Mesoscopic Photogrammetry with an Unstabilized Phone Camera

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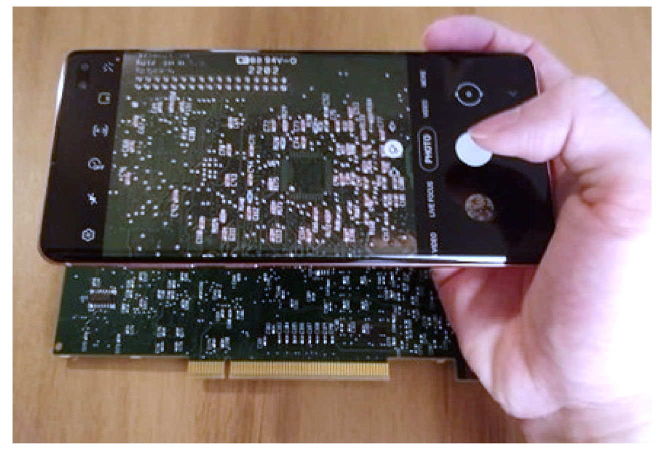
CVPR VIRTUAL JUNE 19-25

Summary

- We developed an end-to-end, intensity-based, CNN-regularized[1], photogrammetric reconstruction algorithm that stitches multiple phone camera images taken at close range under freehand motion
- We demonstrate high-accuracy (10s of μm) 3D profilometry of mesoscopic samples (sub-mm variation)

