Net-Centric and Cloud Software and Systems I/UCRC

Lensless and Pinhole Event Sensing and Detection

Presenter: Joshua Rego

Date: November 30, 2023

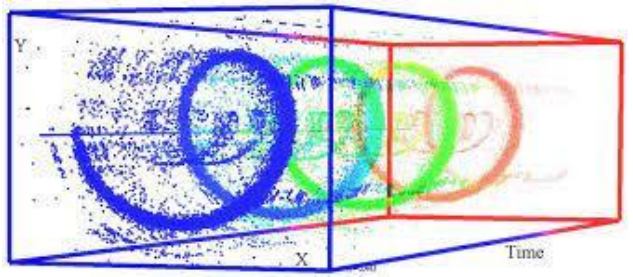
Project Motivation

Real-World Applications:

- Autonomous Navigation
- Interactive Robotics
- Visual Awareness for Disabilities
- Sports Training & Feedback

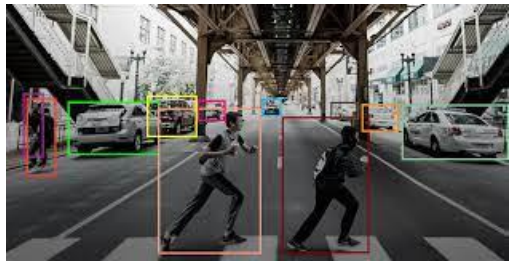
Event Camera Benefits

- Low-latency
- Low-powered
- High Dynamic Range



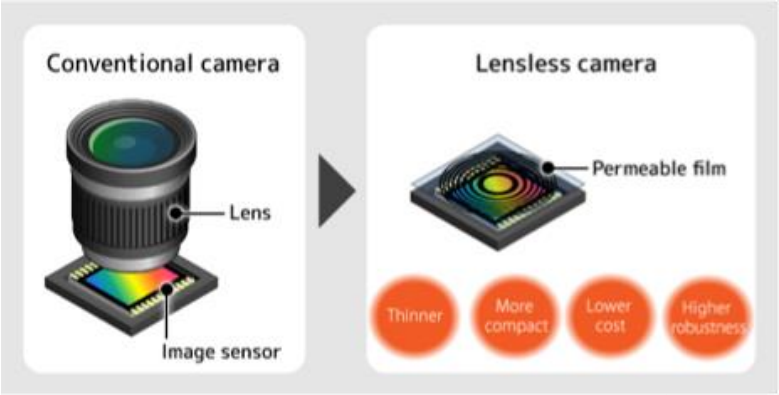
Computer Vision Tasks:

- Optical Flow
- Object Detection & Tracking
- Environment Mapping
- Image/Video Reconstruction



Lensless/Multi-Pinhole Optics:

- Minimal optical thickness for size-constraint applications
- Ability to measure depth and angular information



Project Overview

Tasks:

Task#	Task Description
1■	Develop forward-model simulation framework to generate data for experiments and future training
2■	Determine optical element for high-SNR event sensing through theoretical optimization and experimental analysis
3■	Develop & train DL model for lensless event and depth reconstruction.
4■	Benchmark performance for various CV tasks

Project Milestones:

Task#	Planned Completion	Milestone (Deliverable)
1■	3/23	Simulation and hardware development
2■	6/23	Benchmarking
3■	9/23	Computational footprint analysis
4■	12/23	Finalize algorithms

Research Goals:

