

Problem

Current laser speckle imaging based tracking techniques are unable to reliably detect absolute **multi-axis** of objects with **minimum hardware complexity** in a **dynamic setting**.

Aim

Accurately capture absolute multi-axis rotations with a single lensless camera utilizing laser speckle imaging.

Related works

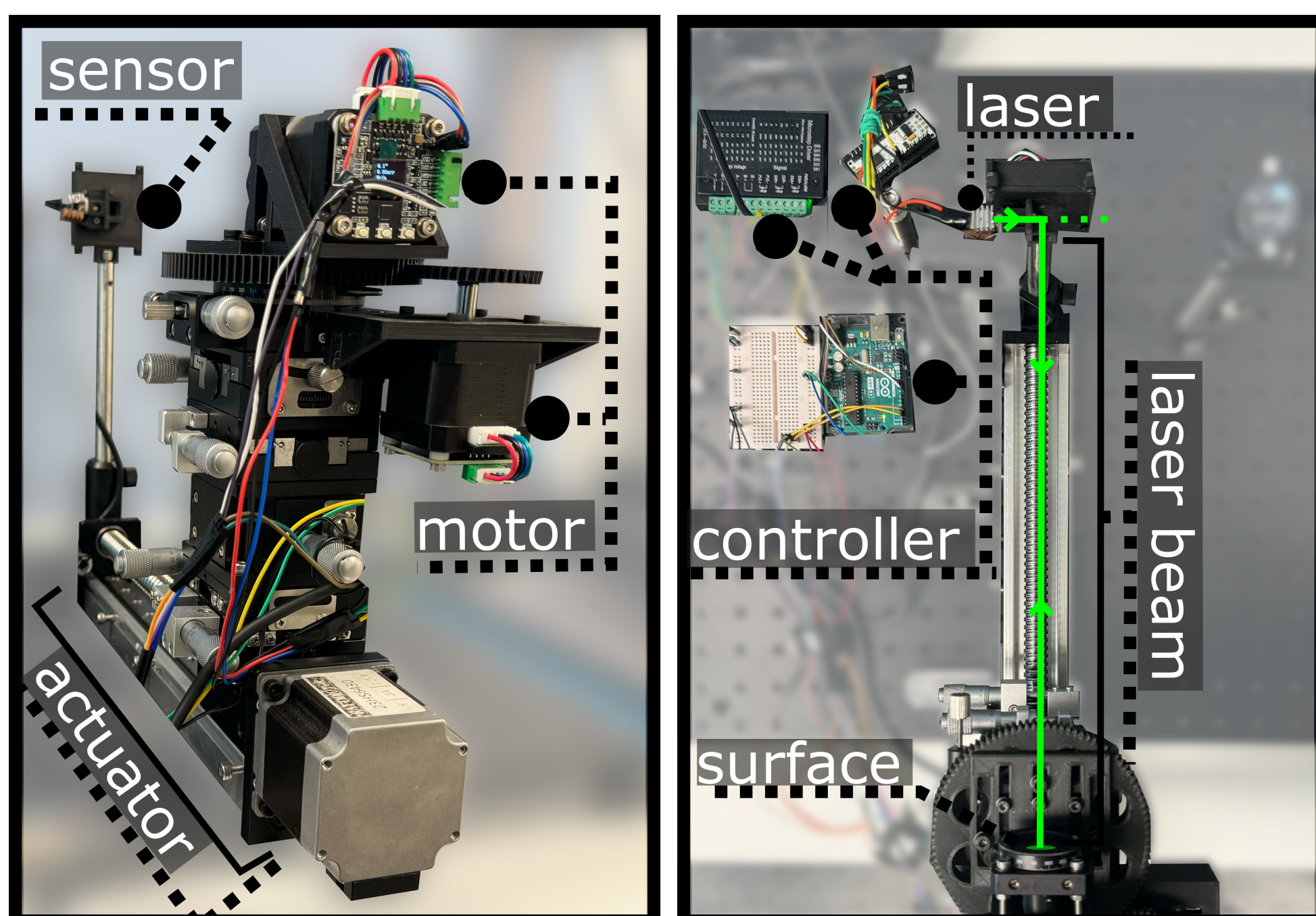
Method	Type	Rot. DOF	Sensors	Acc. (°)
This work	Absolute	3	1	0.3*
Gibson et al.	Absolute	2	1	0.6*
Heikkinen et al.	Relative	2	2	-

Others:

- ✗ Multiple sensors.
- ✗ 3 degrees of freedom.
- ✗ Absolute rotations.
- ✗ Dynamic settings.

