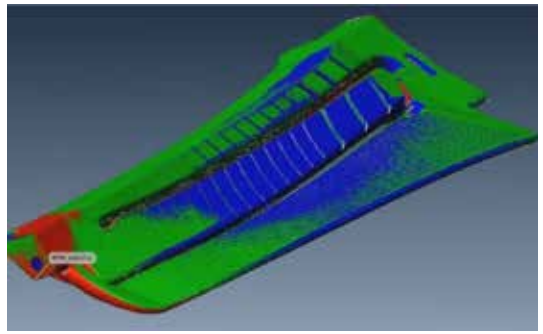
LCF Light Controlled Factory

Loughborough University

Outline

- Motivation
- Pick-and-place demonstrator
- Implementation details and results
- Summary





Projected fringe scanner:
Phase Vision Quartz 1200 DBE
Images courtesy Phase Vision Ltd

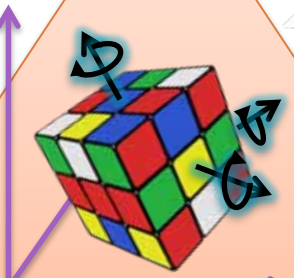
Motivation

Automated assembly, machining, verification – need for **recognition** and **pose estimation** of marker-free objects

Object Recognition

Robotic assembly

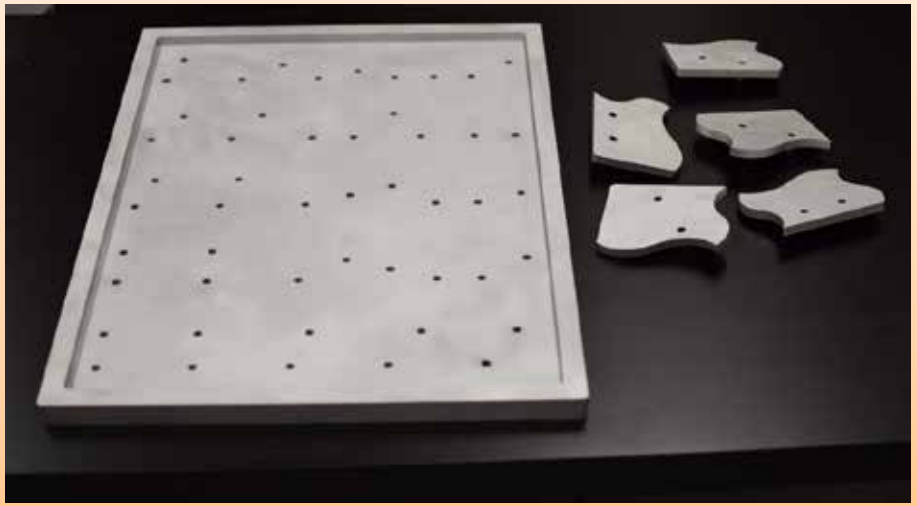
Machining



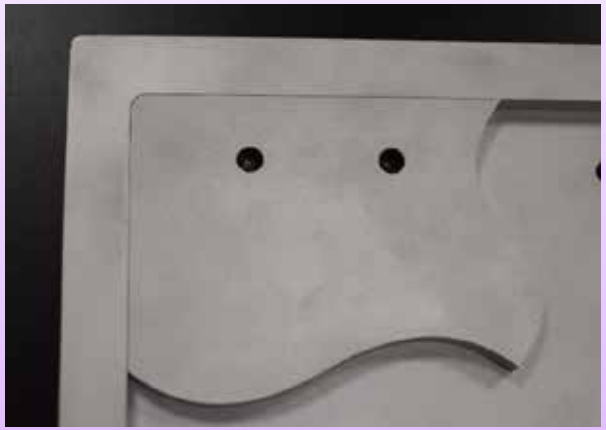
Pose Estimation

Quality Control

6 Degrees-of-freedom ‘pick and place’

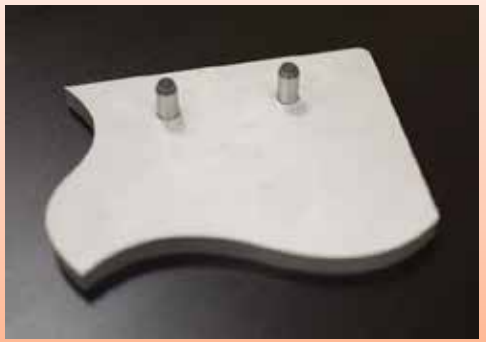


25 ‘jigsaw’ pieces fabricated from 10mm aluminium plate



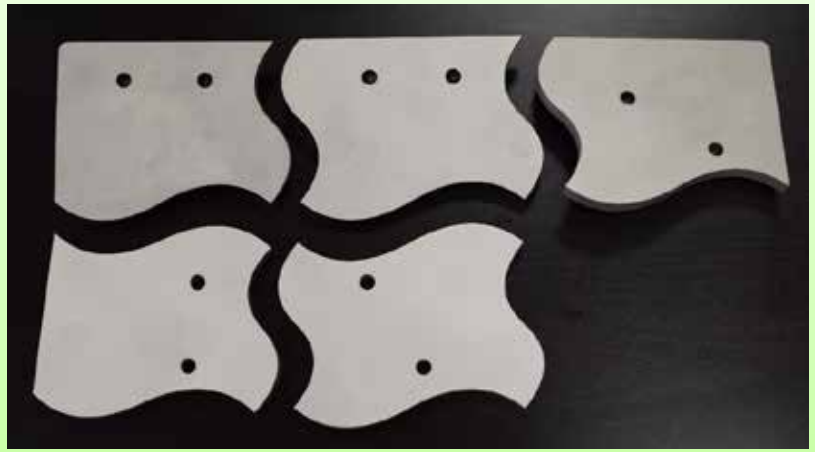
Precisely machined: 200 mm piece-piece and piece-border separation

- Each piece located by two 8mm dowel pins
- Receiving holes in the base have 8.1 mm diameter (50 mm clearance)

