Shadow-Free Projection with Blur Mitigation on Dynamic Deformable Surfaces

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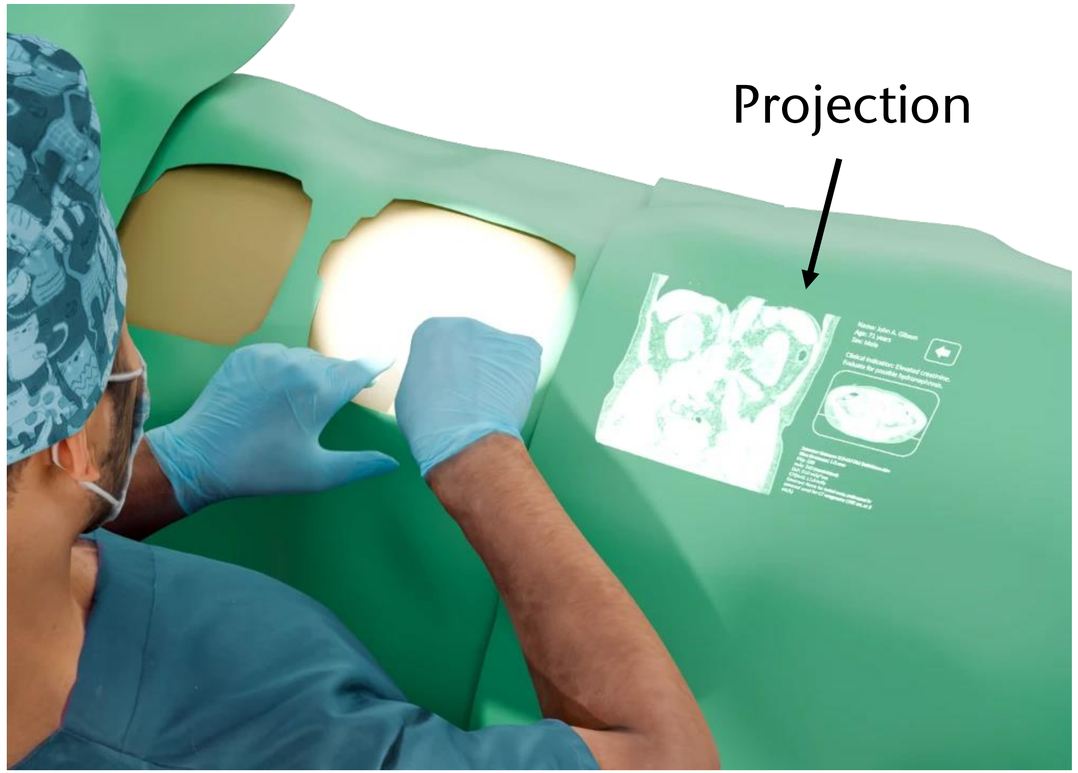
Motivation


Santorini
Island in Greece
Picturesque island
in the southern
Aegean Sea

Motivation

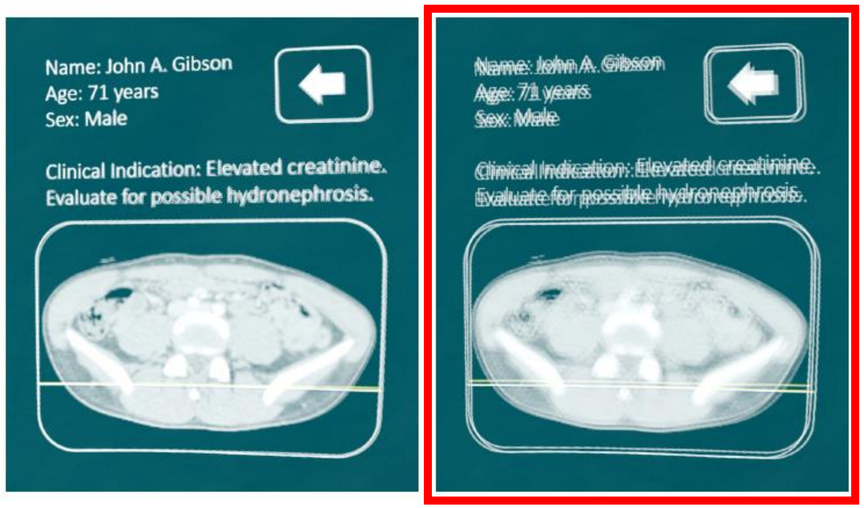


Multiple Projectors

Research Gap

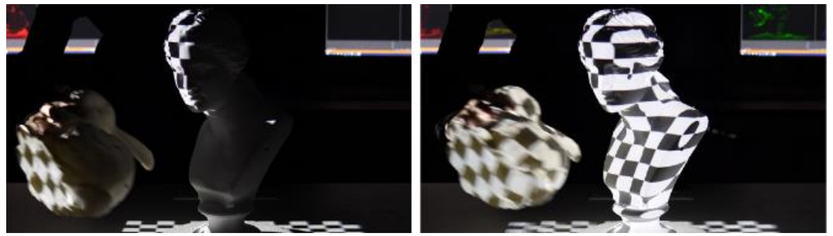
Multiple projectors for **avoiding shadows** on **deformable surfaces**