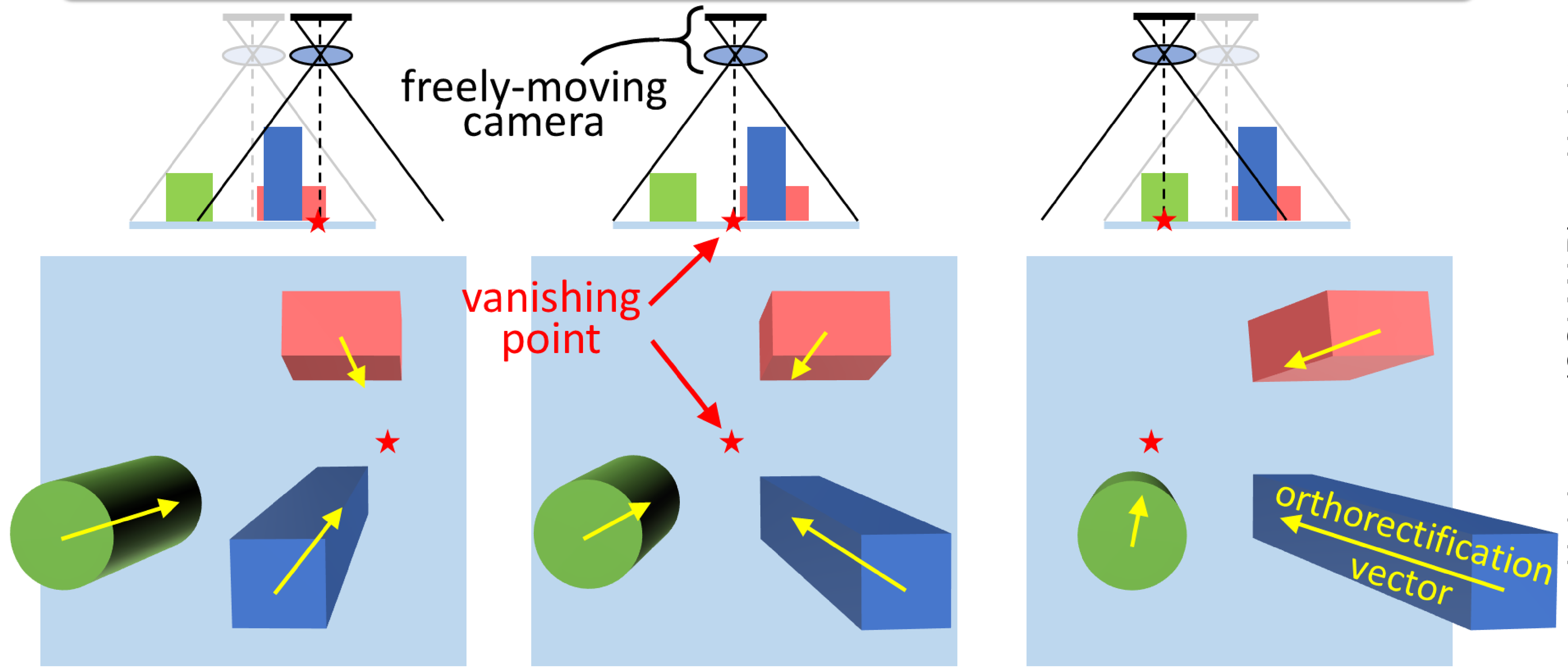
Motivation

- Smartphone cameras and 3D photogrammetric/ structure-from-motion (SfM) algorithms are designed for large objects far away (10s of cm ~ infinity)
- But, can we use our smartphones to get high-resolution 3D height profiles using a sequence of very close-range images (5-10 cm)?



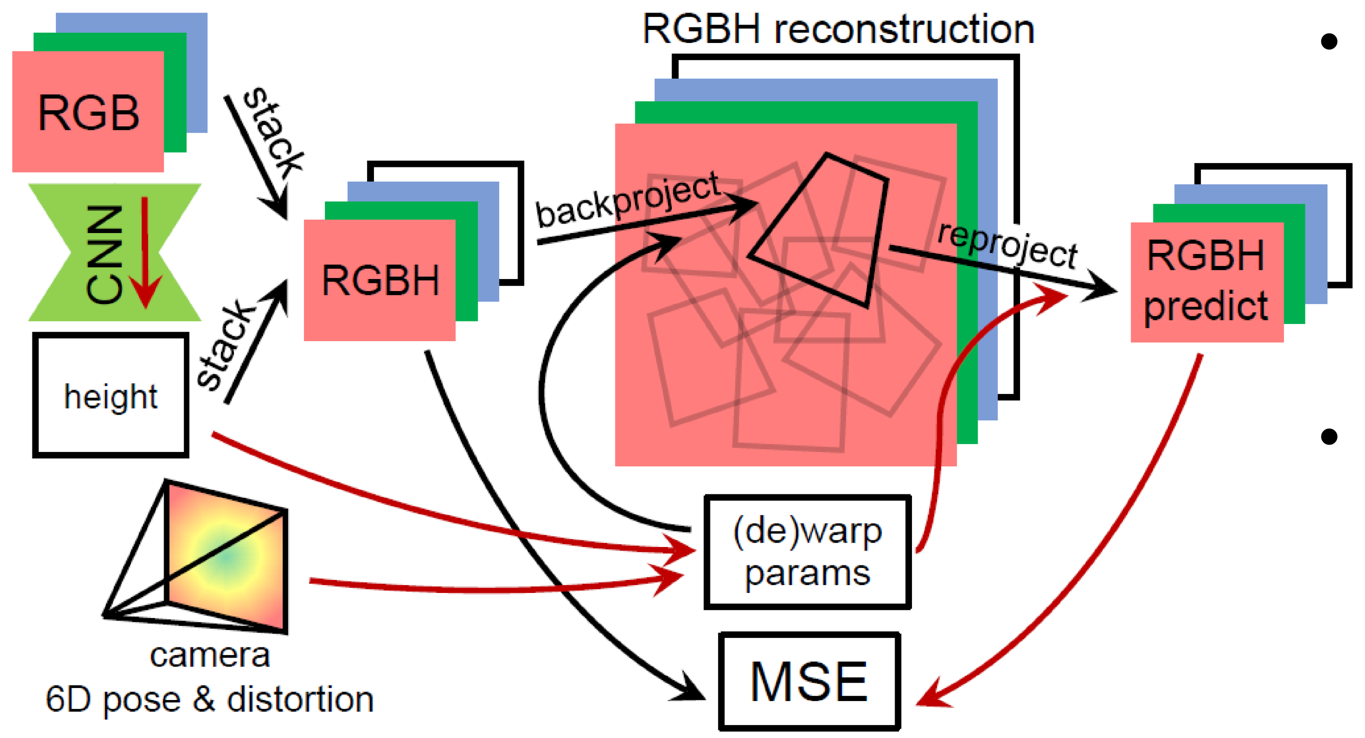
- Applications: low-cost approach for historical artwork documentation, material inspection, biomedical imaging