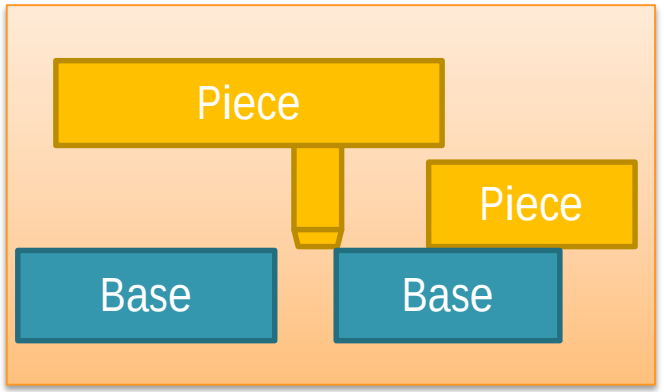


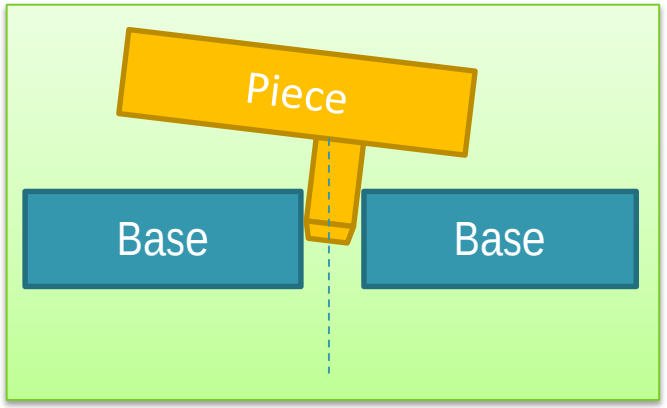
Challenges

1. Unique identification of pieces



- Puzzle piece blanks – 5 distinct parts
- Blanks + holes – 25 unique geometries

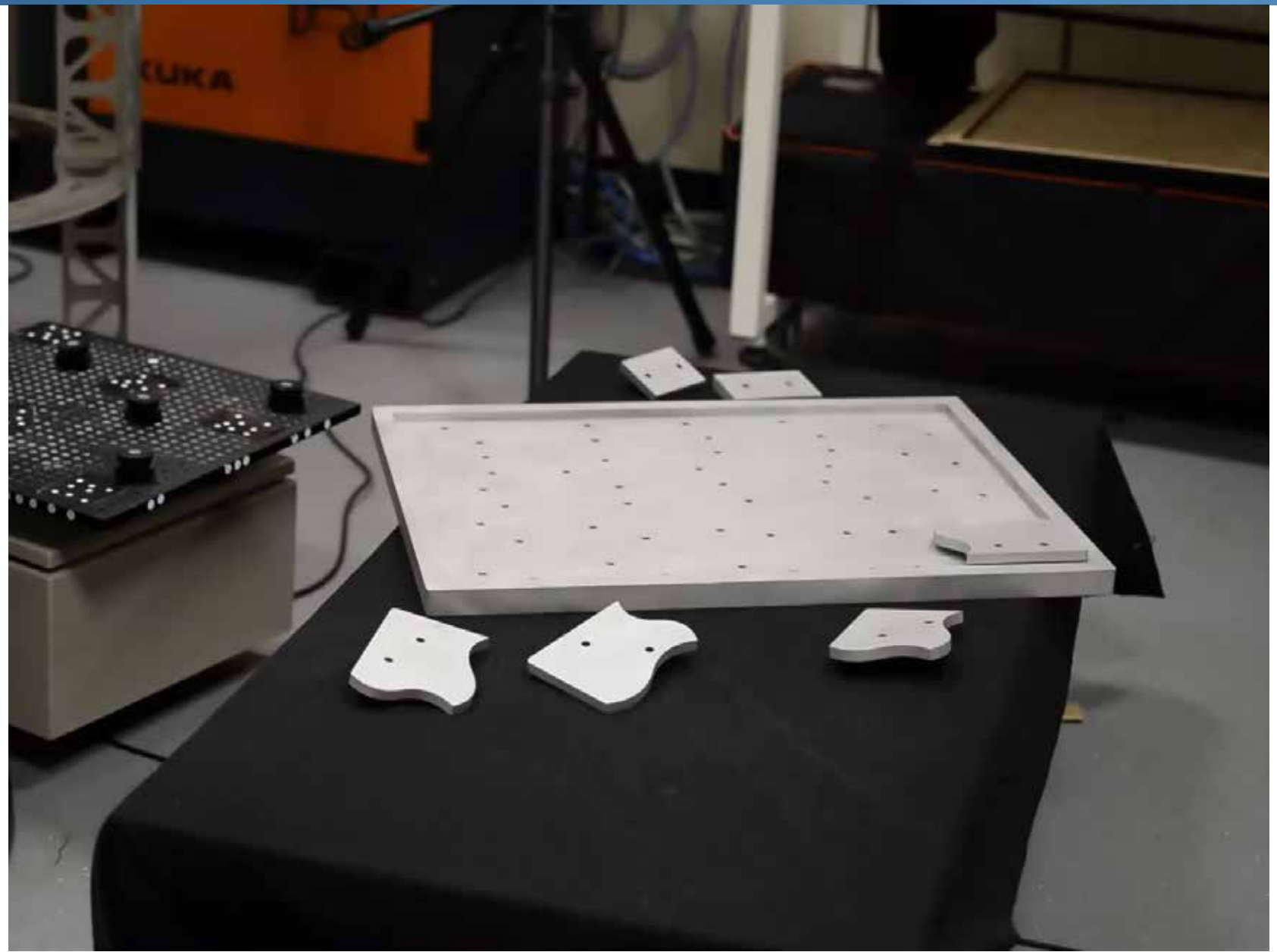




2. Accurate estimation of pose

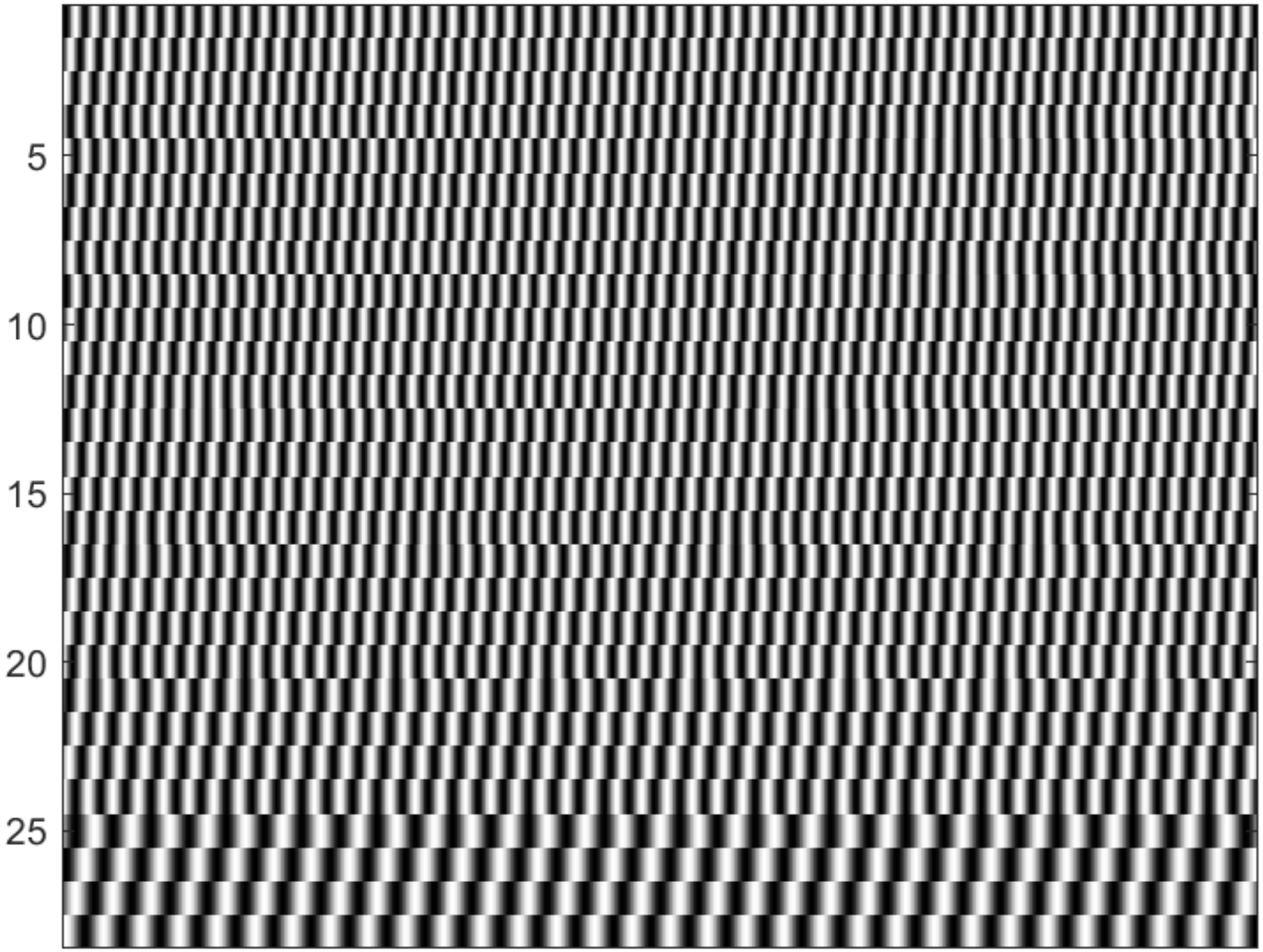
3. Accurate registration of co-ordinate systems

Metrology enabled ‘pick and place’



Sinusoidal fringe pattern sequence

e.g. 64 fringes combined with 4-frame phase stepping algorithm requires 28 patterns



High-speed data acquisition

Camera

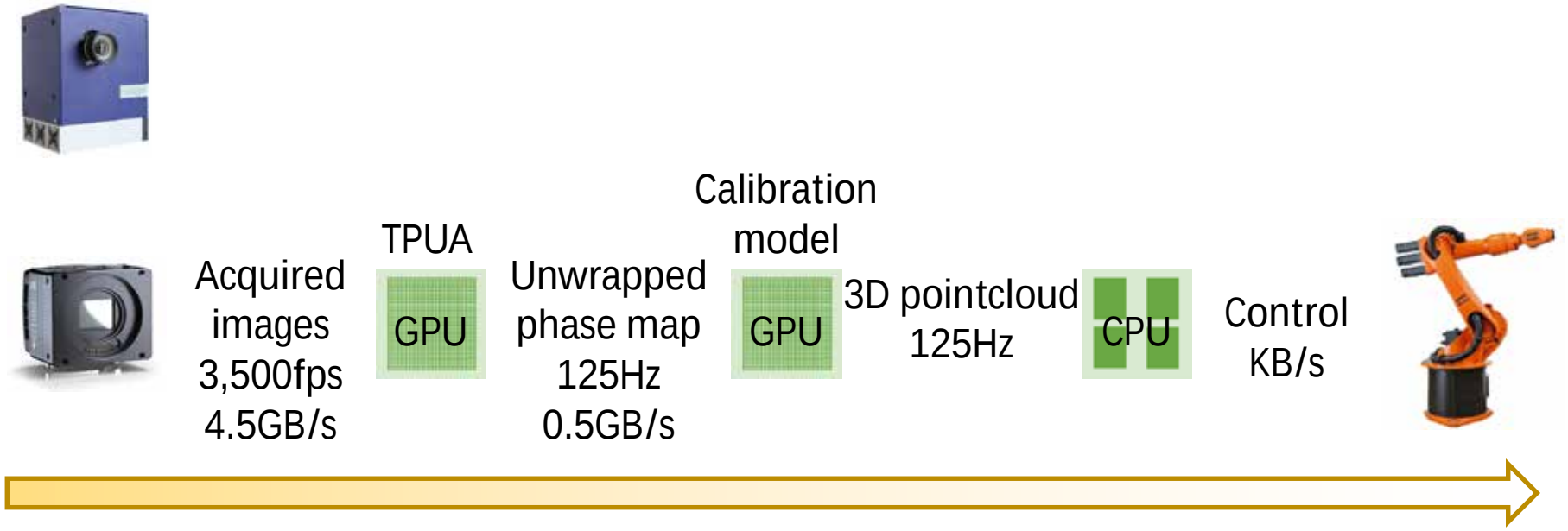
- Ximea XiB-64 10-bit camera
- 1280x864 (1.1Mpx) @ 3,500fps
- Mono10p packed data @ 4.5GB s^{-1}