Testbed

Dataset collection & validation.

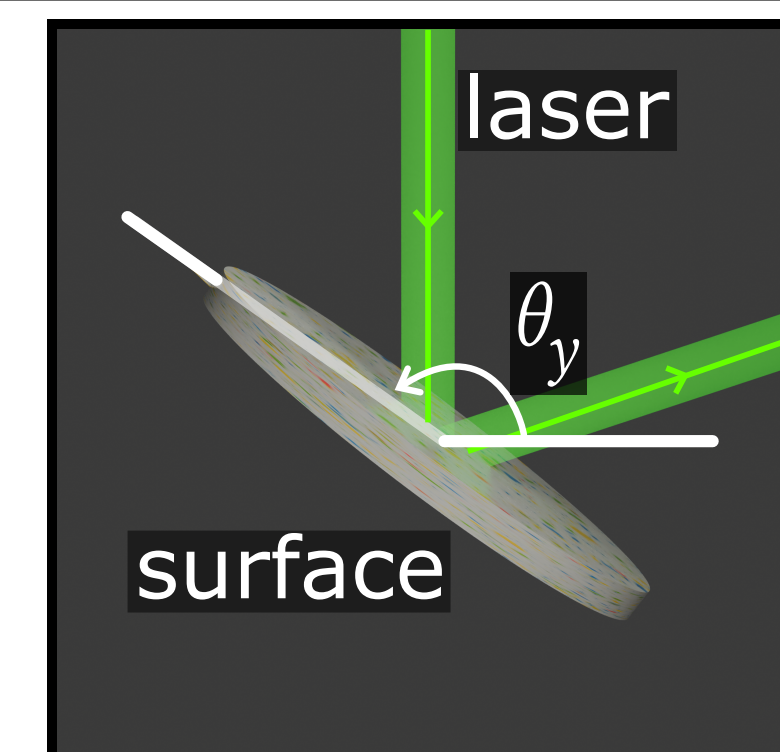


References

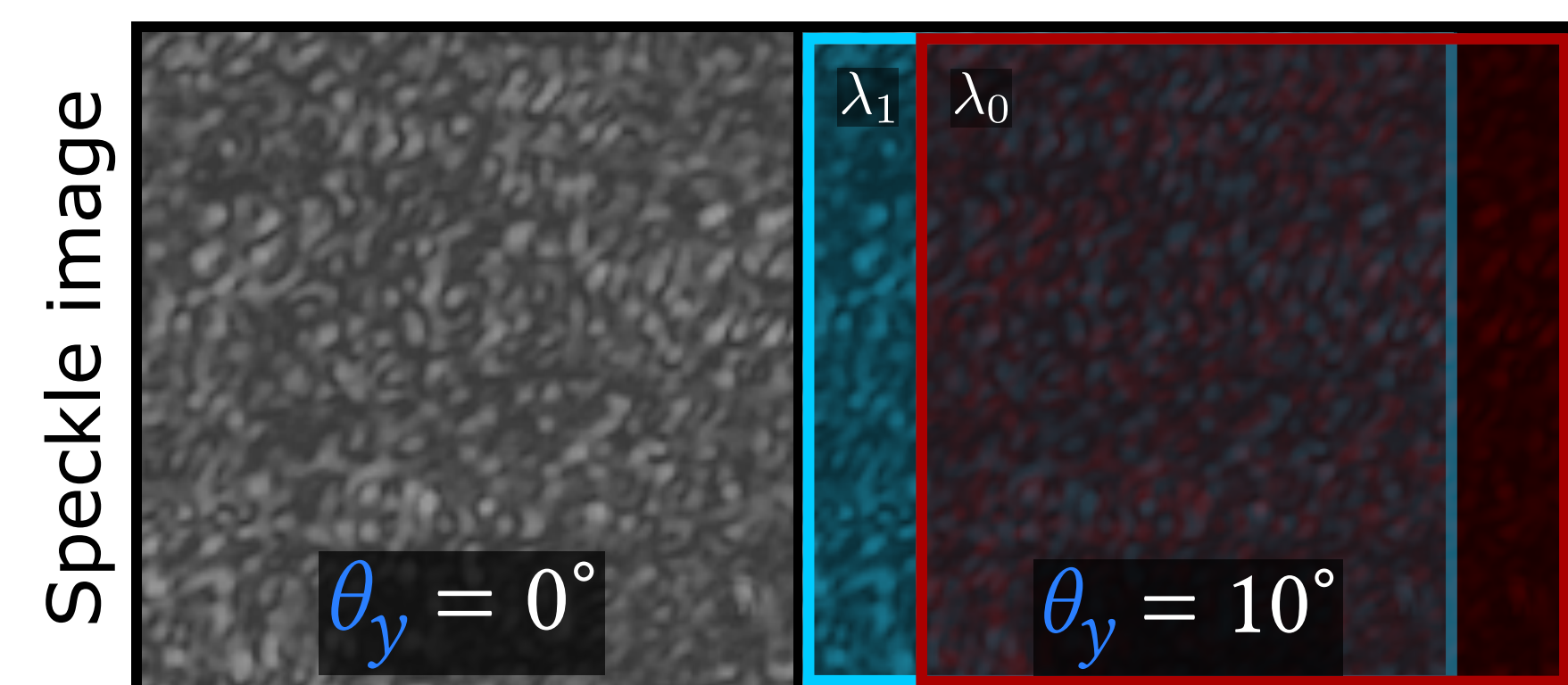
- Mustafa Doga Dogan, Steven Vidal Acevedo Colon, Varnika Sinha, Kaan Akşit, and Stefanie Mueller. 2021. Sensicut: Material-aware laser cutting using speckle sensing and deep learning. In The 34th Annual ACM Symposium on User Interface Software and Technology. 24–38.
- Sam J Gibson, Thomas OH Charrett, and Ralph P Tatam. 2024. Towards High Resolution Absolute Angle Sensing using Dual-Wavelength Laser Speckle. In 2024 IEEE International Instrumentation and Measurement Technology Conference (I2MTC). IEEE, 1–6.
- Juuso Heikkinen and Gary S Schajer. 2024. Self-calibrated defocused speckle imaging for remote surface motion measurements. Optics and Lasers in Engineering 173 (2024), 107914.
- Jan Zizka, Alex Olwal, and Ramesh Raskar. 2011. SpeckleSense: fast, precise, low-cost and compact motion sensing using laser speckle. In Proceedings of the 24th annual ACM symposium on User interface software and technology. 489–498.