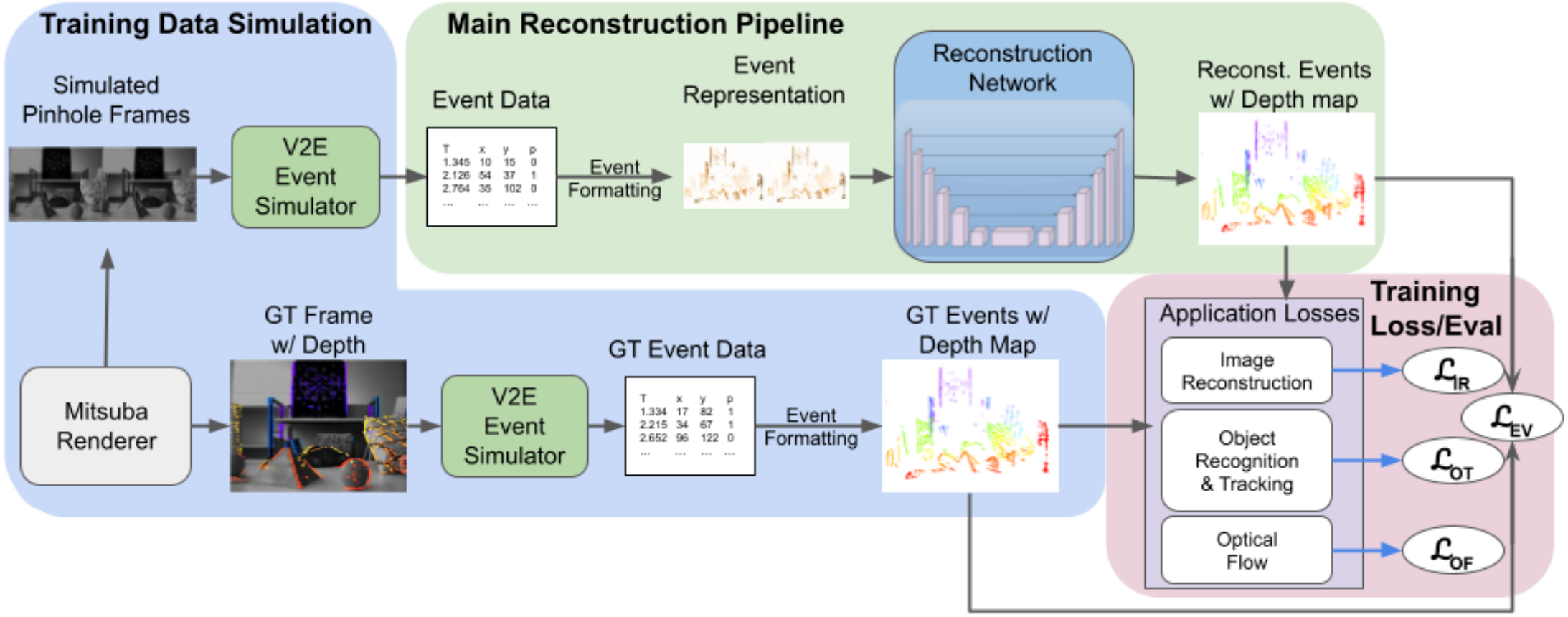
1. Develop a framework for lensless event-based sensing
2. Develop algorithms for applications in computer vision
3. Hardware implementation of these algorithms for prototyping
4. Clear documentation of research, lessons learned and recommended approaches

Benefits to Industry Partners:

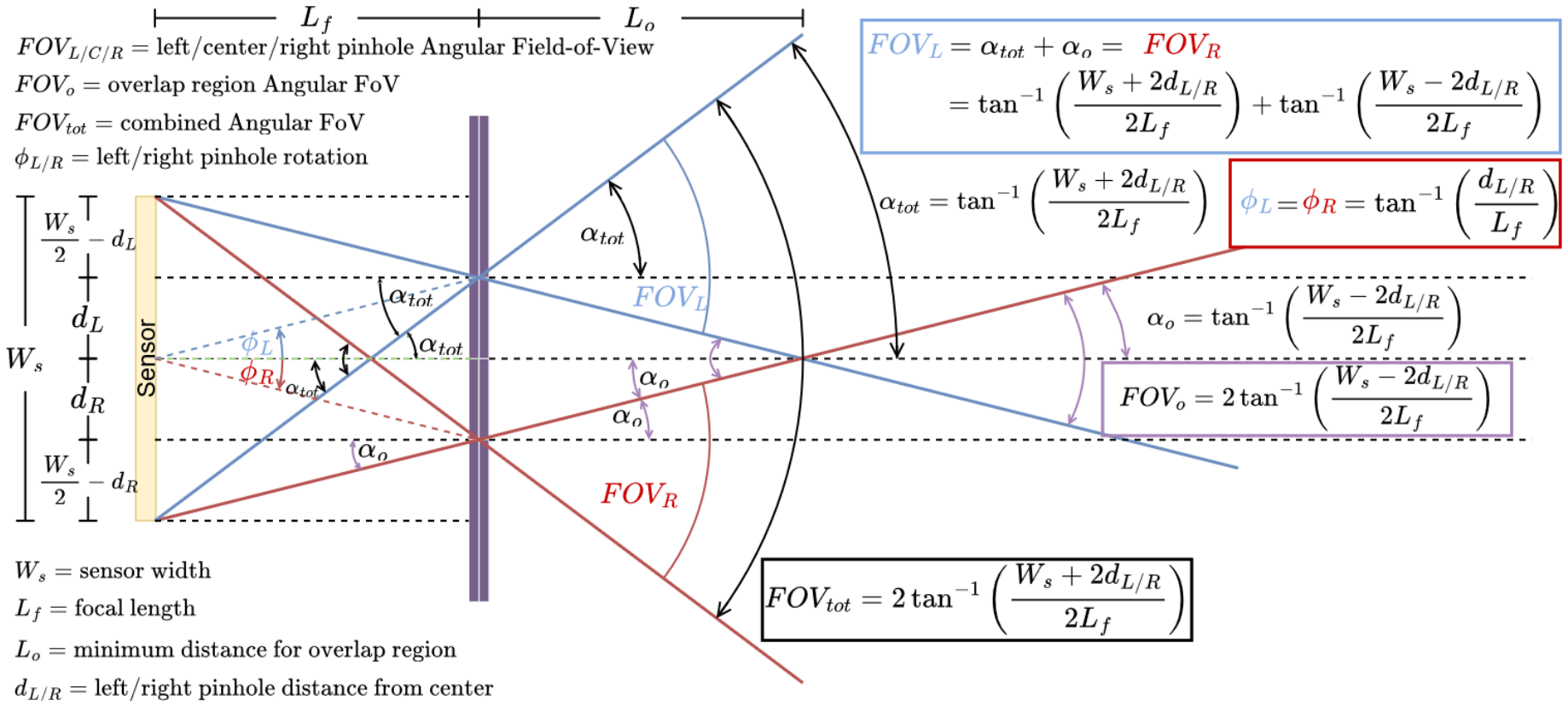
1. Energy-efficient computer vision applications
2. Hardware design and toolflow development for event cameras.