Projector

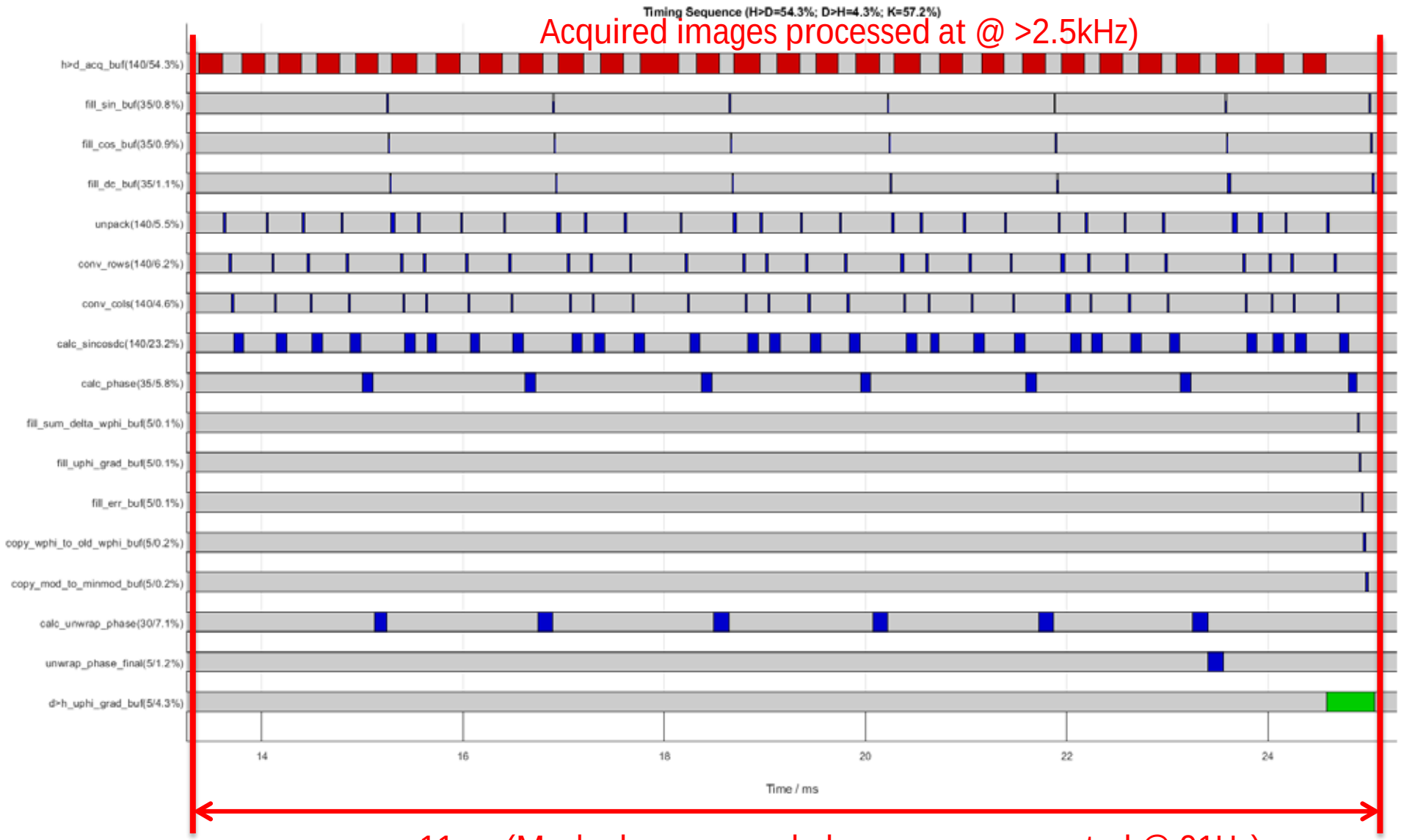
- Vialux 0.7” DMD projector
- 1024x768 @ 22kHz
- 8-bit patterns @ 290fps

Real-time 3D robot vision

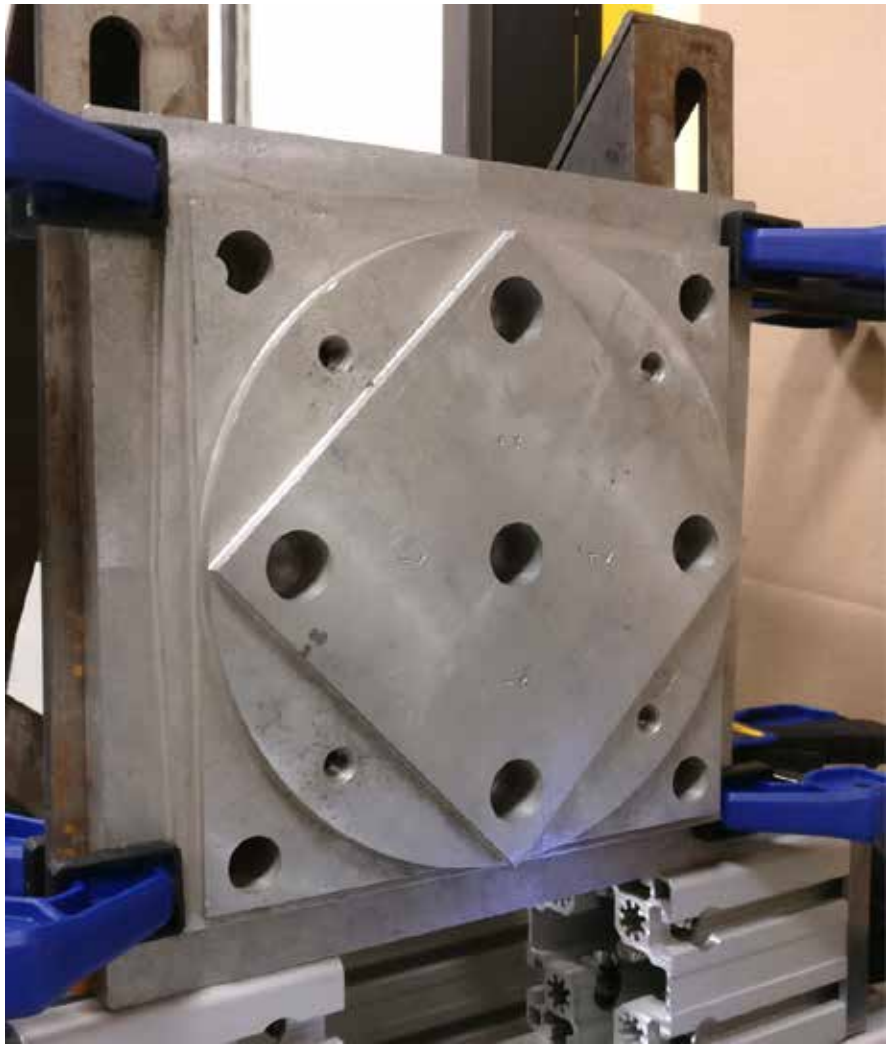
- Sinusoidal fringe projection
- Reverse exponential sequence: 28 patterns
- Temporal phase unwrapping algorithm (TPUA) implemented on GPU

