TEXAS STATE UNIVERSITY
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Integrated Camera and Lighting System
Hazard Detection Unit

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NASA TEXAS space grant consortium

Problem Description

Lunar Terrain Vehicles (LTVs) require safe, effective operation in environments characterized by:

- ⋆ Rugged terrain
- ⋆ High contrast lighting
- ⋆ Regolith interference

Our Solution

We've designed and tested a **mmWave RADAR** based hazard detection system for enhanced situational automation and navigation safety.

- ⋆ Zero visibility required for operation
- ⋆ Regolith penetration capability
- ⋆ Real-time hazard mapping for operator
- ⋆ Compact, low-power, low-latency design
- ⋆ Outputs bounding box structures for autonomy°

Effective detection envelope: 2.19–30 m.

Close range resolution: 3.9 cm.

Full pipeline executes within a **250 ms** per-frame budget.

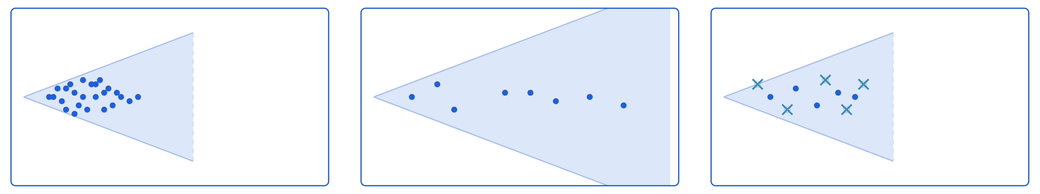
° Each hazard is represented as a 3D axis-aligned bounding box (AABB) classified as either rock or crater. The structure encodes the box's corners, centroid, physical dimensions, volume, and a persistent track ID.

Features

The system exposes **configurable endpoints** at every stage. Sensor profiles are selected at startup, detection parameters are tuned in real time via GUI or JSON.

Sensor Configuration Profiles

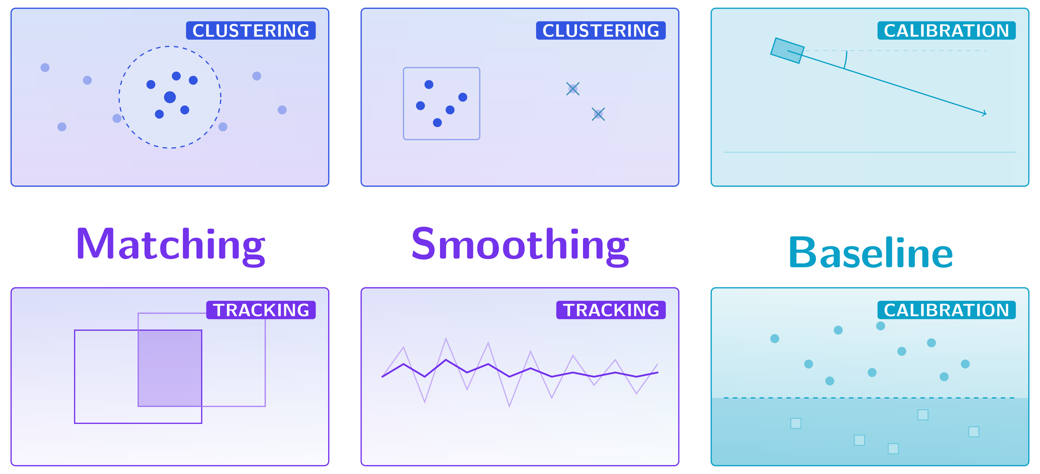
High Resolution | High Range | Low Noise