Physical model: plane-plus-parallax



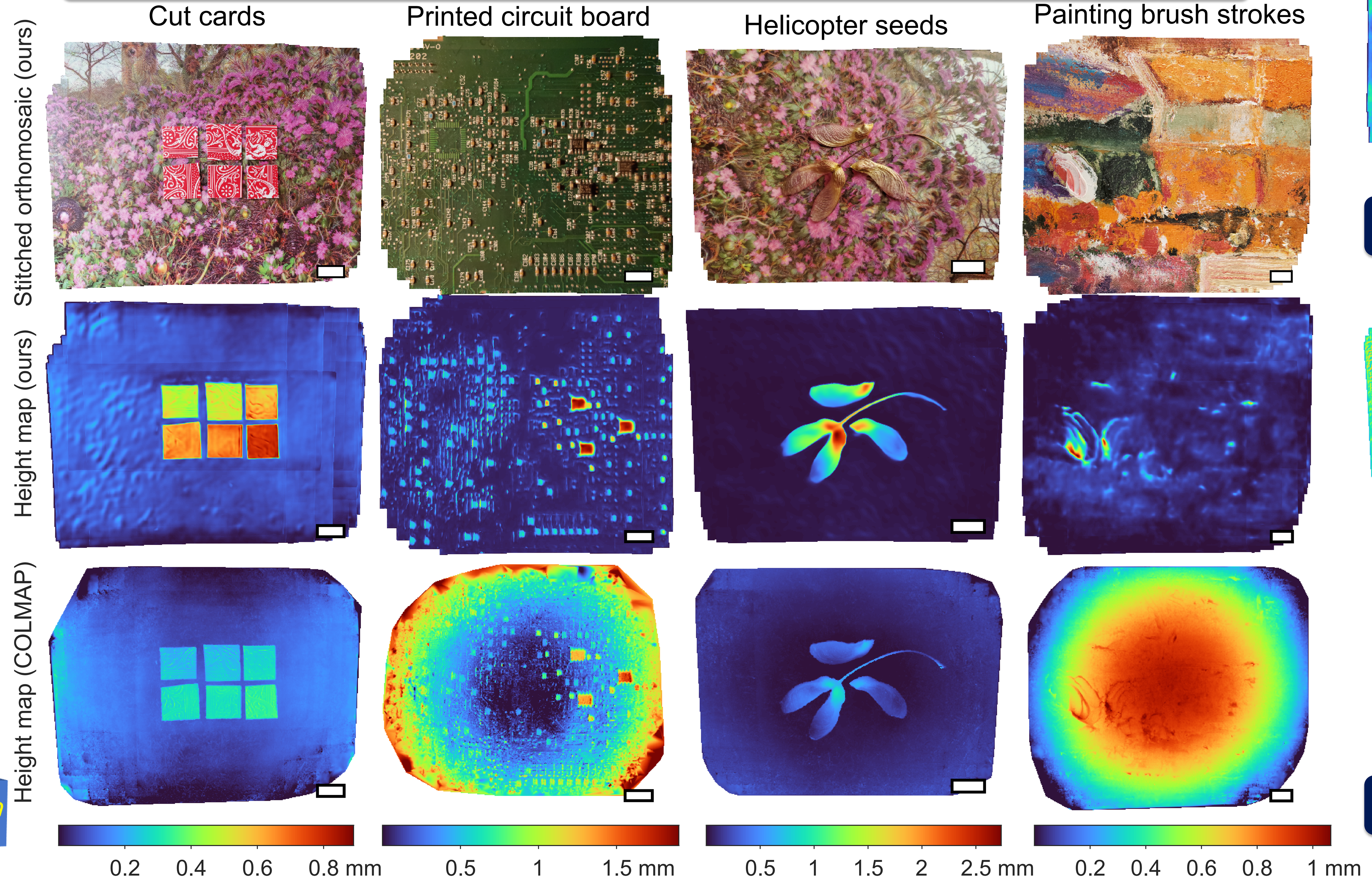
Parallax-correcting orthorectification vector lengths are proportional to height, which are optimized jointly with camera 6D pose