- Not adressed by related work
- Imposes high precision requirements



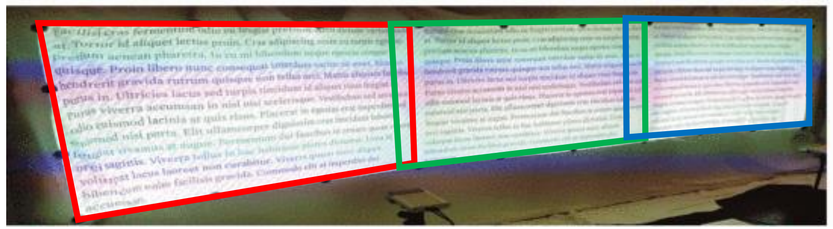
Examples of related work

Siegl et al. (2015), ACM ToG



Nomoto et. al. (2022), IEEE TVCG

Pre-scanned rigid objects



Ibrahim et al. (2024), IEEE VR

No shadow avoidance

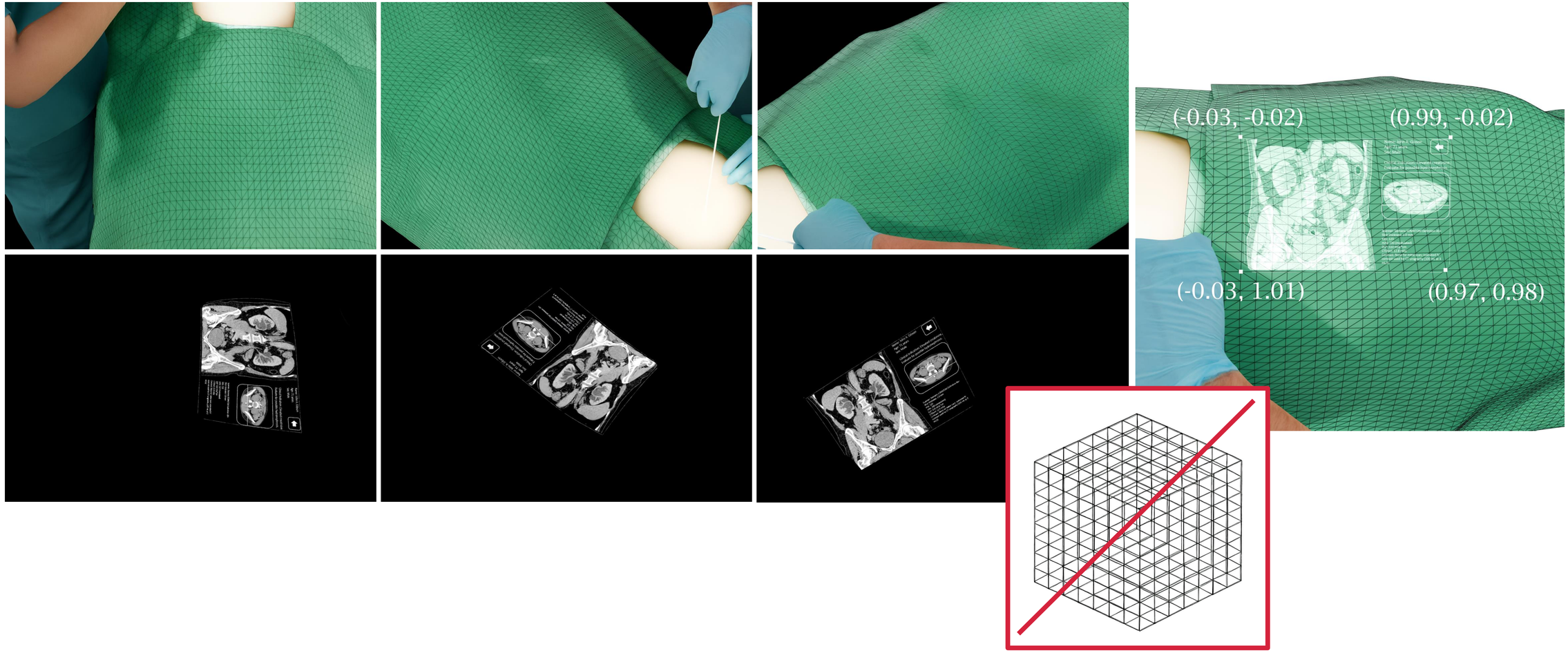
Geometric Correction

Projector 1

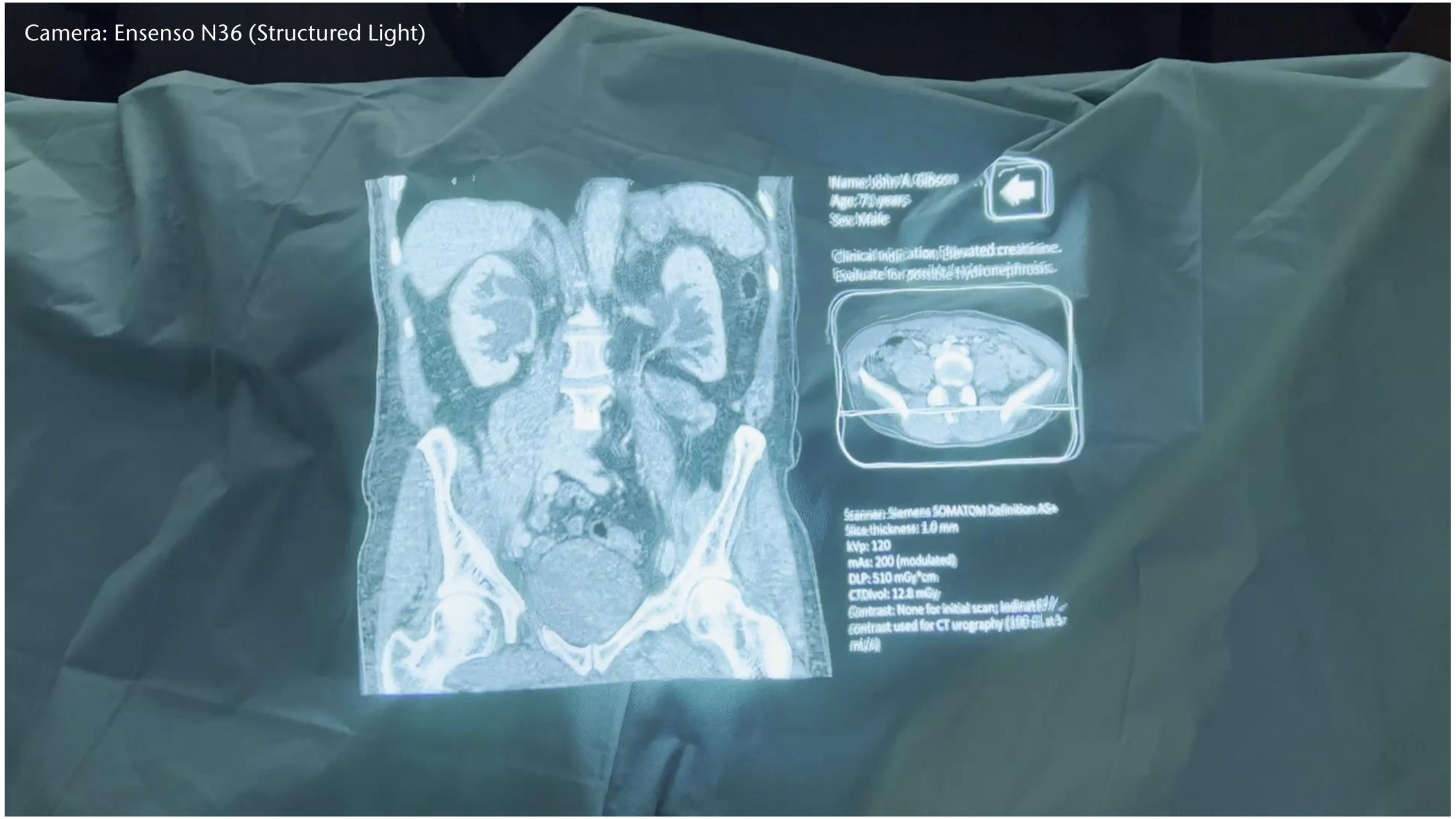