Real-Time Parameter Tuning*

Radius | Density | Tilt

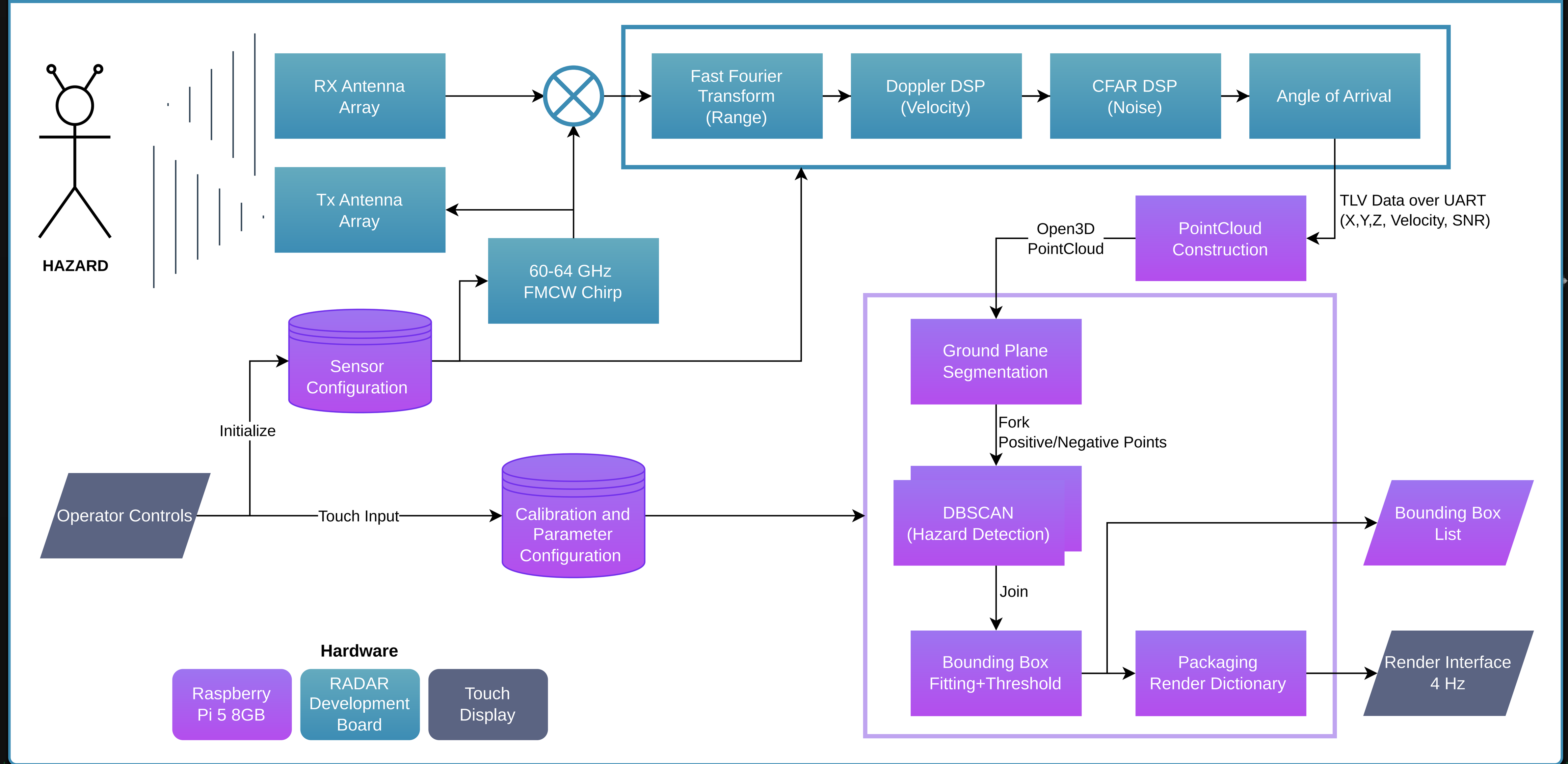
Matching | Smoothing | Baseline



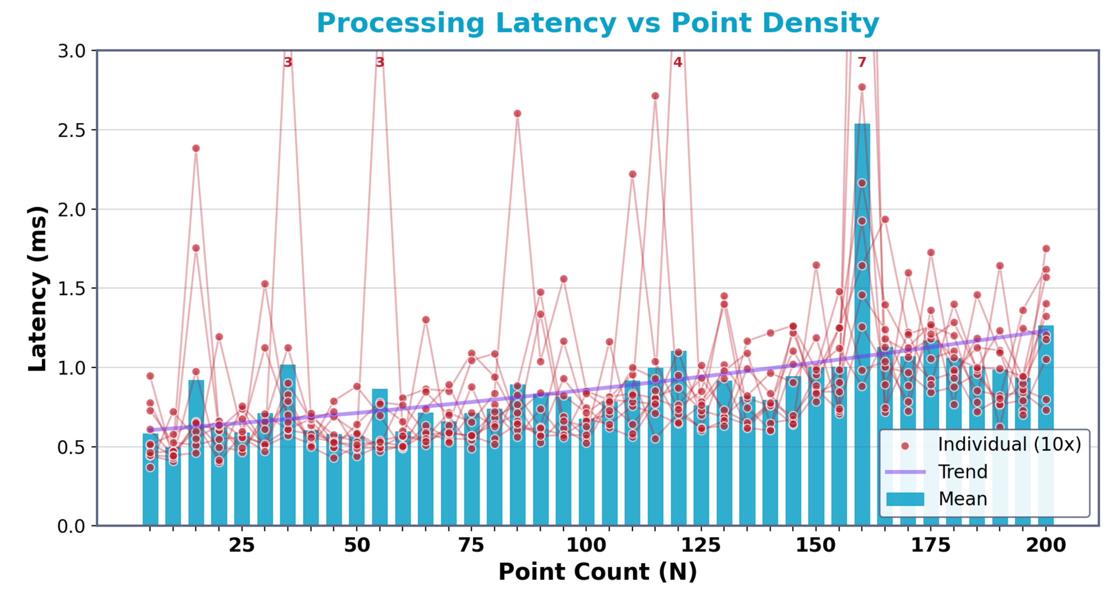
- ⋆ **Calibration** establishes the ground plane for the system to distinguish positive and negative anomalies.
- ⋆ **Clustering** parameters then control if and how these anomaly points are grouped into distinct hazards.
- ⋆ **Tracking** parameters enable smooth and persistent IDs for these hazards, across multiple frames.

* 48 total configurable parameters across 4 subsystems. These are exposed in the GUI.