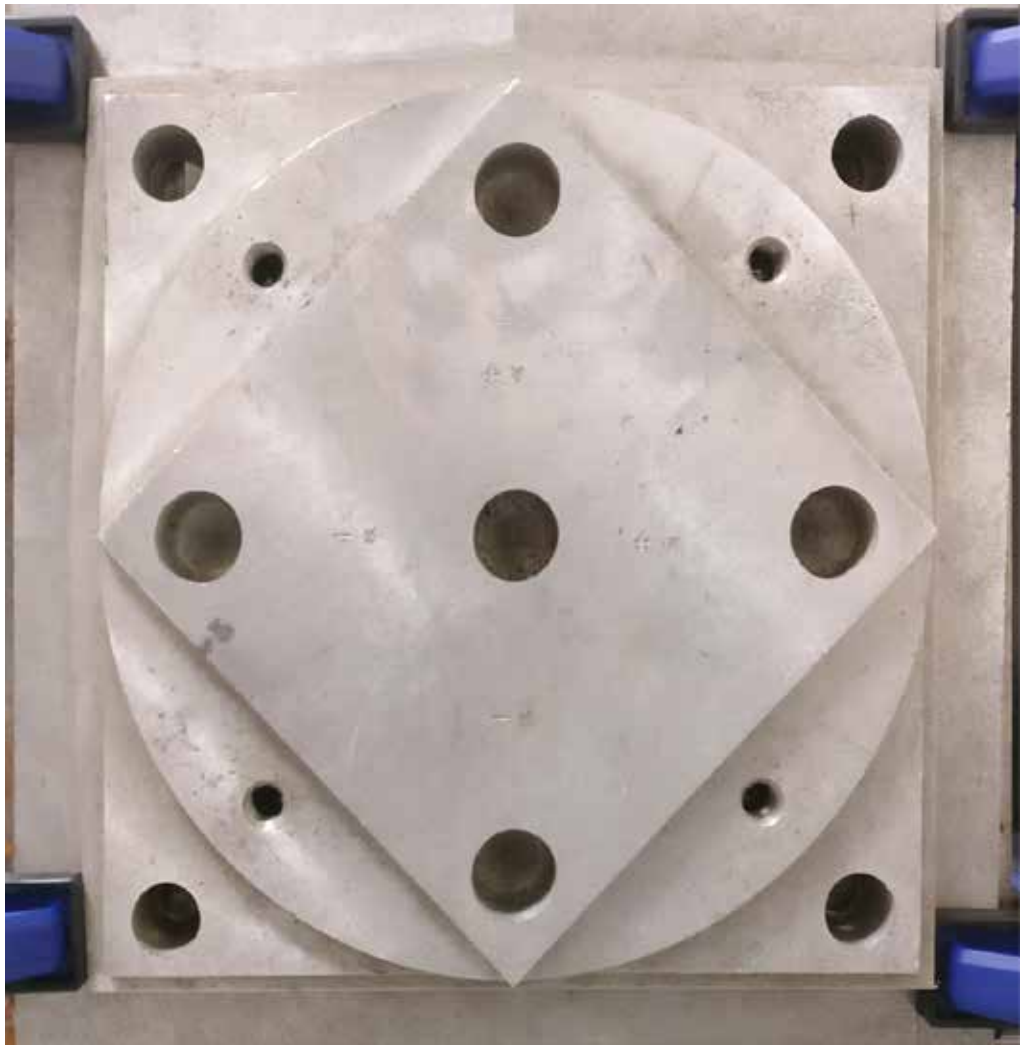


GPU task timeline

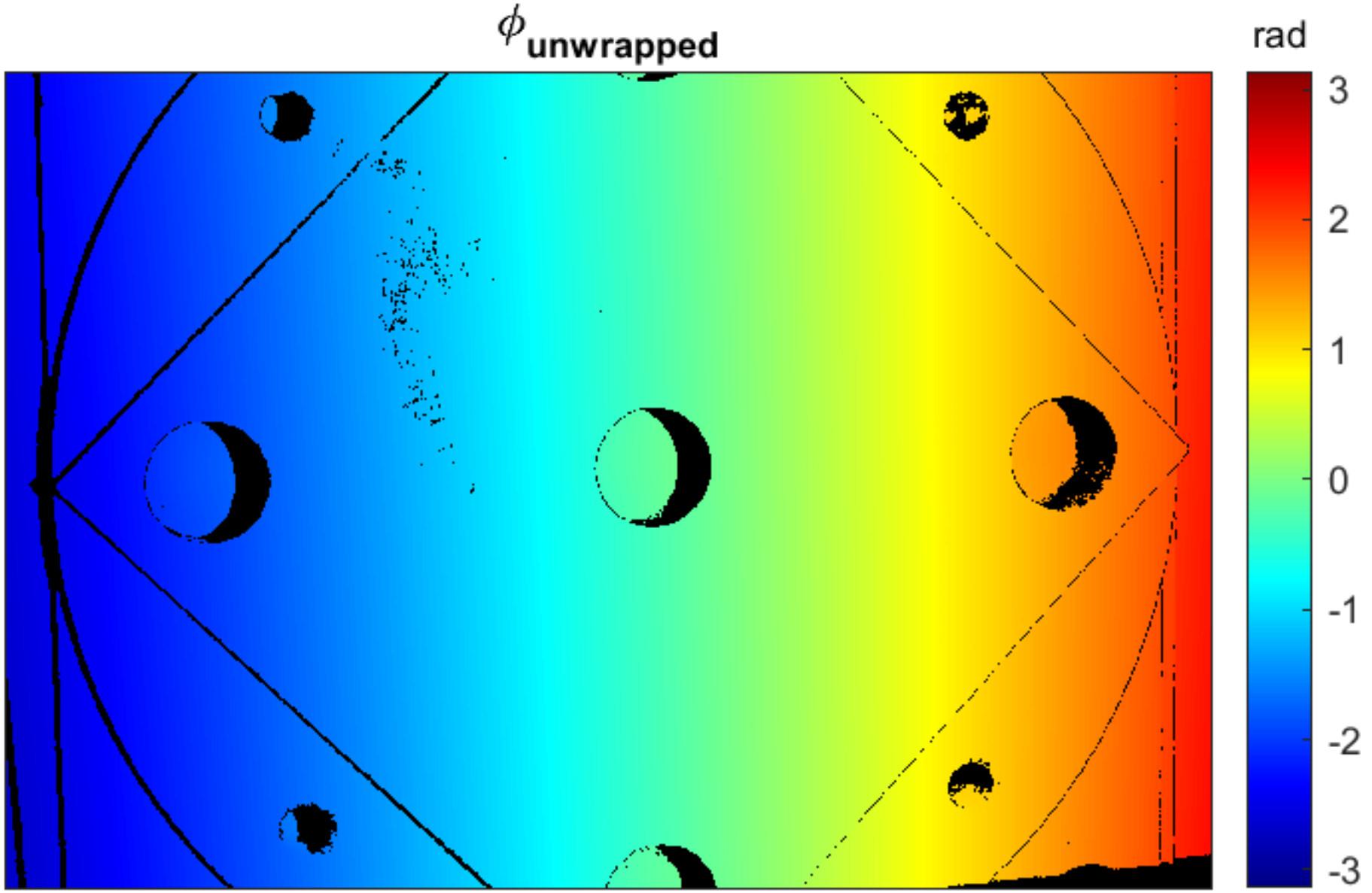


Machined component

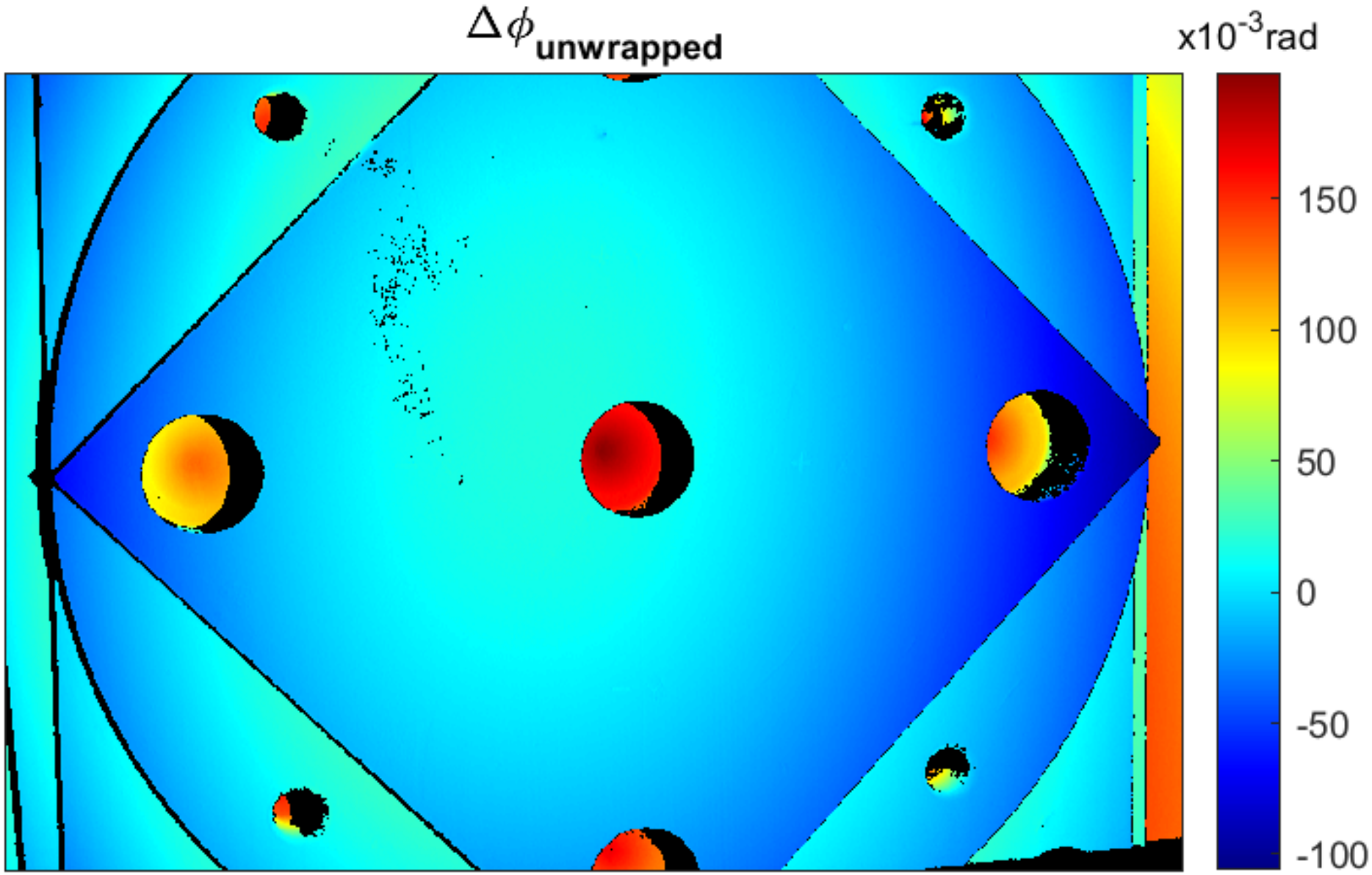




Unwrapped phase



Unwrapped phase (ramp removed)



Real-time 3D robot vision

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BUT PROJECTION OF 8-BIT GREYSCALE PATTERNS IS LIMITED TO 290FPS

Acquired images 3,500fps 4.5GB/s

TPUA

GPU

Unwrapped phase map 125Hz 0.5GB/s

91Hz

Calibration model

GPU

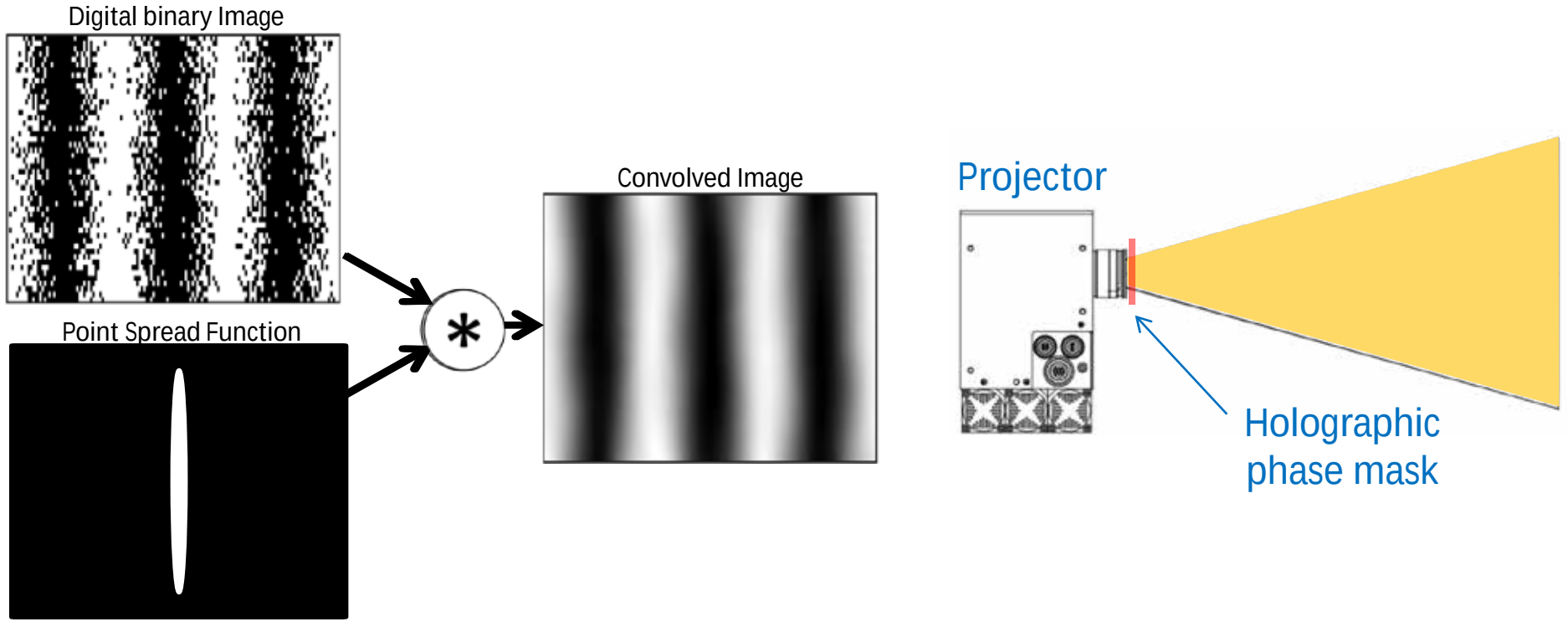
3D pointcloud 125Hz

CPU

Control KB/s

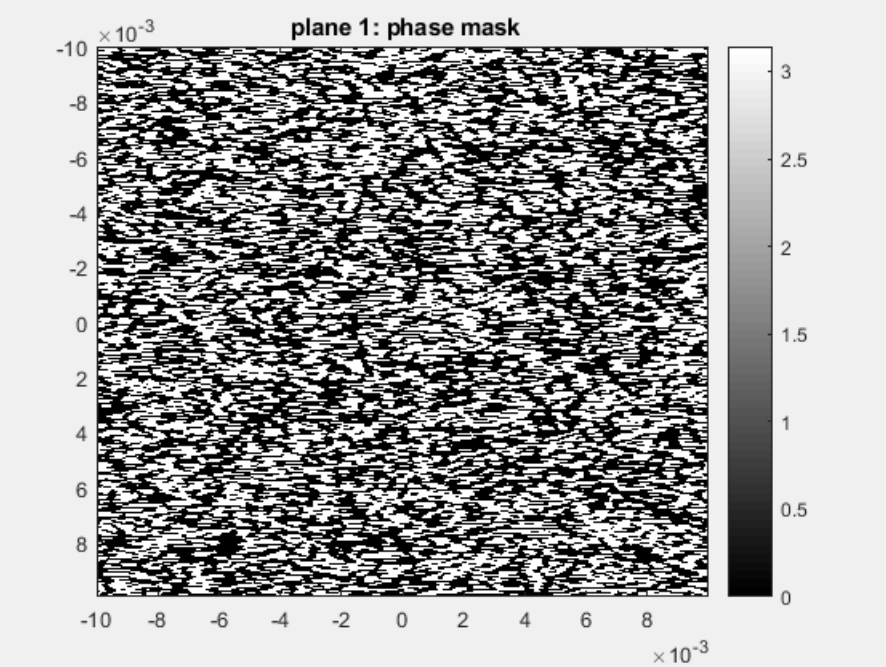
