SpecTrack: Learned Multi-Rotation Tracking via Speckle Imaging

Ziyang Chen[1], Mustafa Doğa Doğan[2], Josef Spjut[3], Kaan Akşit[1]

University College London, Adobe Research, NVIDIA

Computational Light Laboratory
https://complightlab.com

SIGGRAPH ASIA 2024 TOKYO 東京

Problem ①

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 ②

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

Related works ③

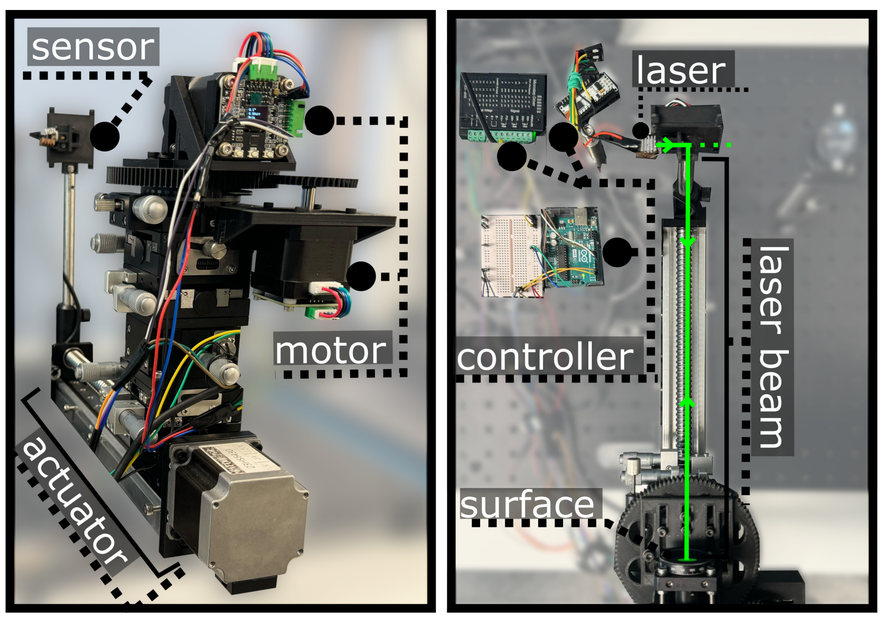
Method	Type	Rot. DOF	Sensors	Acc. (°)
This work	Absolute	3	1	0.3*
Gibson et al.	Absolute	2	1	0.6*
Heikkinen et al.	Relative	2	2	-

Others:

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

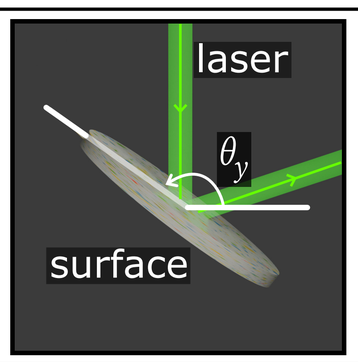
Testbed ⑤

Dataset collection & validation.