End-to-end 3D reconstruction and stitching algorithm



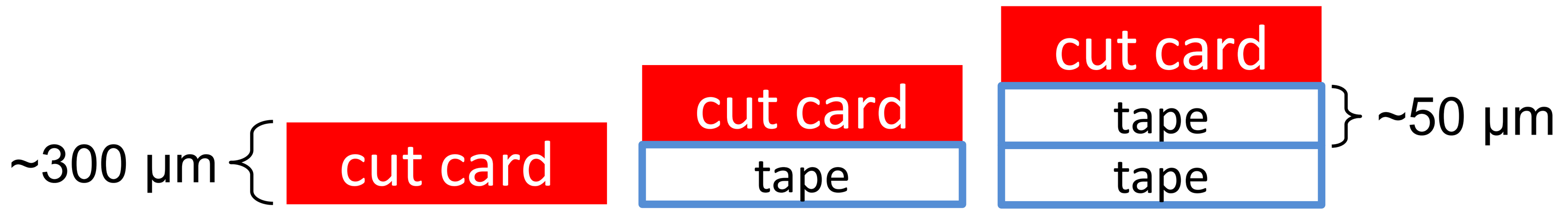
- Treat height as an unknown 4th image channel, parameterized as the output of an untrained CNN (DIP[1])
- Minimize reprojection error with respect to CNN, camera poses, and distortion simultaneously

Results: stitched orthomosaics and 3D height maps



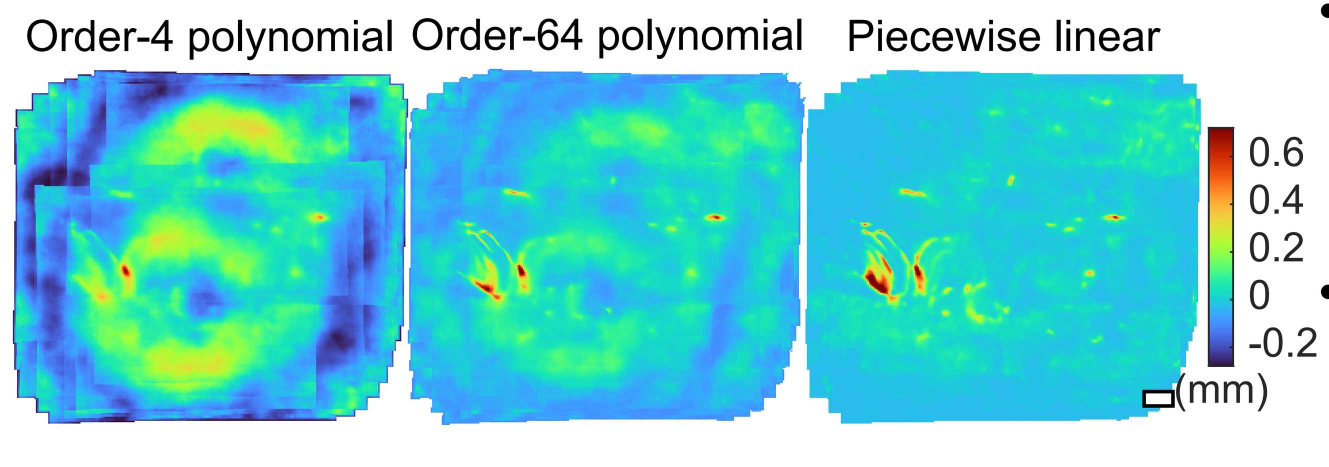
Our method yields height maps with 10s-of-μm accuracy; however, COLMAP[2] consistently underestimates height at this scale (scale bars = 1 cm)