Achieving higher frame rates

- Project binary patterns @ >20kHz
- Greyscale patterns require sequence of bitplanes (e.g. 256x slower)
- Extend projector's point spread function (PSF) to introduce spatial blur and generate pseudo-sinusoidal fringe patterns
- Isotropic PSF achievable using defocus or spherical lens aberrations
- Anisotropic PSF achievable using custom optics

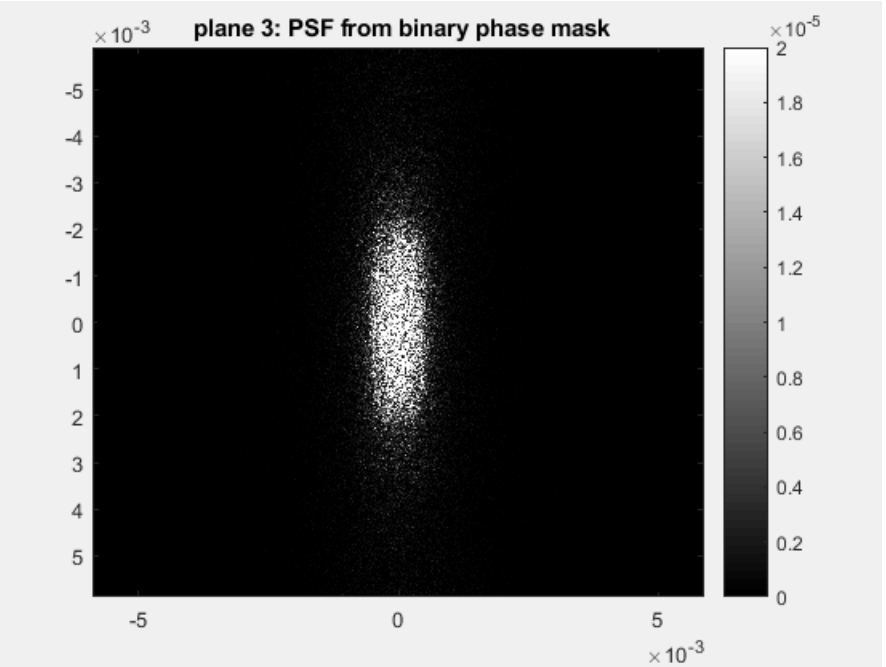


Holographic phase mask

- Numerical model based on polychromatic Fourier optics
- Photolithography followed by reactive-ion etching (RIE)
- Features size is 300nm