Projector 2

Projector 3

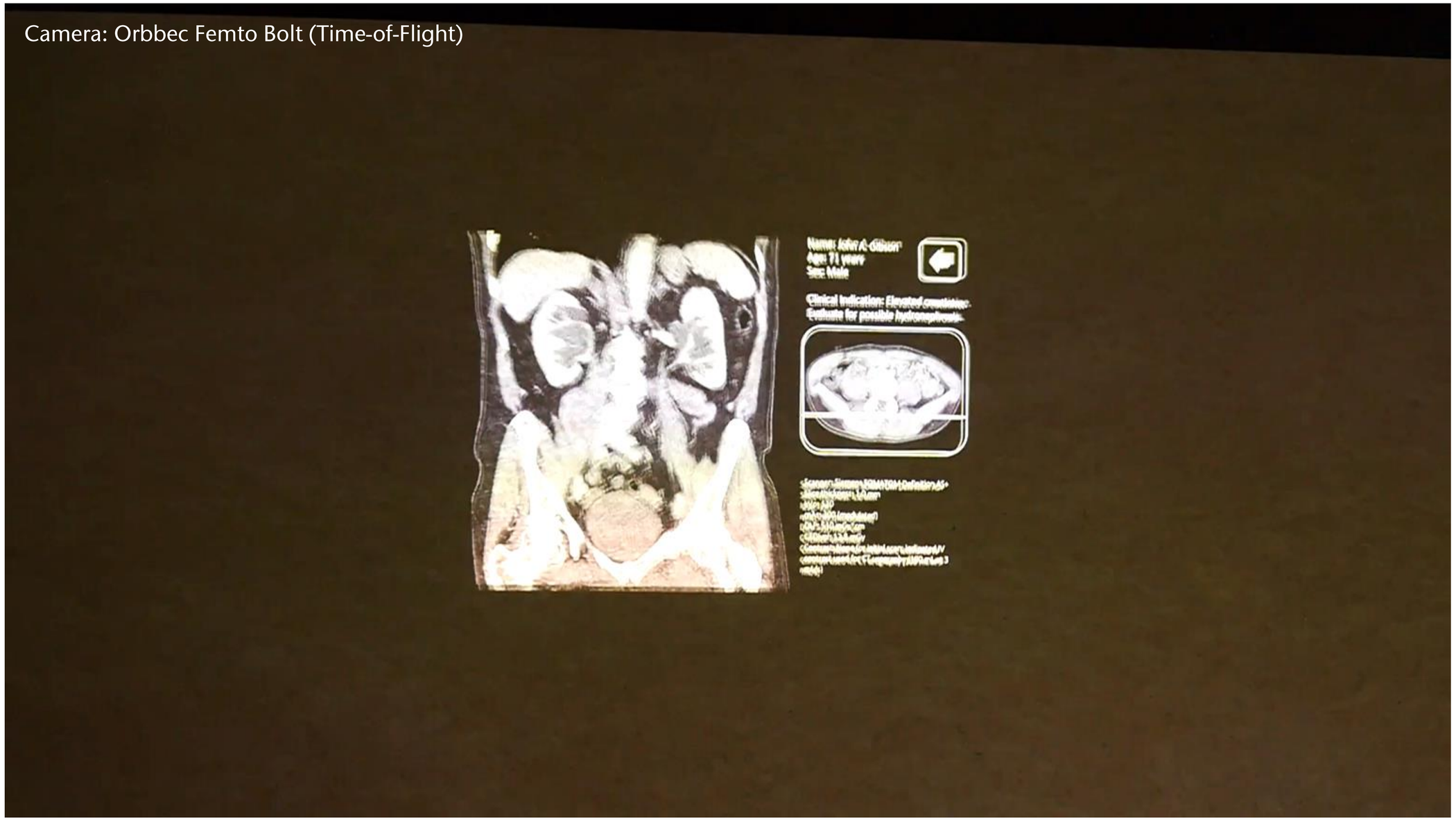
Viewer‘s Perspective



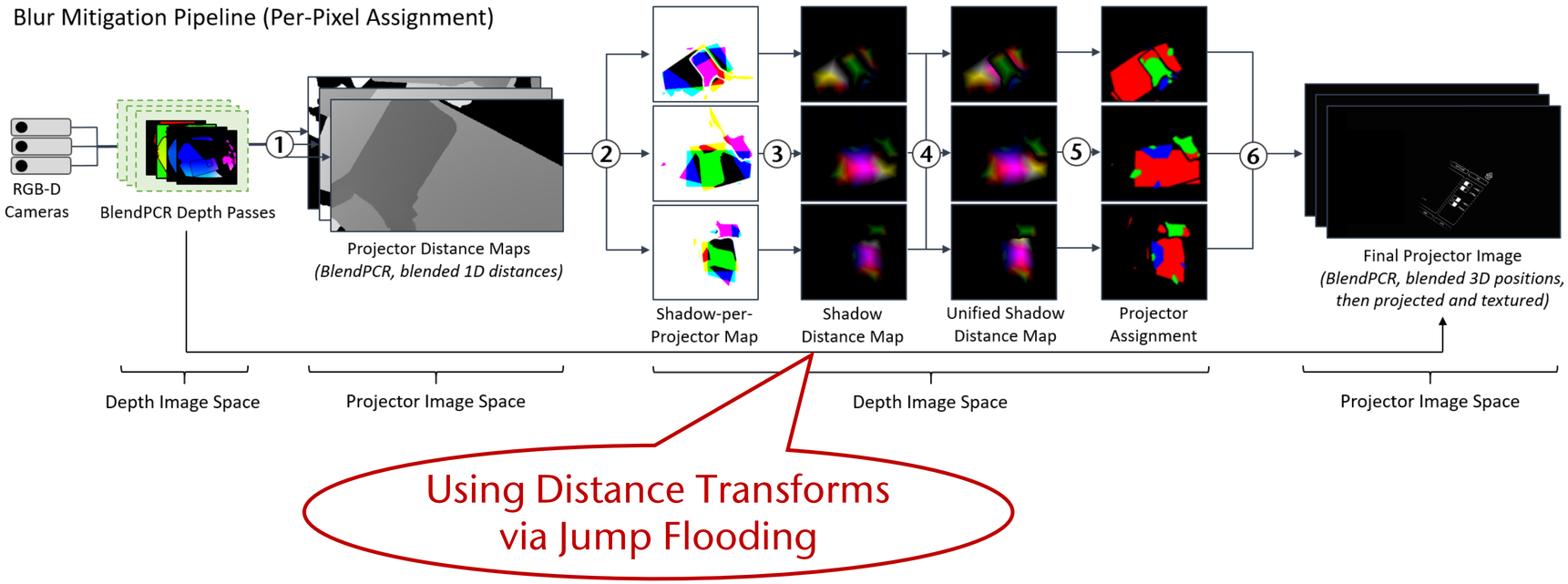
Geometric Correction



