Position and Orientation Detection of Spacecraft Using Neural Networks Trained on Event Data

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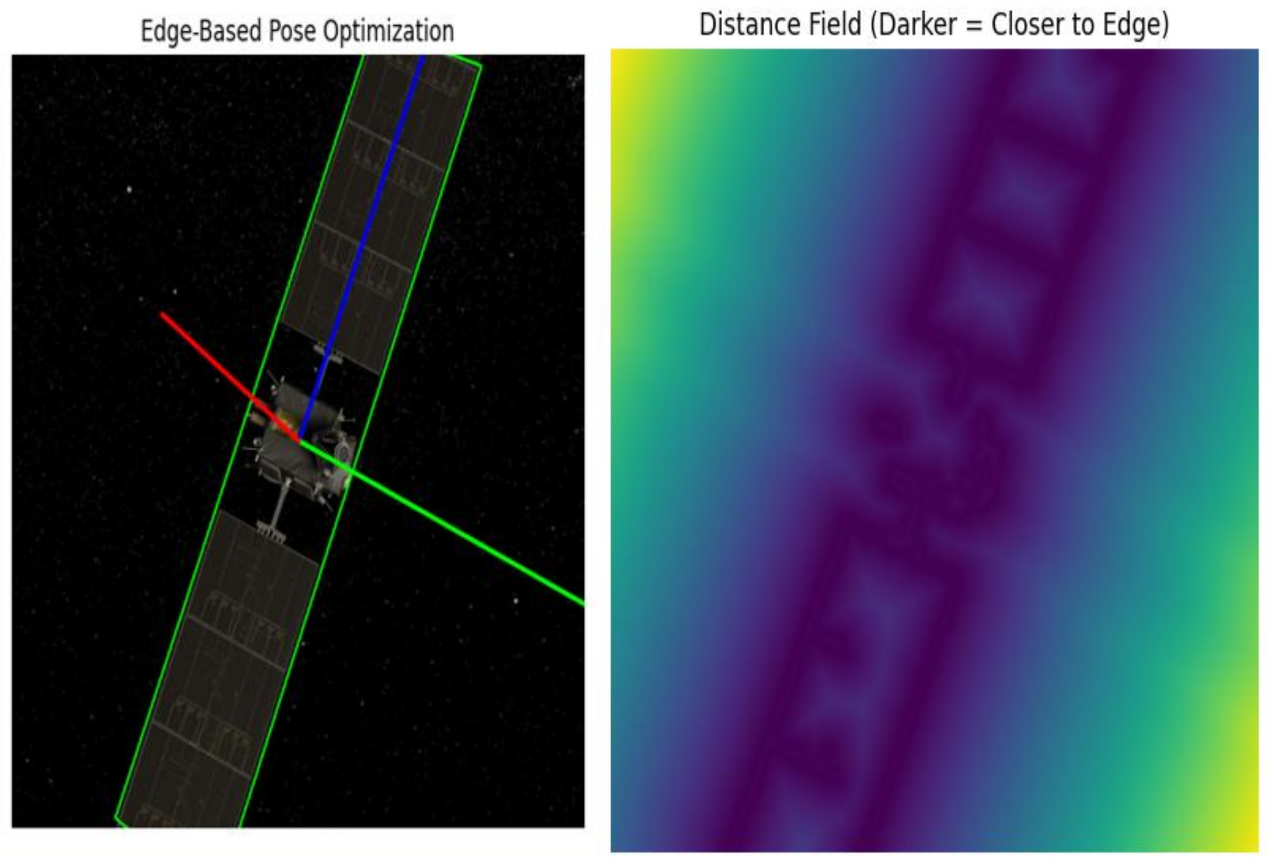
Research Question

How can event-based vision systems enhance the accuracy and efficiency of position estimation and tracking of spacecraft in low-light and high-contrast conditions compared to their frame-based counterparts?