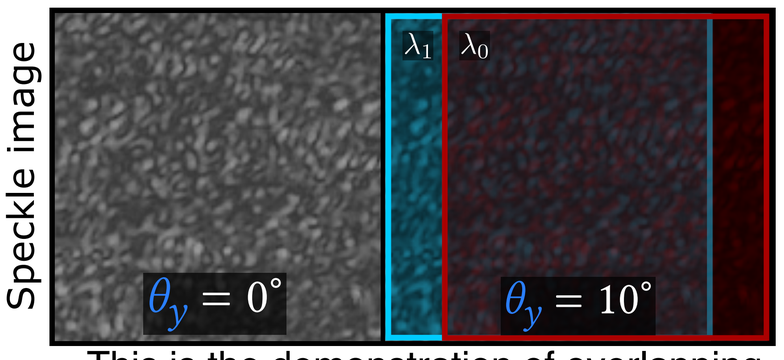


Proposed Method: SpecTrack ④

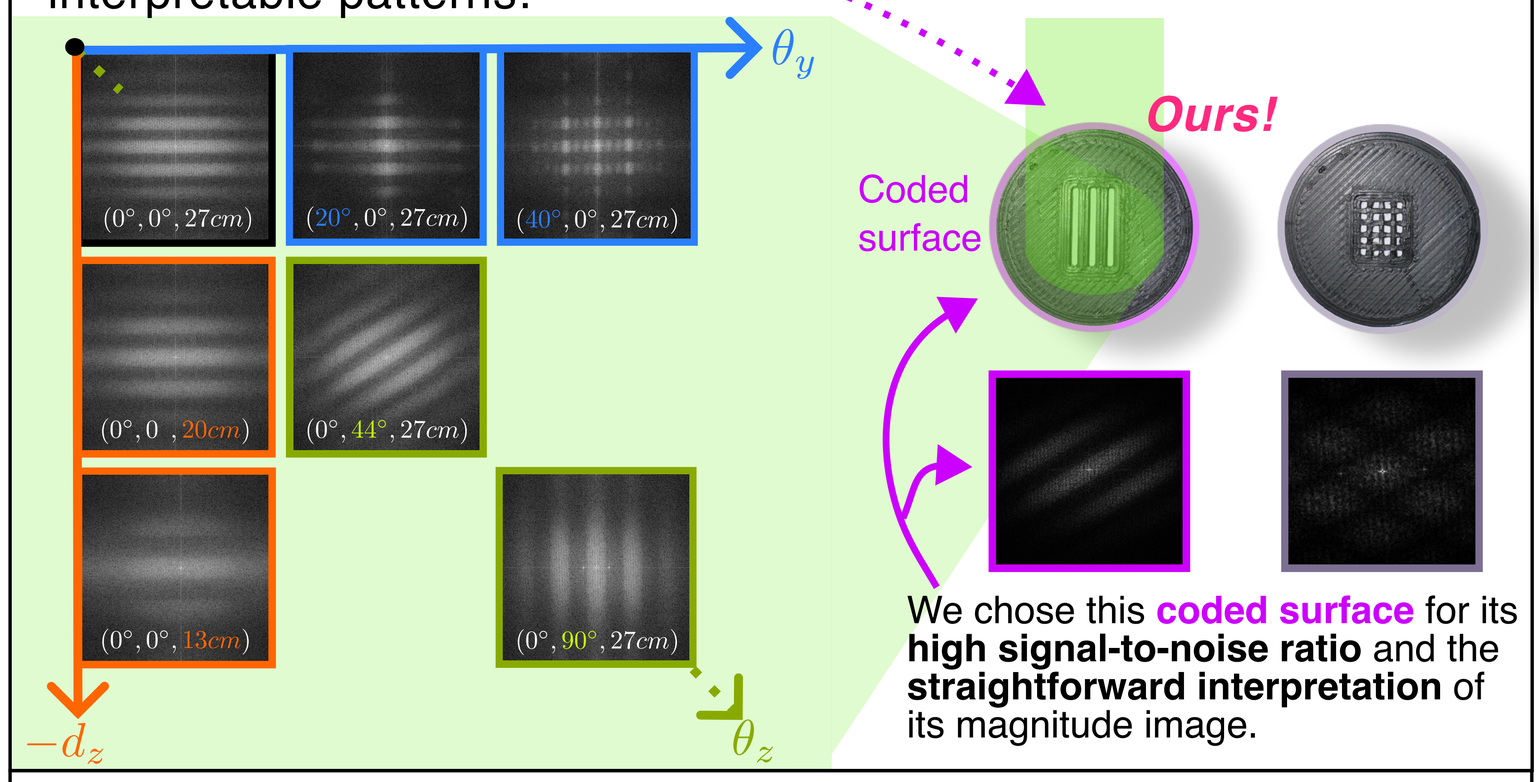
- Speckle patterns are random dot patterns formed when laser light reflects off rough surfaces and captured by an imaging sensor.
- Different poses result in varying speckle patterns, particularly when using a laser with **multiple wavelengths** (multiple peaks in the spectrum).



- 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 roation***, ***z-axis rotations***, and ***z-axis displacements***) or ***coded surface*** reveals interpretable patterns:

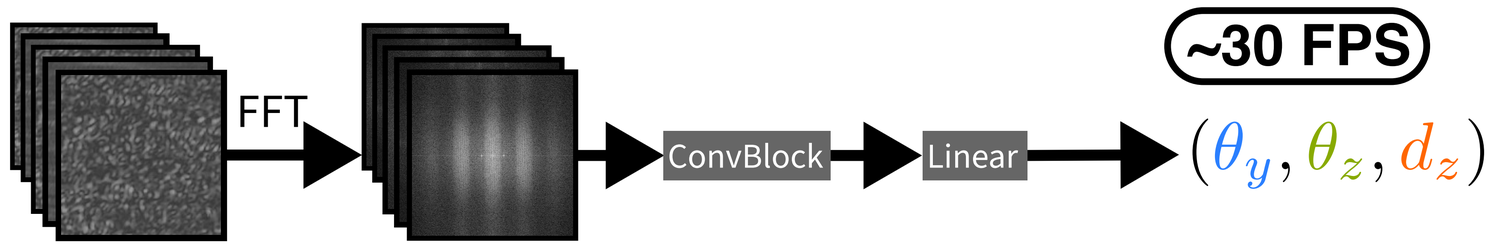


This is the demonstration of overlapping speckle images if the laser light has **exactly two wavelengths.**



We chose this **coded surface** for its **high signal-to-noise ratio** and the **straightforward interpretation** of its magnitude image.

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



Conclusions ⑥

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 displacment*** 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

References ⑦

- 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.