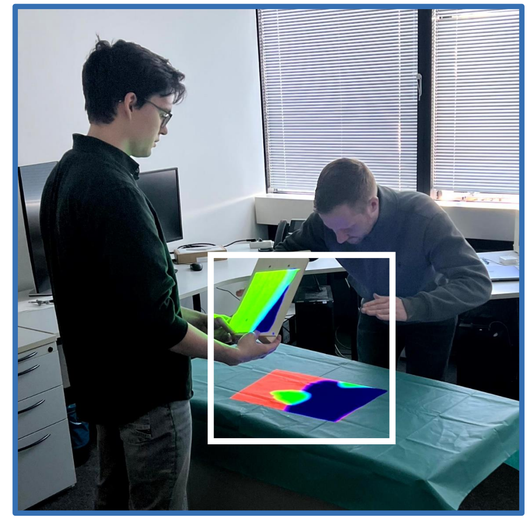
Geometric Correction

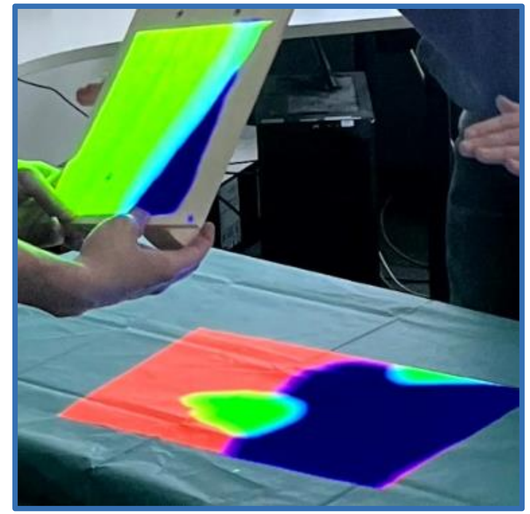


Efficient Blur Mitigation Pipeline



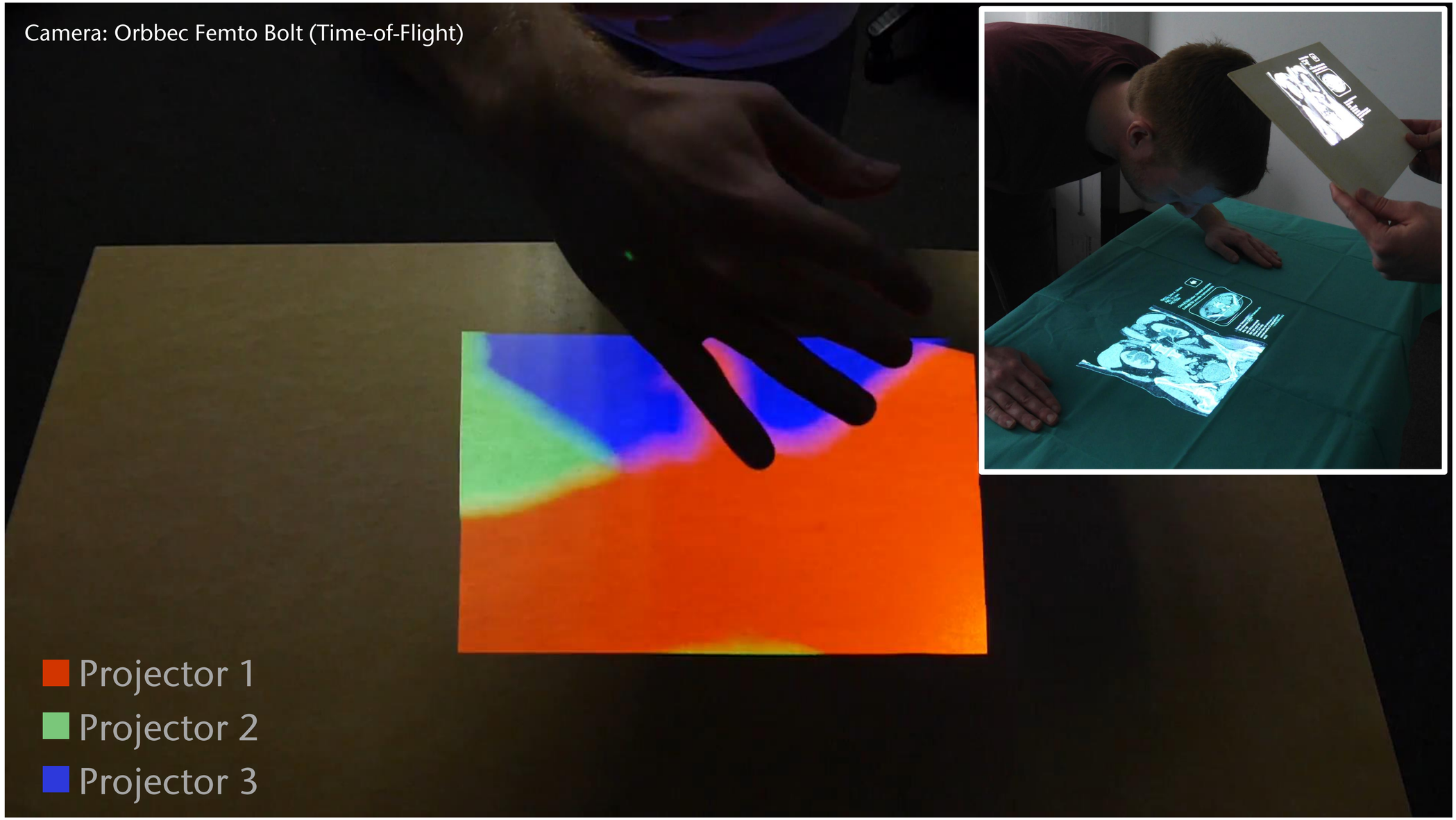
Details in the paper!