[2] ■ Milestone complete or is on track for planned completion date
■ Milestone has changed from original sponsor-approved date (Why?)

Overall Pipeline



Designing optimal dual pinholes for event sensors



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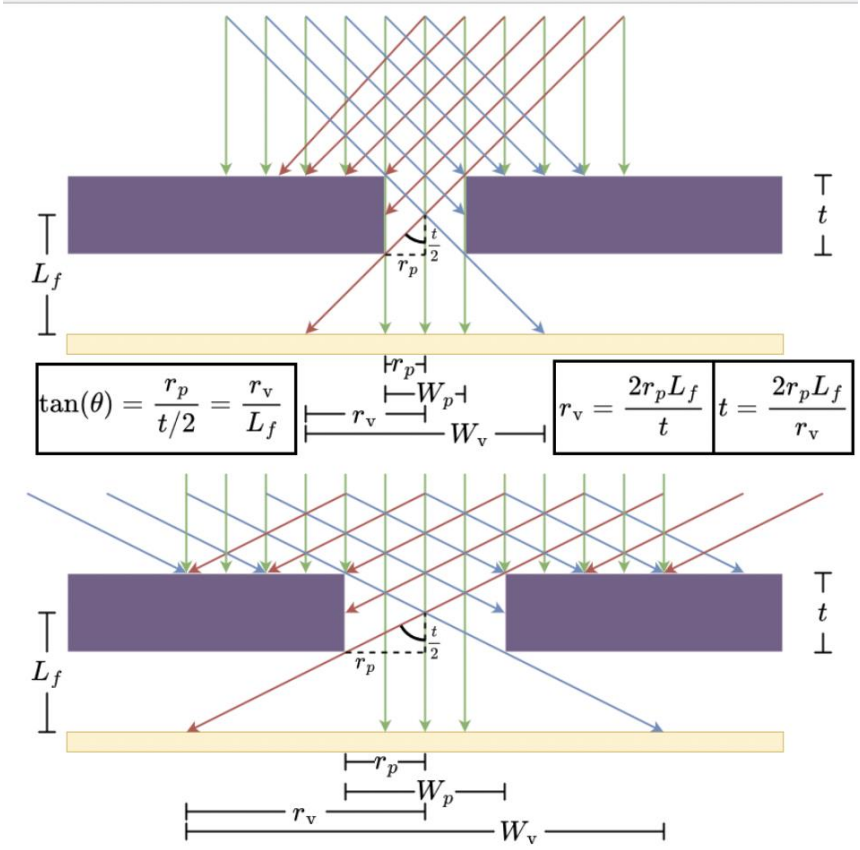
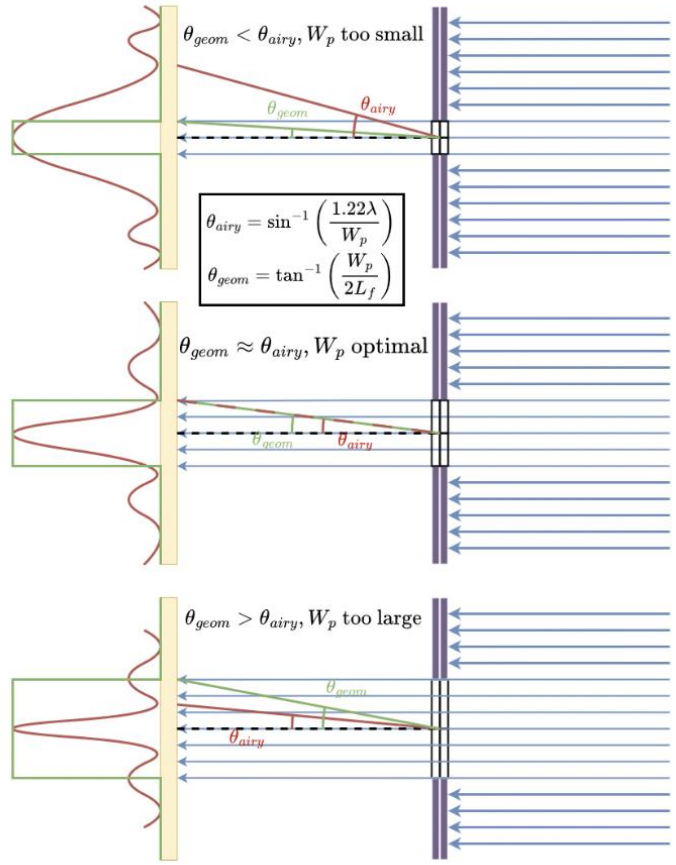