Quantification of height accuracy



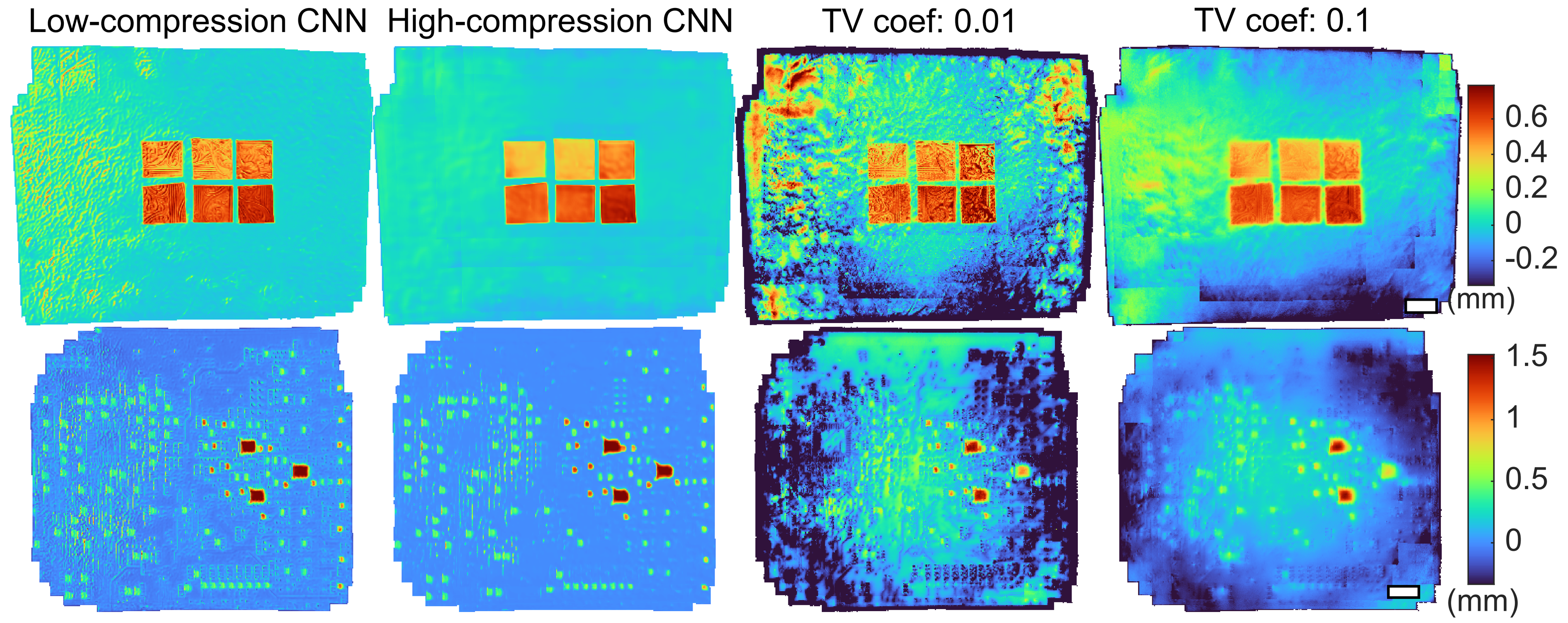
- Cut playing cards backed with 0-5 layers of scotch tape, whose thicknesses were measured using calipers
- Our method: **26.3-μm** mean abs. error
- COLMAP[2]: 95.6-μm mean abs. error

Importance of distortion modeling



- Without accurate modeling of distortions, ring artifacts arise
- Piecewise linear model outperforms polynomials

Importance of CNN reparameterization



Regularization with an untrained CNN/DIP outperforms traditional regularization techniques (e.g., total variation)

Open-source code and data

github.com/kevinczhou/mesoscopic-photogrammetry

[1] Ulyanov et al. "Deep image prior", CVPR 2018
[2] Schonberger et al. "Structure-from-motion revisited", CVPR 2016