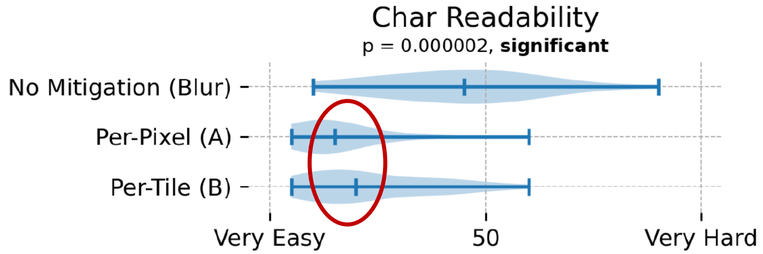
Projector 1
Projector 2
Projector 3

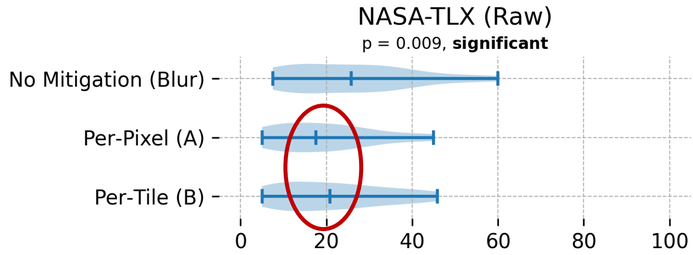
Blur Mitigation Results



User Study

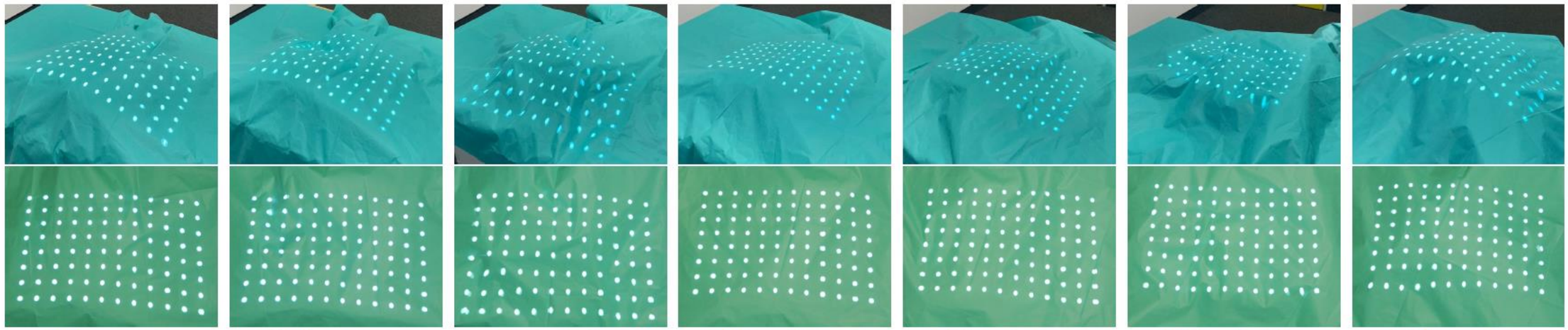
- Investigation of blur mitigation with simulated, reproducible shadows against baseline.
- Blur mitigation significantly:
  - ➢ **increased readability**
  - ➢ **reduced workload** (NASA-TLX)
- Participants (n=23; 7 female, 16 male) significantly preferred blur mitigation.