Pinhole Vignetting

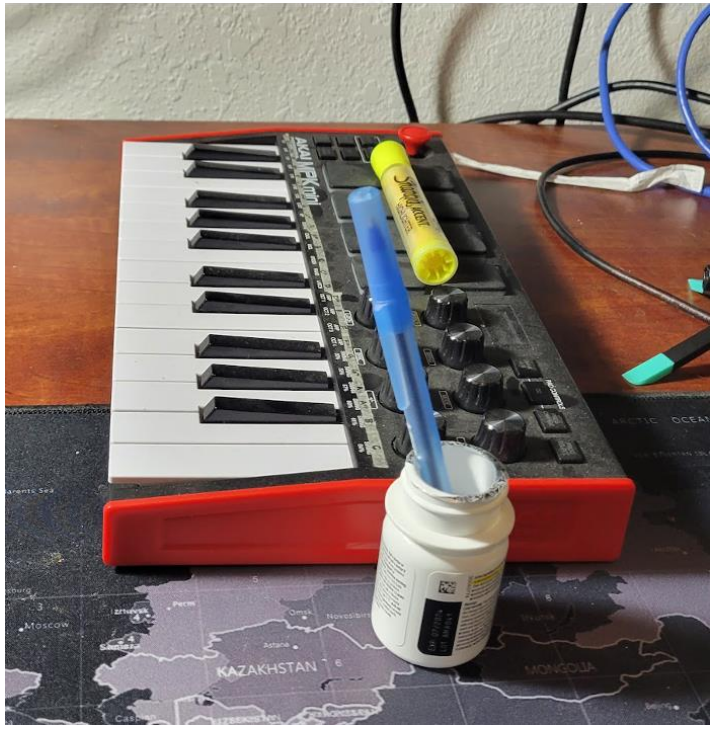


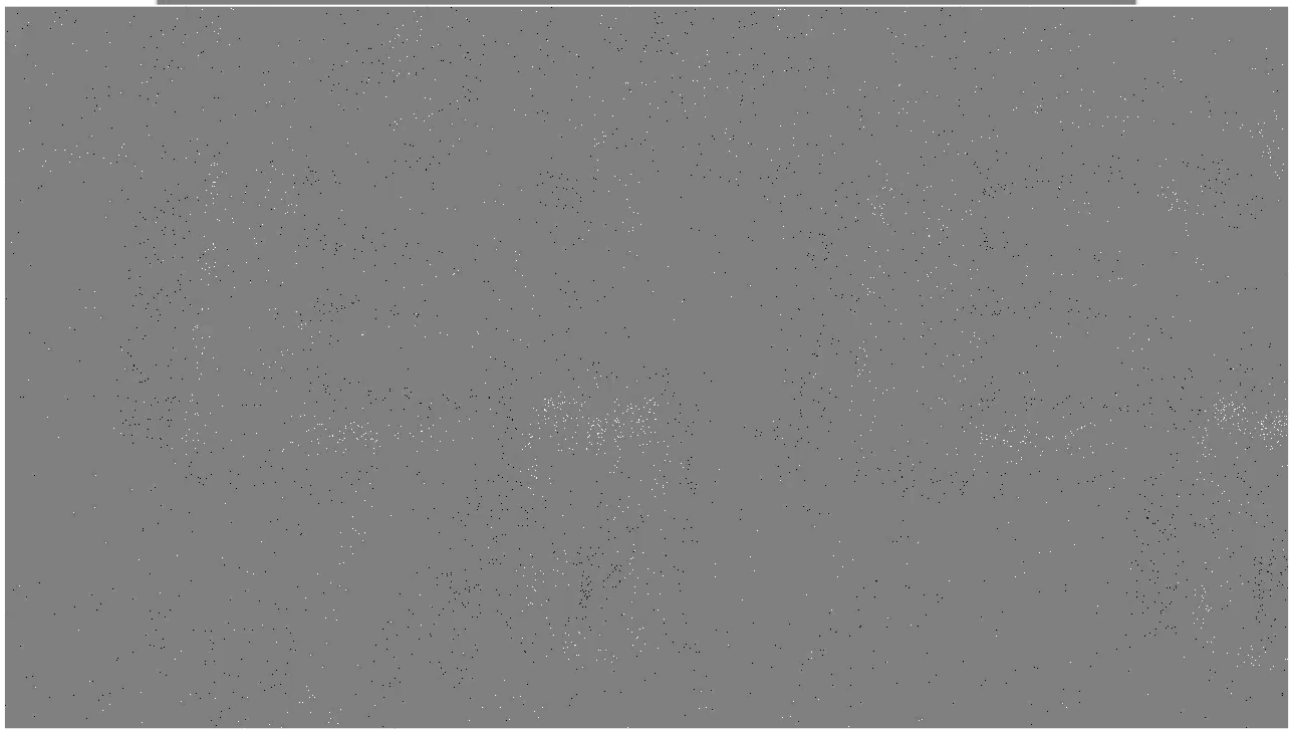
Optimal Pinhole diameter

Experimental prototype

Prophesee megapixel event camera

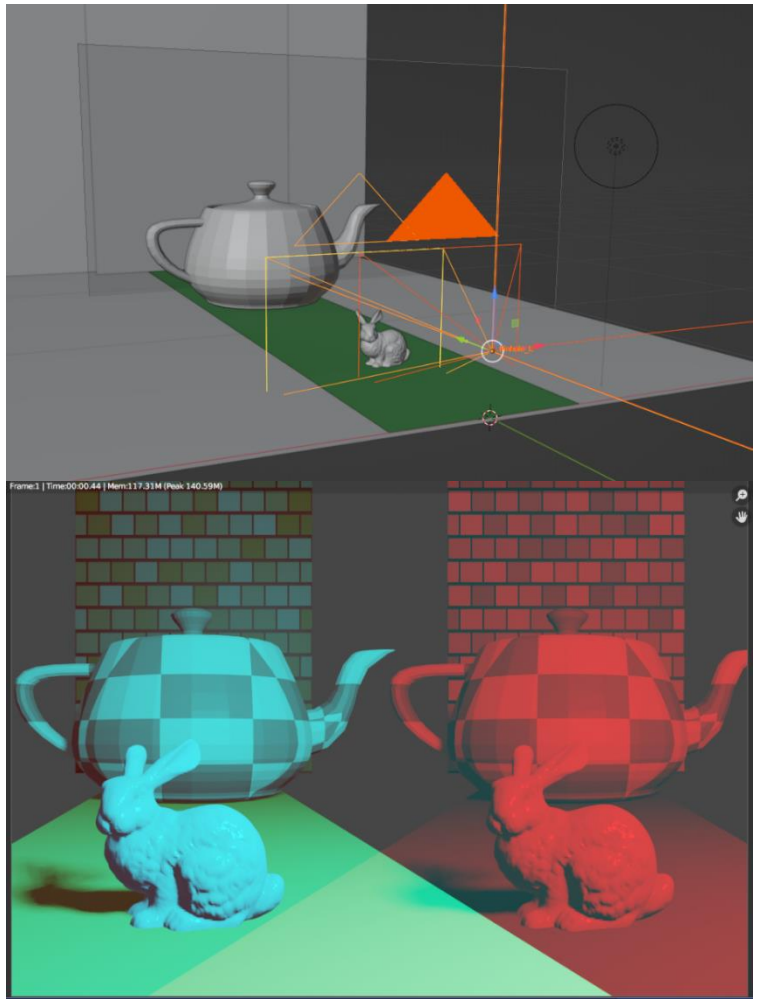
Prophesee PSF Events



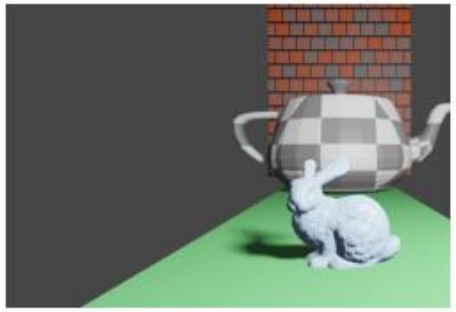


Blender Simulations

Prophesee Stereo
Resolution: [1024 x 720], SensorSize: [6.22mm x

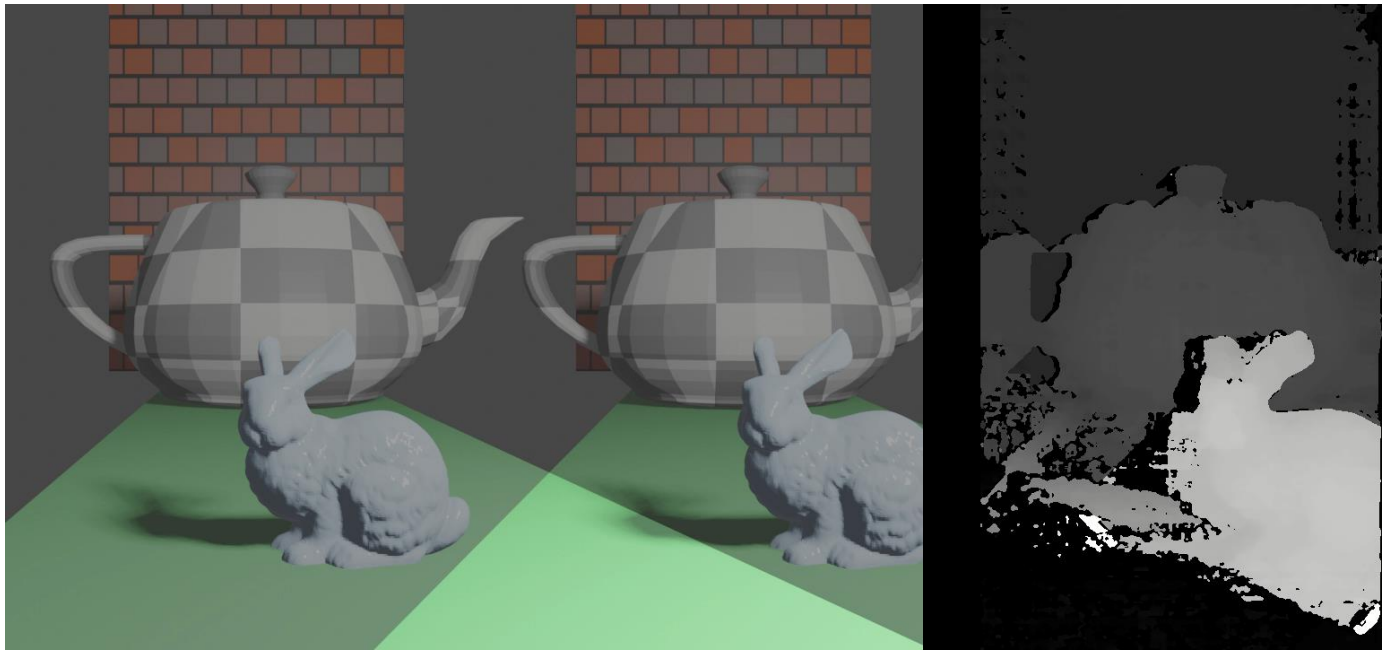


Left Pinhole View



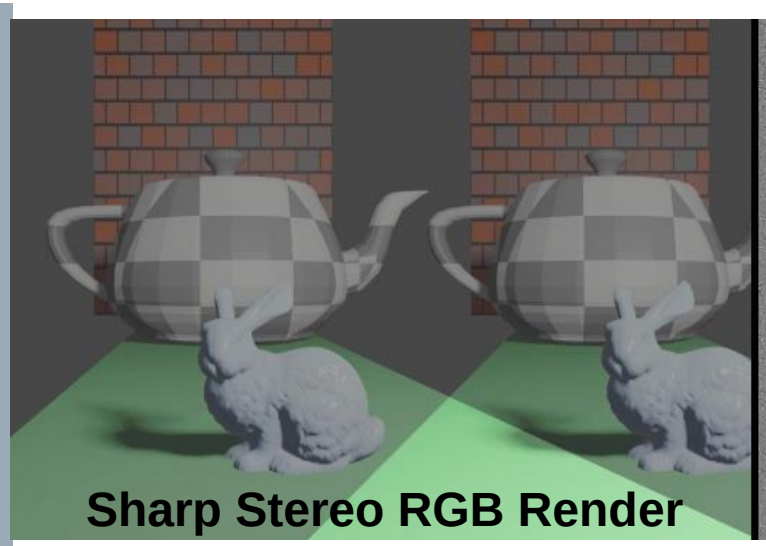
GT Disparity map

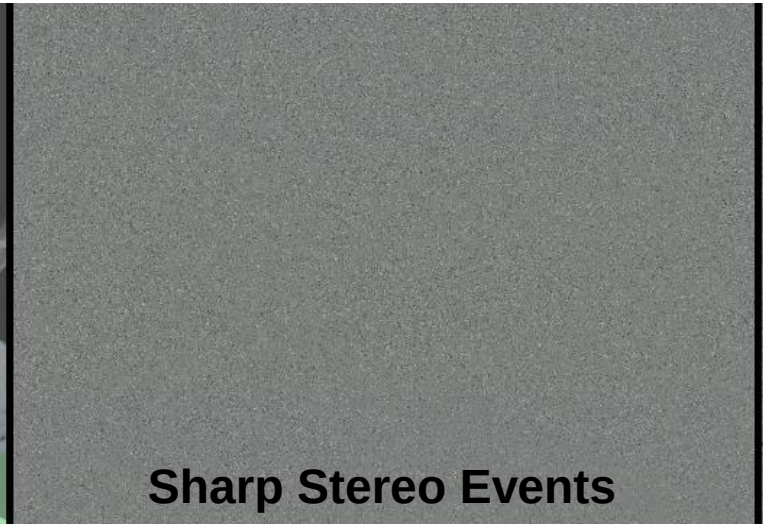
Right Pinhole View

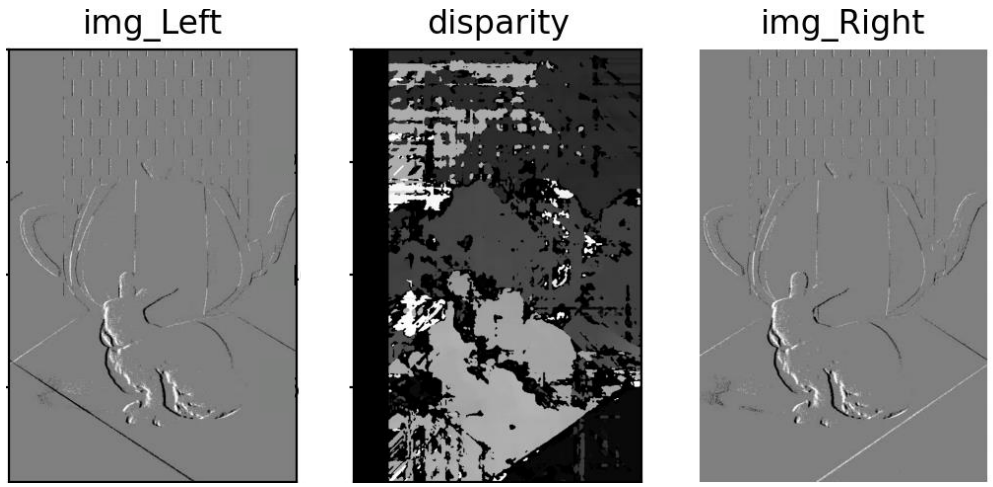


Blender Simulations

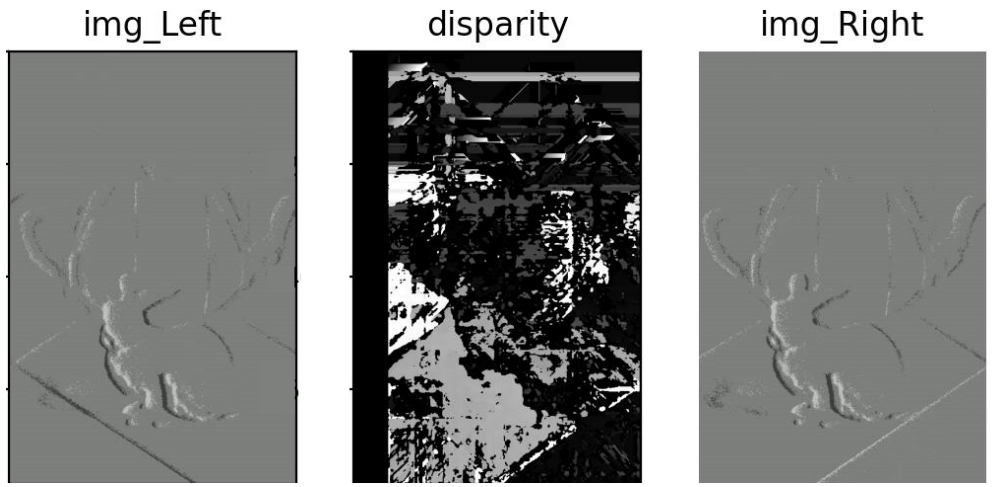