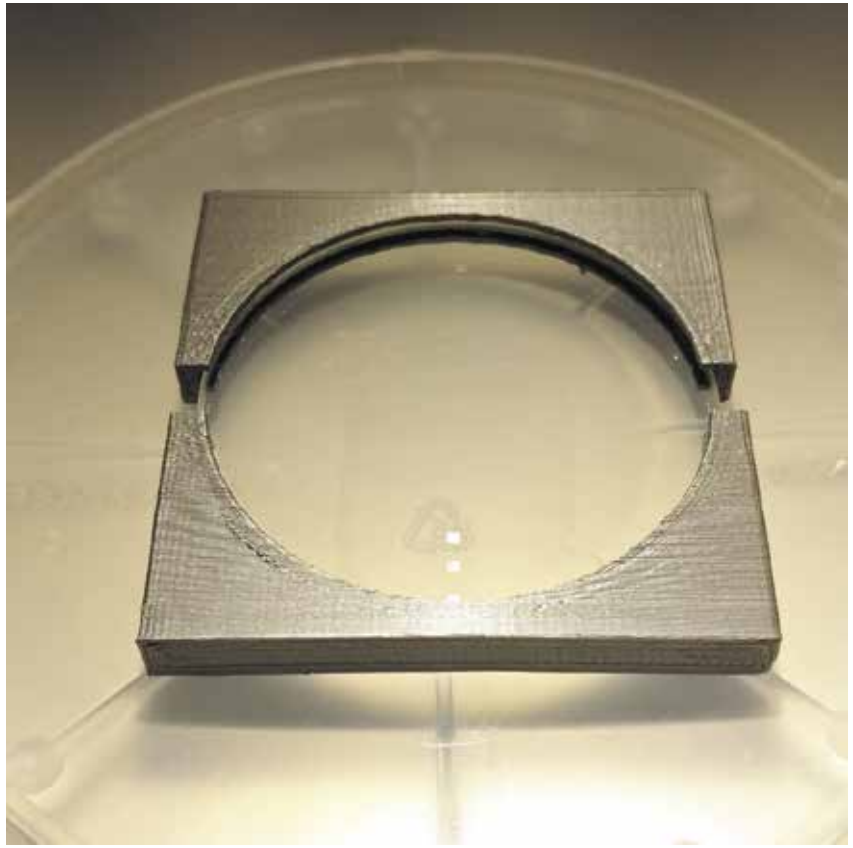


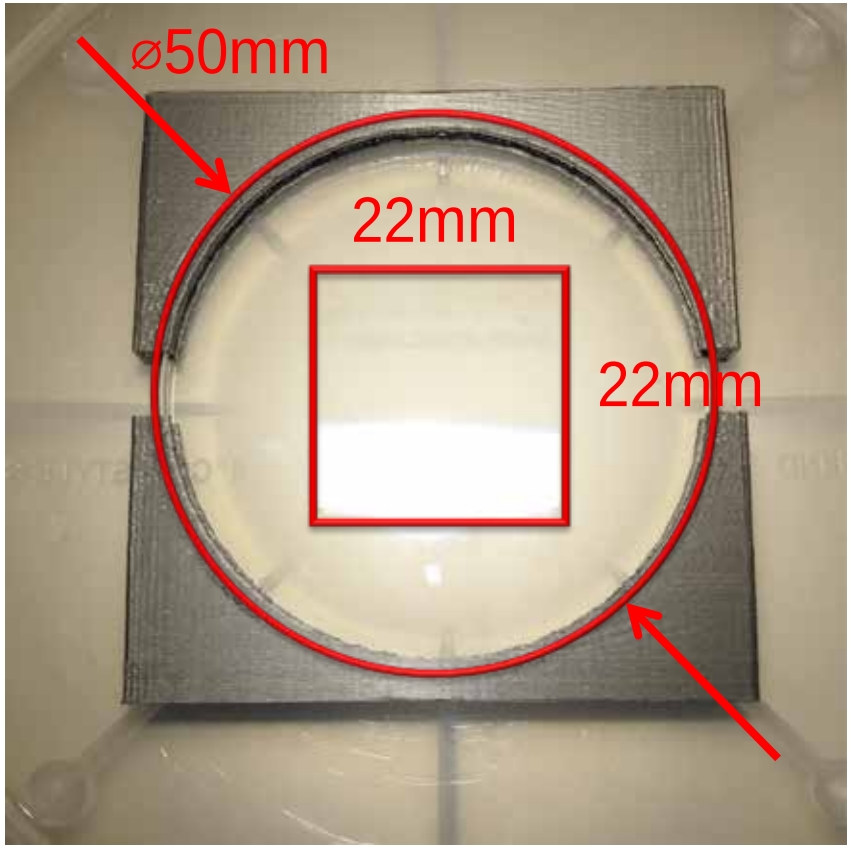
Binary phase mask



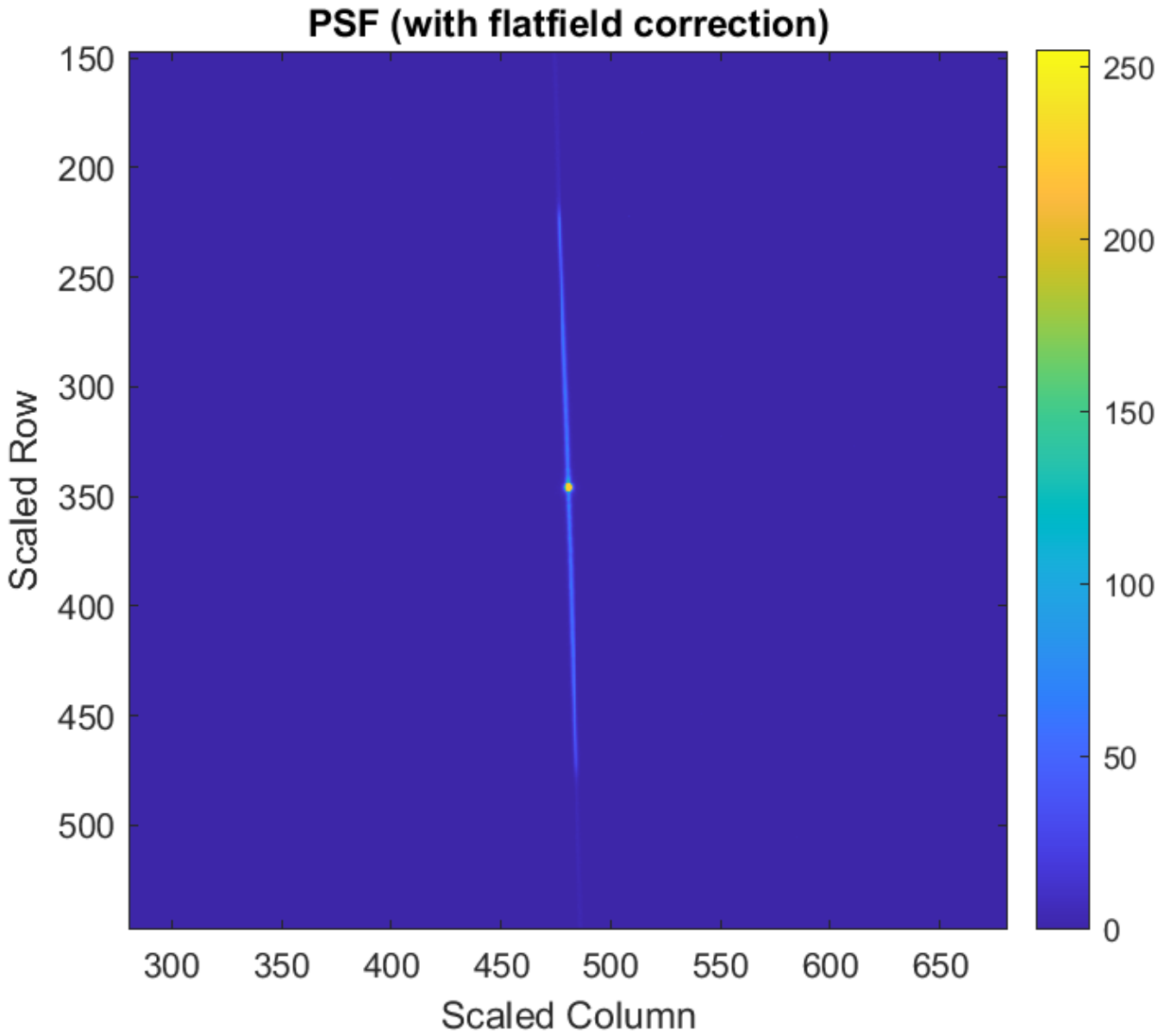
Anisotropic point spread function

Holographic phase mask