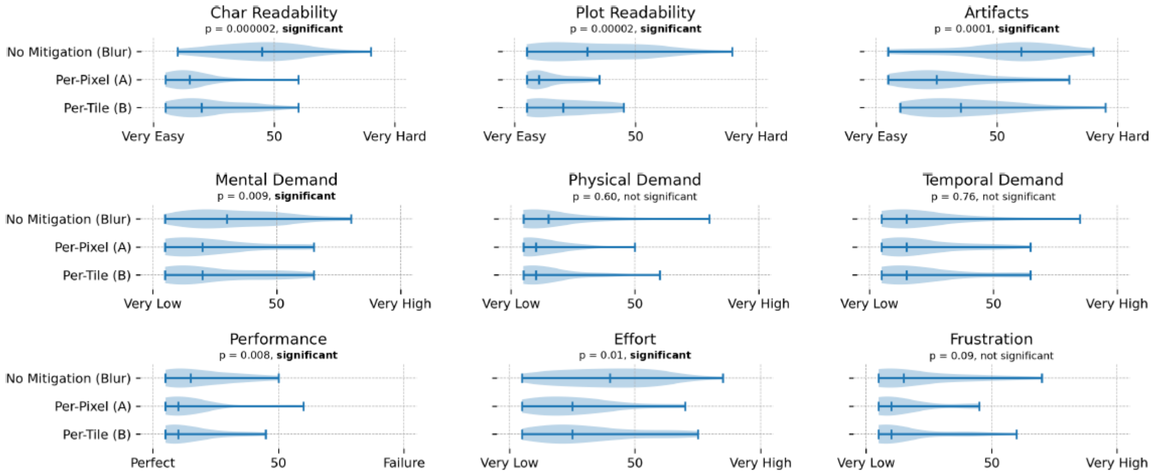


Results

- Overall pipeline only requires **22 ms** on a single RTX 4090, driving:
  - **3 depth sensors** (each 640 x 576)
  - **3 UHD projectors** (each 3840 x 2160)
- Visible divergence on average only **1.6 mm** on highly uneven surfaces.

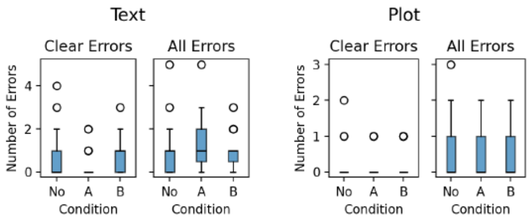


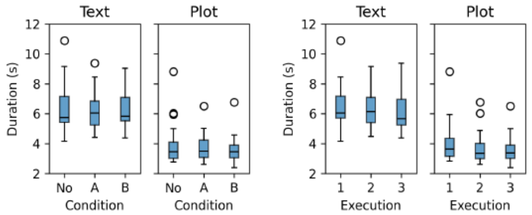
Results

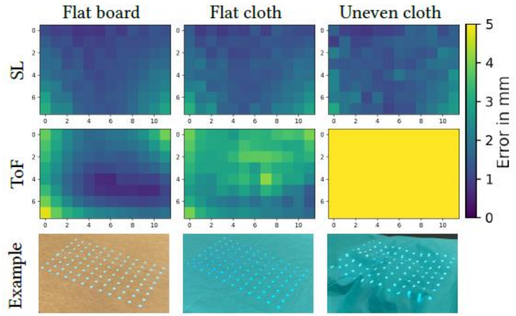


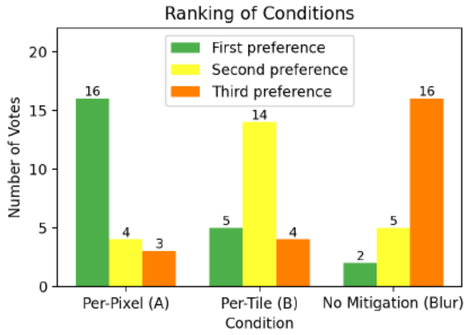
	Friedman	Pairwise Wilcoxon		
	No, A, B	No vs. A	No vs. B	A vs. B
Mental Demand	0.009 (**)	0.03 (*)	0.066	1.0
Physical Demand	0.6	0.47	0.81	1.0
Temporal Demand	0.76	1.0	1.0	1.0
Performance	0.008 (**)	0.094	0.16	1.0
Effort	0.012 (*)	0.023 (*)	0.75	0.68
Frustration	0.093	0.094	0.29	1.0
Char Readability	2.4e-06 (***)	0.0002 (***)	0.0004 (***)	0.34
Plot Readability	1.8e-05 (***)	0.0004 (***)	0.021 (*)	0.18
Artifacts	0.0001 (***)	0.0002 (***)	0.068	0.59
NASA-TLX (Raw)	0.009 (**)	0.041 (*)	0.184	0.964