Event Simulations (V2







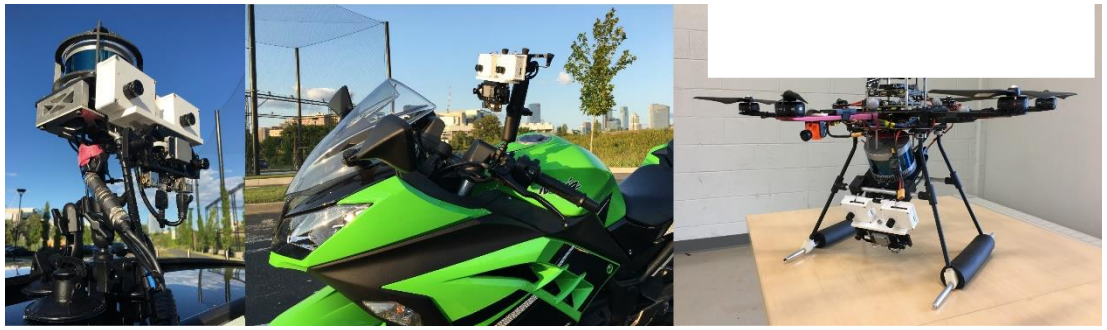
Disparity from Sharp Stereo Events

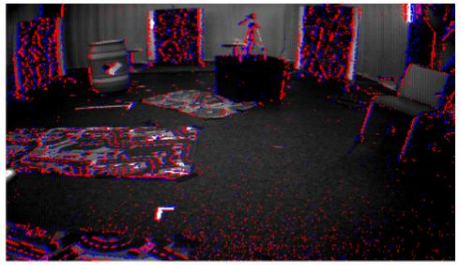


Disparity from PSF Blurred Stereo Events

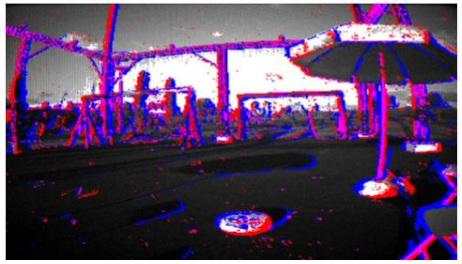
Additional Datasets

The Multivehicle Stereo Event Camera Dataset: An Event Camera Dataset for 3D Perception





Hexacopter Indoor

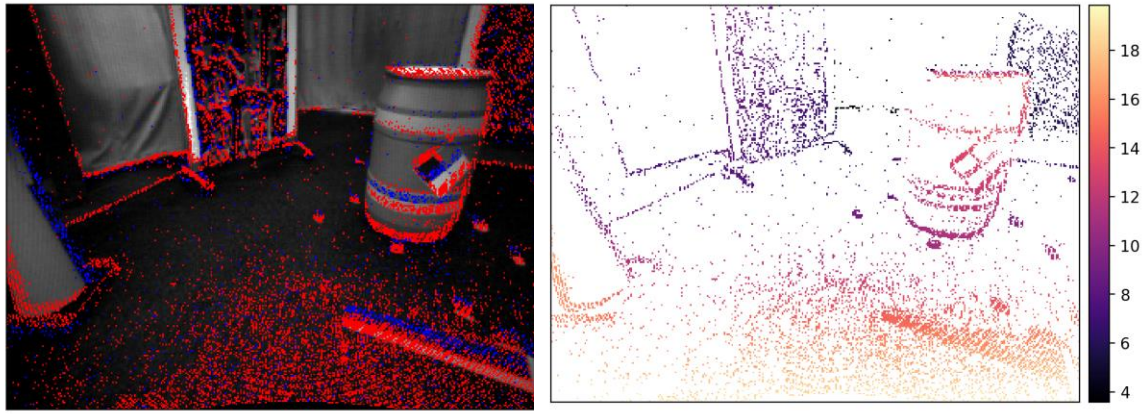


Hexacopter Outdoor

Daytime Driving

Nighttime Driving

- Captured with stereo DAVIS event cameras
- Has events, intensity frames, and dense depth available



Next steps

- Network-based depth imaging using dual pinholes with event cameras