Point spread function: measured @ 460nm



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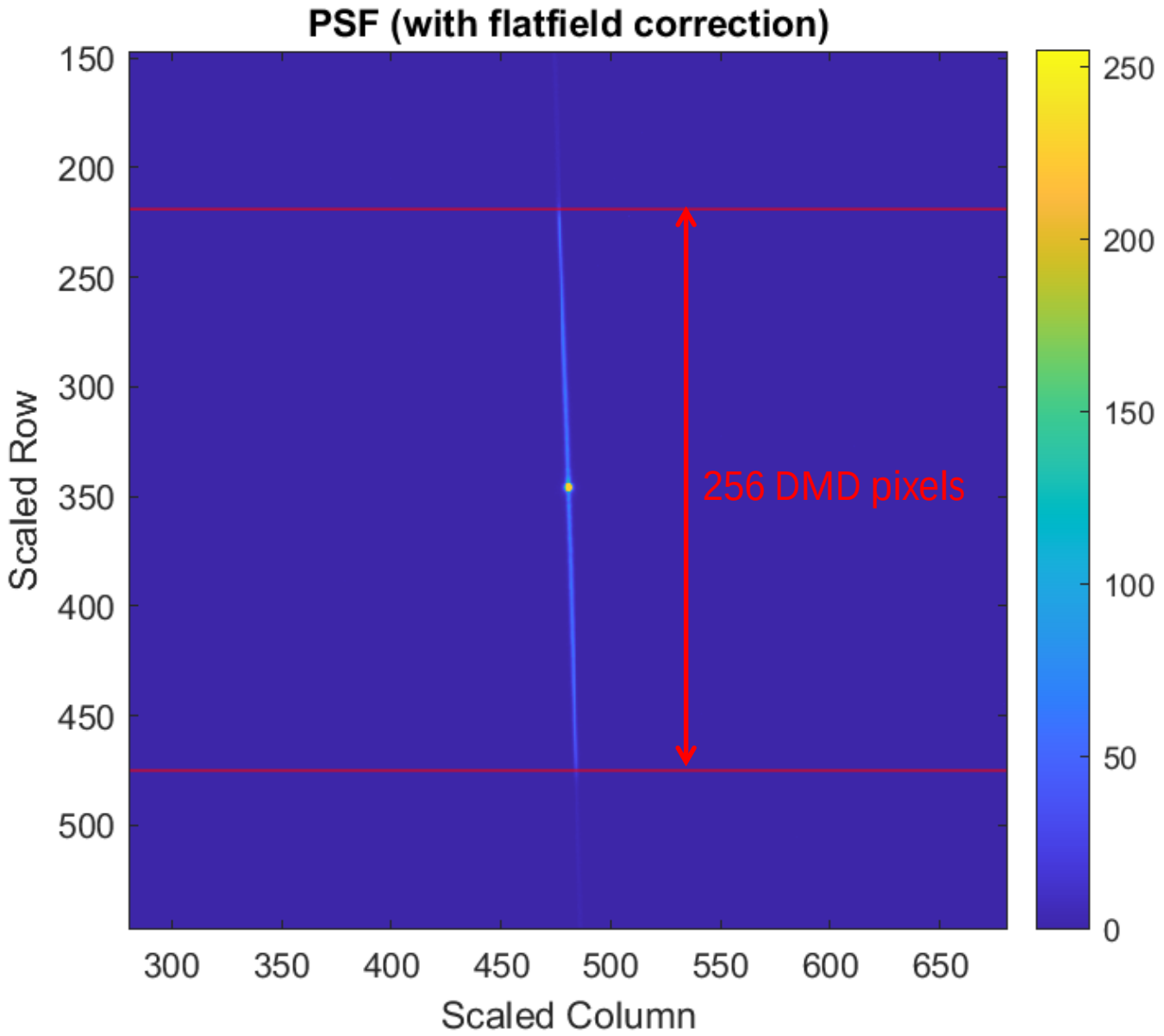
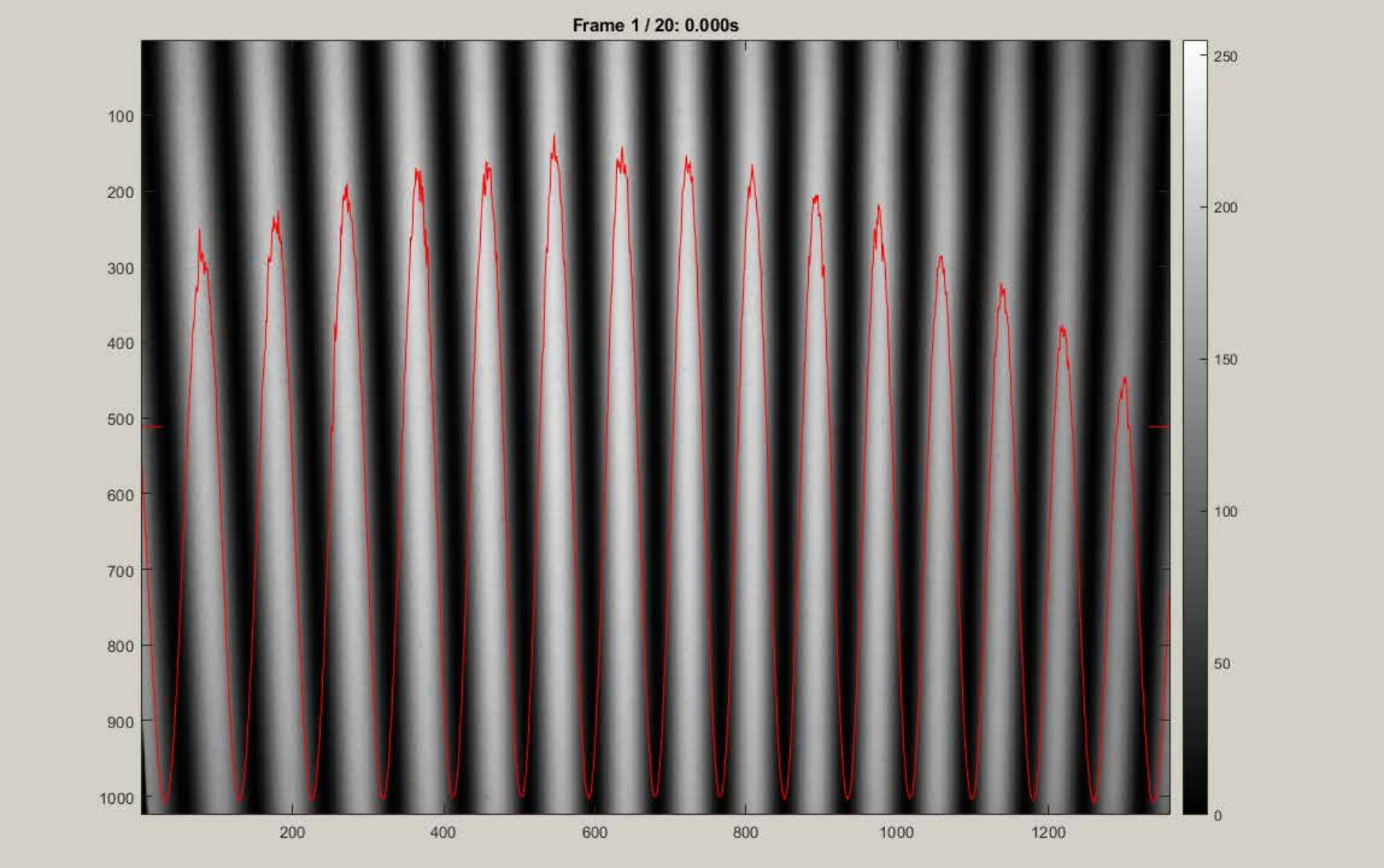
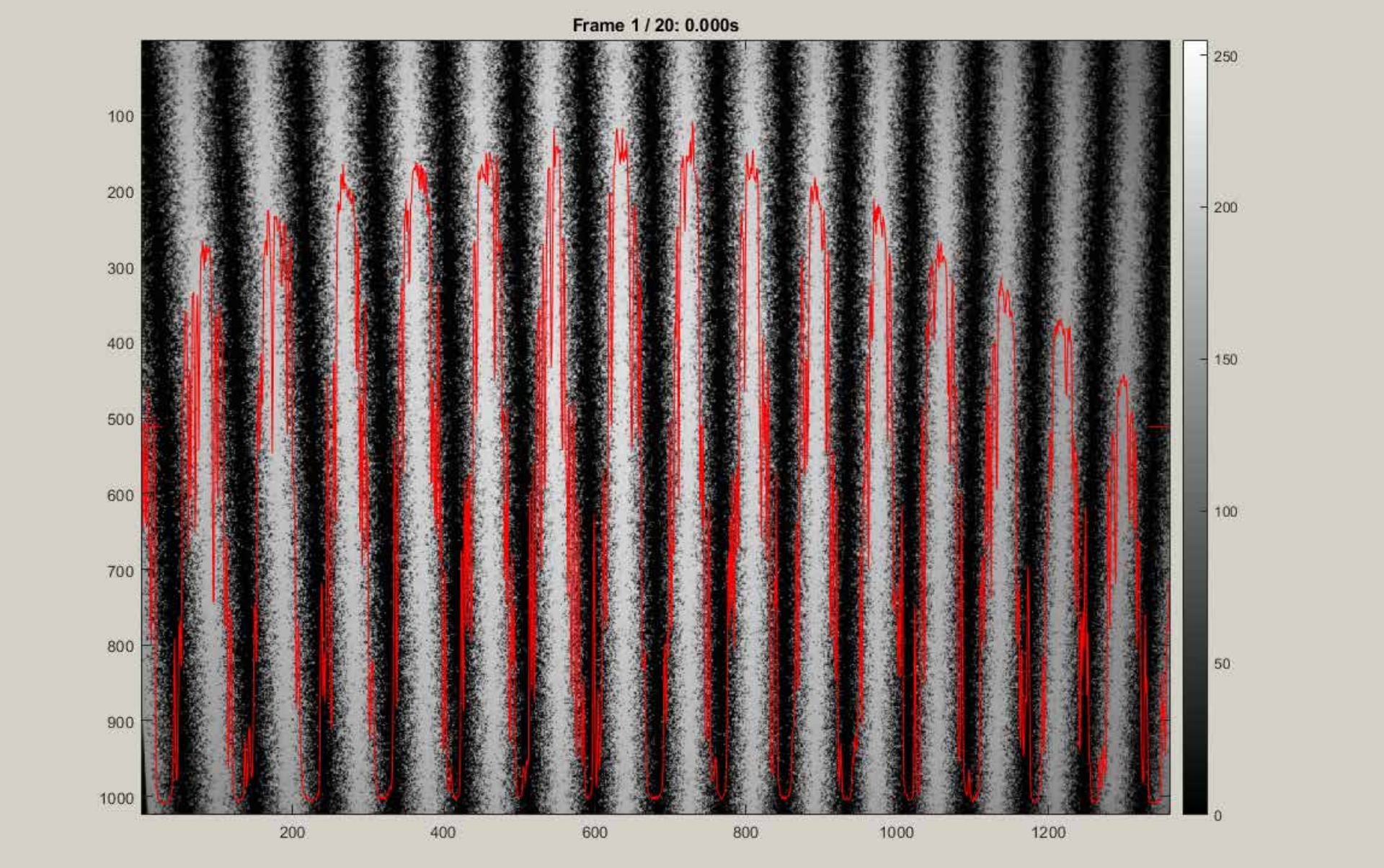