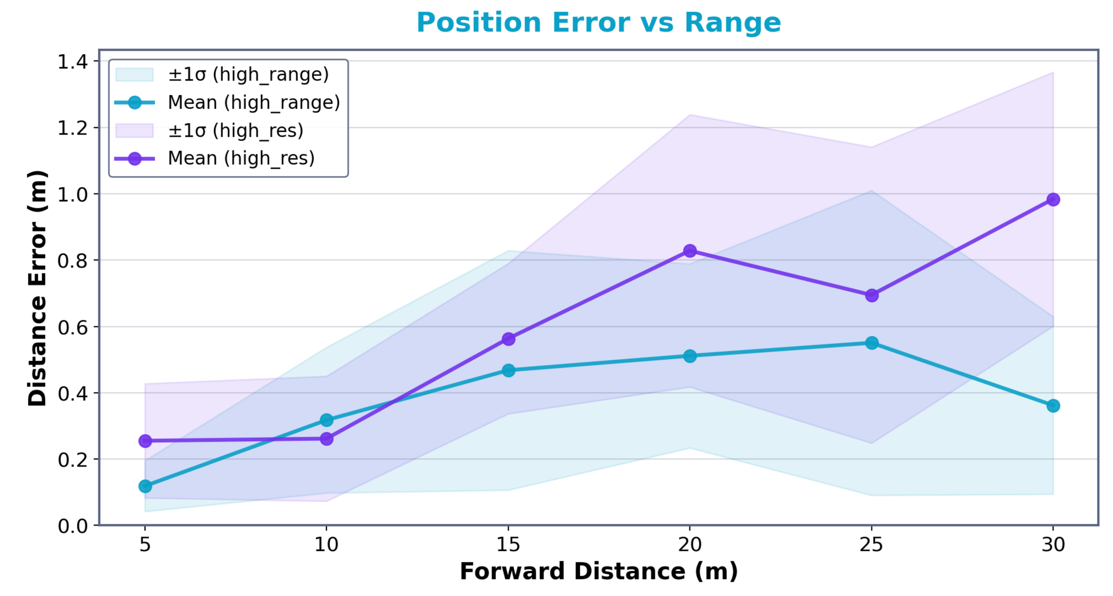
System Level Flow Diagram



System Performance



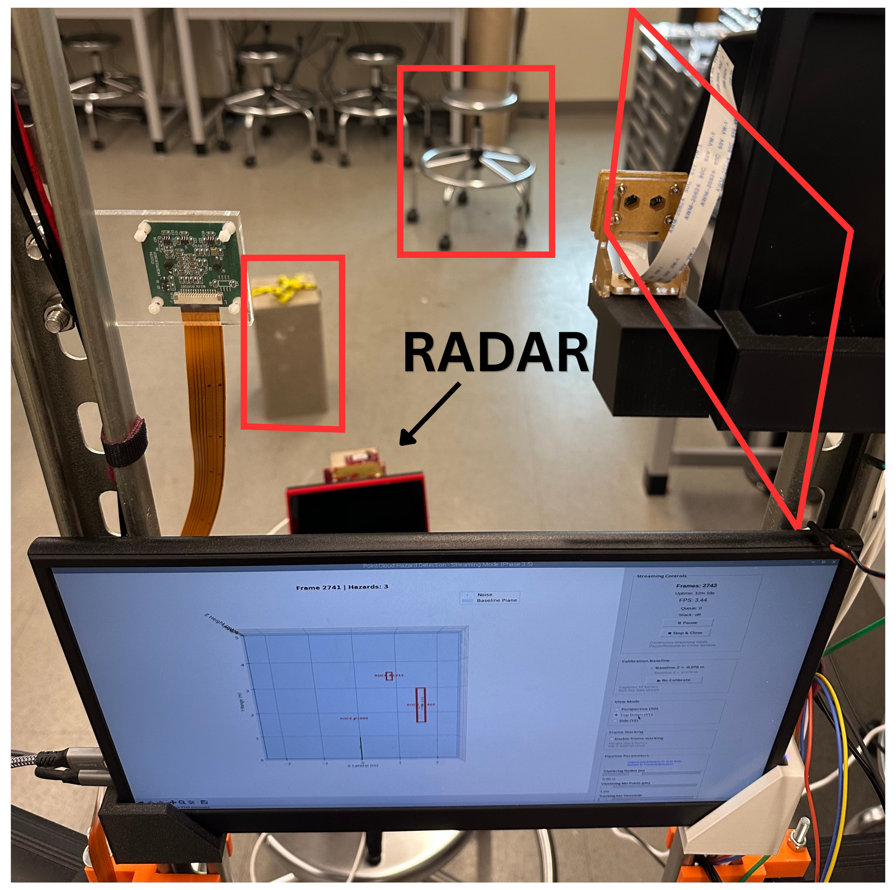
For Total Average Processing Latency: +20 ms at any N due to **interface rendering**. Occasional spikes in individual runs are attributed to the OS-level. While still falling under the latency budget, these spikes are occasionally noticeable especially as they are amplified by interface rendering.



The **high_range** sensor configuration profile maintains lower error at distance compared to **high_res**, whose denser point cloud trades range accuracy for close-range fidelity. Both profiles highlight reliable short-range detection overall.

Deployment Details:

- ⋆ Runs on a **Raspberry Pi 5** 8GB (ARM64, no GPU) using Open3D's C++ backend for real-time DBSCAN clustering acceleration.
- ⋆ **TI IWR6843LEVM** 60 GHz mmWave sensor, mounted at 2.0 m height with −26° downtilt to maximize usable FoV and crater detection (±55° azimuth, ±40° elevation).
- ⋆ **UART** over USB at 921.6 kbps; DSP firmware delivers processed point clouds (≤500 pts/frame).
- ⋆ LIFO queue drops stale frames under CPU pressure, ensuring the operator always sees the newest frame.



Hazard Detection Unit physically implemented into ICLS lighting array. The interface is showing a top-down view where the recognized hazards are emphasized in the image.

Operational Modes

Three interchangeable data sources:

- ⋆ **Live RADAR frames** (from the sensor)
- ⋆ **CSV replay** (tune retroactively from recorded missions)
- ⋆ **Simulated PointClouds** (synthetic test data)°

° Procedural point clouds matching the sensor's FoV and range constraints allow downstream autonomy developers to validate their integration against realistic hazardous scenes without requiring live hardware.

Future Work

We've designed a **lighting array plugin** to demonstrate how our tracked bounding boxes could be used to automate a physical lighting array. We propose an implementation strategy for executing dynamic lighting configurations based on solar angle and the terrain context we provide.

Existing Lighting Design

Execution Matrix

Solar Angle	Rock ↑	Crater ↓
BACKLIT†	Far Flood	High Spot
SIDE LIT	Low Spot	Low Spot
ECLIPSED†	Low Spot‡	Close Flood‡

† Asymmetric lighting to preserve depth perception.
‡ Dimming as distance decreases to prevent overexposure.

Meet the Team

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