- Extending to multiple pinhole arrays (light field imaging) using event cameras
- Adding active illumination to improve SNR, recover back more information in the scene

Progress and Future Work

Task#/Description	Status	Progress
1. Develop forward-model simulation framework to generate data for experiments and future training	■	- Working simulator is currently being used to generate data for experiments and will be used to generate final training datasets - Functions as intended for the scope of our current optics and can be extended later as needed.
2. Determine optical element for high-SNR event sensing through theoretical optimization and experimental analysis	■	- Dual pinhole determined as appropriate optics for extracting depth information from stereo single camera sensor.
3. Develop & train DL model for lensless event and depth reconstruction.	■	- Framework to train for event reconstruction is ready to train for pinhole sharpening on events. - Network based training for event depth reconstruction currently underway with comparisons to existing methods
4. Benchmark performance for various CV tasks	■	- Benchmark tests will be performed on output events for image reconstruct, optical flow, and object detection &tracking - Have begun setting up simulation framework for these experiments
5. Documentation of research and development	■	- Code is being developed in a reproducible fashion - Targeting paper submission in the spring

■Significant Finding/Accomplishment ■Task Complete ■Task Partially Complete ■Task Not Started

Efforts to Seek Additional Sponsorships and Collaborations

- Qualcomm

Objective Evidence Supporting NCSS Value Proposition

Category	Objective Evidence
Papers, Publications, Presentations/Venue	We anticipate publications in the spring semester
Products (Software, Data, Designs, etc.)	1. Lensless event camera hardware prototype constructed 2. Developing software simulations for this new type of sensing
Student Placements	1. Joshua Rego, graduate research assistant.