Proposed Method: SpecTrack

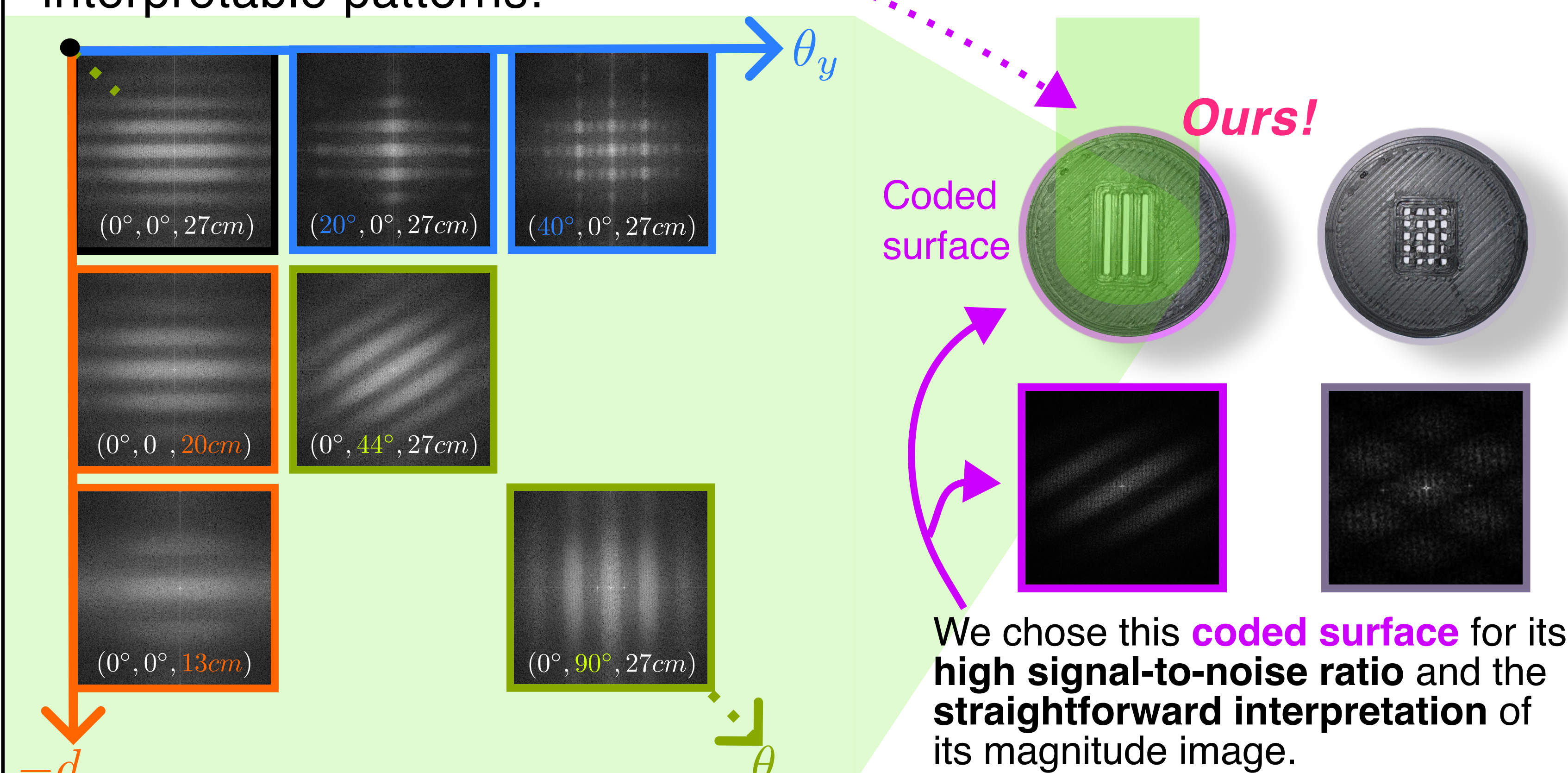
- Speckle patterns are random dot patterns formed when laser light reflects off rough surfaces and captured by an imaging sensor.
- Different poses result in varying speckle patterns, particularly when using a laser with **multiple wavelengths** (multiple peaks in the spectrum).



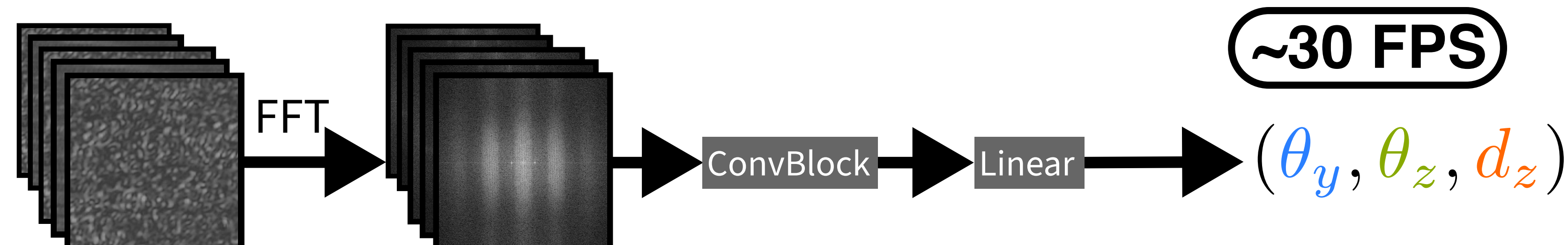
- Rotating the surface along the **y-axis** results in **overlapping speckle images**.
- Using the **Fast Fourier Transform** to get the magnitudes of speckle image from various poses (**y-axis rotation**, **z-axis rotations**, and **z-axis displacements**) or **coded surface** reveals interpretable patterns:



This is the demonstration of overlapping speckle images if the laser light has exactly two wavelengths.



We trained a lightweight neural network on the collected dataset to retrieve poses, using the captured speckle images as inputs.



Conclusions

SpecTrack achieved:

- Y-axis rotation** Mean Absolute Error (MAE) of **0.31°** with a standard deviation of **0.44°**.
- Z-axis rotation** with an MAE of **0.52°** (std = **0.36°**).
- Z-axis displacement** accuracy of **0.15 cm**.

Future work:

Test and refine the system in real-world settings with different lighting, distances, and object motions to enhance its use in VR, AR, and robotics applications.

Webpage



DEMO Video