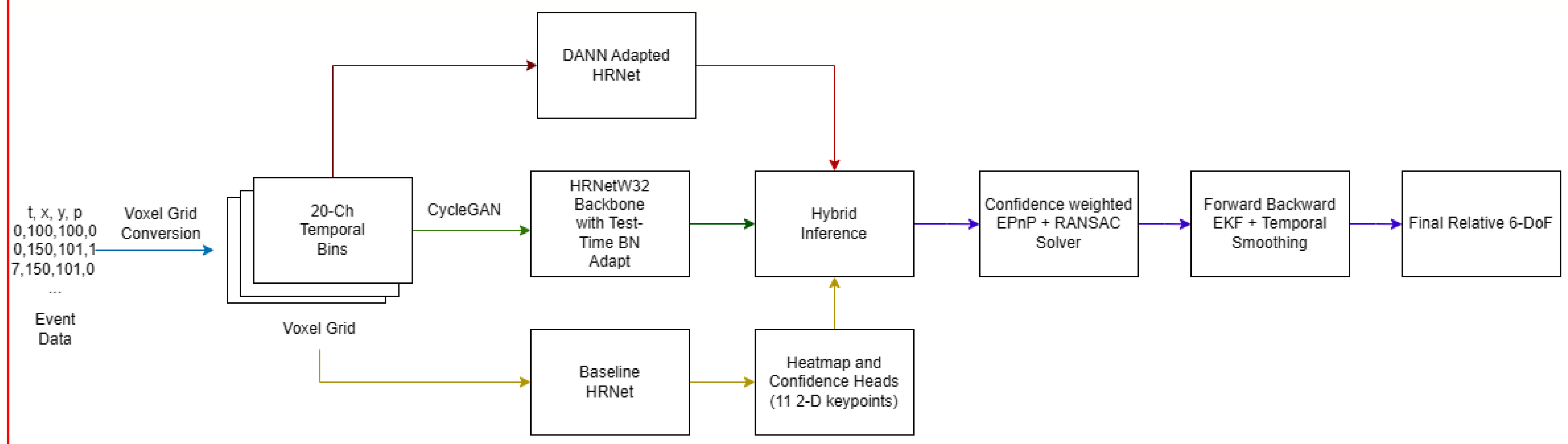
Background

Traditional **spacecraft vision systems** rely on frame-based cameras that struggle with **extreme solar glare** and **deep shadows**, causing sensor saturation or data loss.
Event cameras address these gaps by capturing **per-pixel intensity changes** asynchronously, offering **high dynamic range** and **microsecond precision**. Their ability to eliminate **motion blur** makes them ideal for high-speed **autonomous docking** and tracking **uncooperative satellites** in adversarial lighting.



1. Left Image: Projected Pose. The "Where" and "How" of the spacecraft.
Right Image: Spatial Gradient. The underlying data used for **edge-based** refinement.

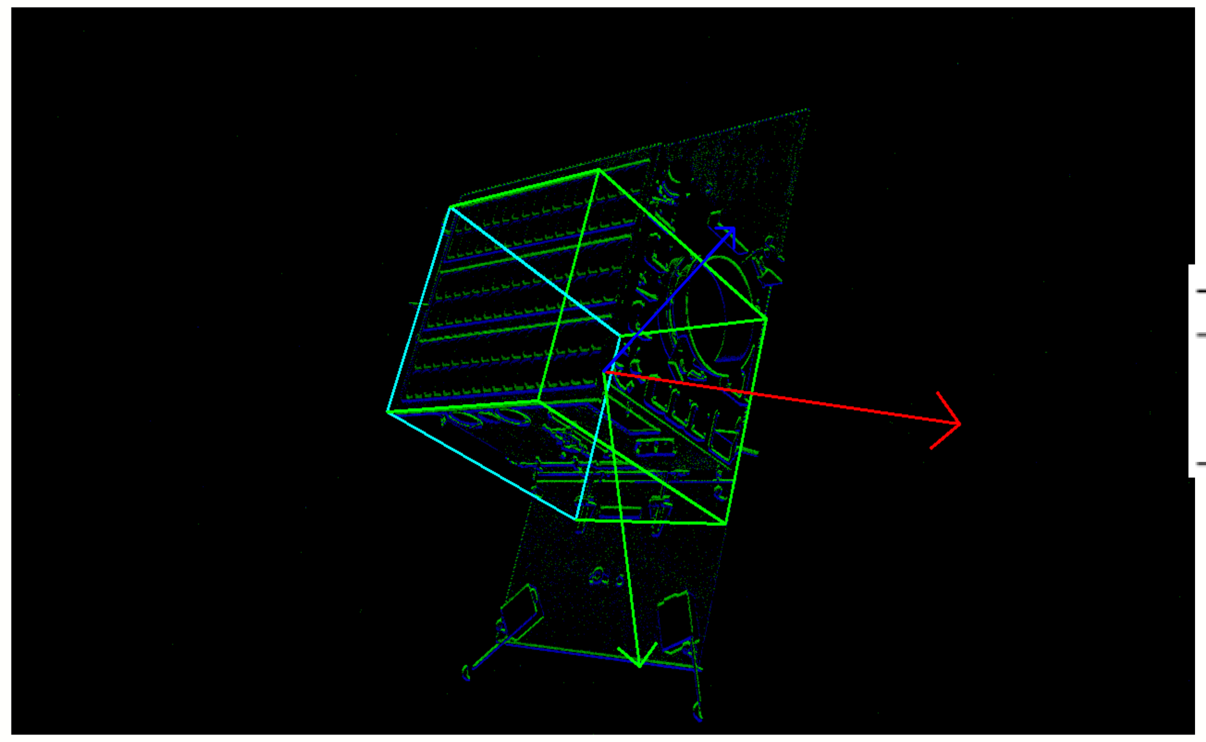
Methodology



2. Pipeline diagram

- Raw event data is processed into **20-Ch temporal bins** via **Voxel Grid Conversion** to preserve microsecond-level timing while enabling neural network compatibility.
- **Hybrid inference** leverages **DANN-adapted HRNet** backbones to generate **2-D keypoints**, which are refined through a **Weighted EPnP solver** and **EKF smoothing** for **6-DoF pose estimation**

Results



Model	Orientation Error (rad)	Translation Error (m)
Baseline HRNet (No Adapt.)	1.9137	0.4546
DANN-Adapted HRNet	1.6820	**0.1121**
HyDEP(Hybrid)	**1.1767**	0.1121

3. Left: Successful event data pose estimation. Right: Pose estimation on SPADES dataset

Future Plans

- **Cross-Dataset Validation**: Evaluate the pipeline on other datasets to test robustness against different satellite geometries and textures.
- **Robustness Benchmarking**: Quantify performance drops under the harsh lighting conditions provided in SPADES to identify specific "blind spots" in the neural network architecture.
- **Deploy on hardware**: Benchmark the pipeline on embedded AI hardware with an event-based vision camera to ensure the pipeline meets the real-time constraints and works on hardware with low power consumption.
- **Sim2Real Refinement**: Benchmark the current pipeline to ensure that the model adapts to unmodeled orbital lighting conditions in real-time.

References

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