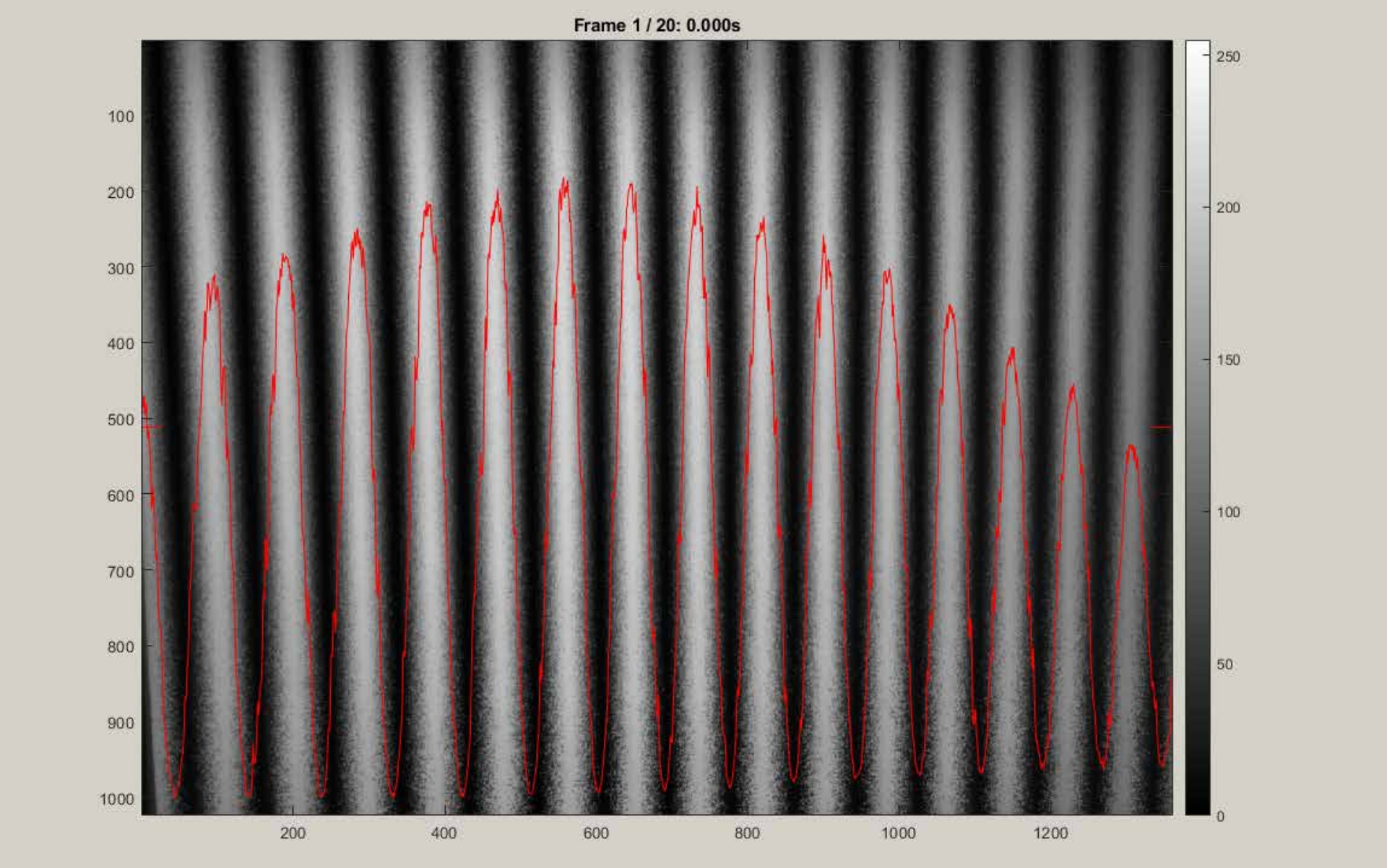
Projected pattern: 8-bit greyscale



Projected pattern: Random binary



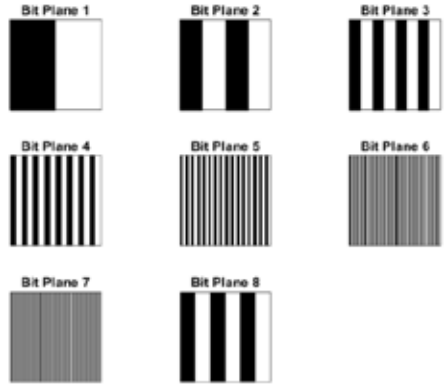
Projected pattern: Random binary with phase mask



Greyscale projection of sinusoidal fringes

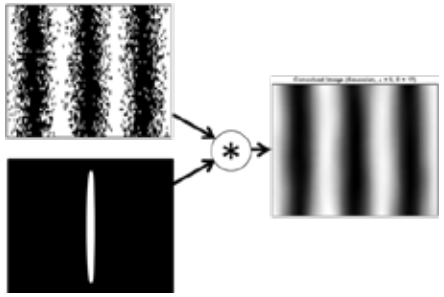
Temporal integration:

- Pro: High spatial resolution
- Con: Limited frame rate (290Hz)



Spatial integration:

- Pro: High frame rate (22kHz)
- Con: Custom optics,
  edge effects at top & bottom



Combined method:

- N-bit temporal integration + M-bit spatial integration
- Match camera frame rate and reduce edge effects

Summary

Motivation:

- Metrology-grade 3D pointclouds @ >100Hz for robot vision

Holographic phase mask:

- Enables sinusoidal fringe patterns @ up to 22kHz
- Evaluating initial samples
- Further manufacturing refinement

Real-time data processing:

- TPUA pipeline implemented on GPU @ 3.2GB/s
- Computing masked unwrapped phase maps @ >90Hz (Rev Exp 64-4)

Next steps:

- GPU calculation of 3D pointcloud
- Pointcloud updates @ >600Hz (reduced fringe sequence)
- Dynamic adjustment of projection sequence
- Closed-loop robot demo