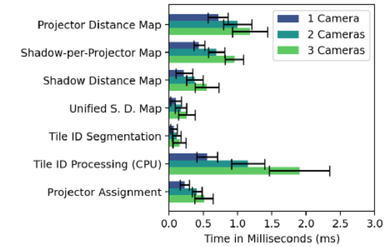
	Kendall's W	Pairwise Wilcoxon (|r|)		
	No, A, B	No vs. A	No vs. B	A vs. B
Mental Demand	0.21	0.55	0.51	0.13
Physical Demand	0.02	0.41	0.32	0.21
Temporal Demand	0.01	0.01	0.14	0.04
Performance	0.21	0.51	0.52	0.22
Effort	0.19	0.6	0.25	0.26
Frustration	0.1	0.56	0.45	0.08
Char Readability	0.56	0.84	0.86	0.34
Plot Readability	0.48	0.88	0.6	0.44
Artifacts	0.38	0.85	0.49	0.28
NASA-TLX (Raw)	0.2	0.55	0.39	0.22

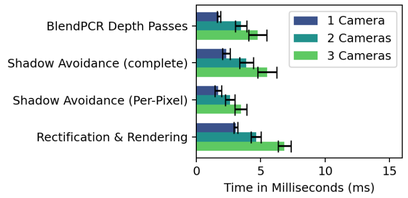












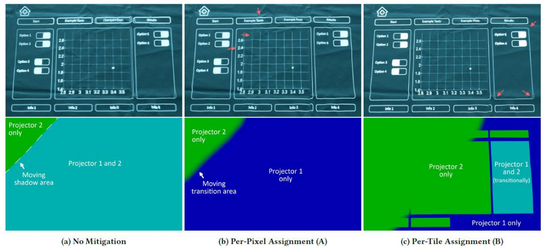
3 ToF-Multi-Path Interference Effects

(a) Default (b) Scenario A (c) Scenario B (d) Scenario C

Surface	Projection Overlap Divergence (POD)			
Interference	Default	Scenario A	Scenario B	Scenario C
(1) Flat board	1.91	4.11	2.74	4.87
(2) Flat cloth	2.86	5.07	4.13	5.78
(3) Uneven cloth	15.28	19.38	16.95	20.61

Surface	Environment-dependent Interference Deviation to Default								
	Scenario A			Scenario B			Scenario C		
Proj.	1	2	3	1	2	3	1	2	3
(1)	1.62	2.10	3.06	0.73	1.08	1.62	2.28	2.51	3.61
(2)	1.35	1.78	2.68	0.57	0.90	1.26	2.24	2.15	3.48
(3)	1.77	2.27	3.66	0.73	0.99	1.58	2.43	2.80	4.31

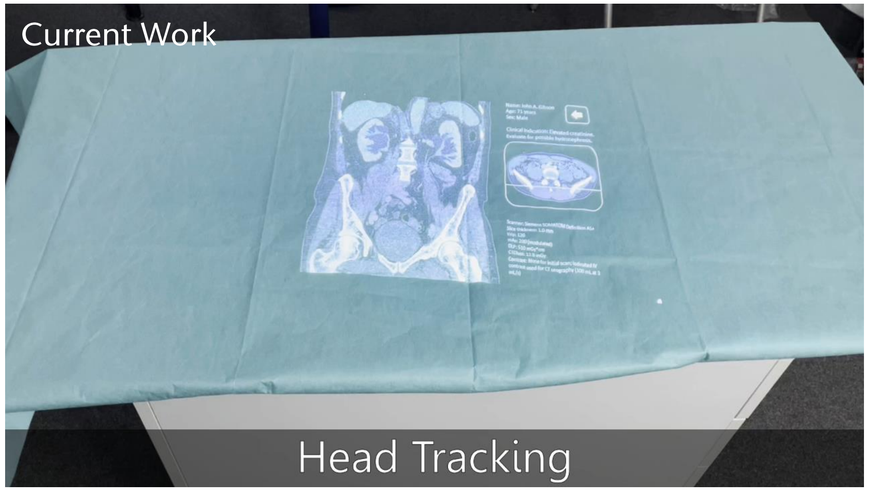
Condition	Ensenso N36 (SL)			Orbbec Femto (ToF)		
	N	Mean	SD	N	Mean	SD
Flat Board	4	1.51	0.87	6	1.91	1.18
Flat Cloth	4	1.60	0.87	6	2.86	1.53
Uneven Cloth	7	1.58	0.91	6	15.28	6.49



(a) No Mitigation (b) Per-Pixel Assignment (A) (c) Per-Tile Assignment (B)

Conclusion

- **Shadow-free** projection
  - ➢ on **deformable surfaces**
- Highly precise geometric correction
  - ➢ visible divergence only **1.6 mm**
- Blur mitigation pipeline
  - ➢ improves **readability** and reduces **workload**
- Source Code is available online



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