BYTEWORKS

SHIVANI BHAT
RAJ MATHURIA
SUYOG REPAL

PROBLEM INSIGHTS

- UGVs require pixel-level semantic segmentation to identify terrain, obstacles, and safe navigation paths in off-road environments.
- Synthetic (digital twin) datasets replace costly real-world labeling but introduce a domain gap.
- The key challenge is ensuring generalization to unseen environments, not just high training accuracy.
- Models must distinguish visually similar classes with precise boundaries and minimal misclassification.
- A complete pipeline is needed: preprocessing, training, validation, and iterative optimization.
- Performance is measured using IoU, accuracy, and robustness under difficult conditions like clutter, lighting changes, and small objects.
- Strong solutions focus on reducing the synthetic-real gap, improving robustness, and providing clear evaluation and reproducibility.

OUR SOLUTION

- U-MixFormer Segmentation Model — 4.1M parameters, ConvNeXt backbone with Mix-Attention decoder
- 7-Class Terrain Segmentation — Sky, Driveable, Rock, Obstacle, Grass, Sand, Rough
- Robustness Testing — FOG & MIST degradation variants with 50+ test images
- 3D Pipeline Visualization — Interactive architecture diagram with particle flow animationReal-time Processing — ~45ms inference per image on GPU
- Hardware Integration — IR/Ultrasonic ensemble for UGV risk assessment
- Cloud Deployment — Vercel frontend + Render backend, auto-scaling
- References: https://arxiv.org/abs/1802.02611 and https://arxiv.org/abs/2312.06272

TECH STACK

TOOLS

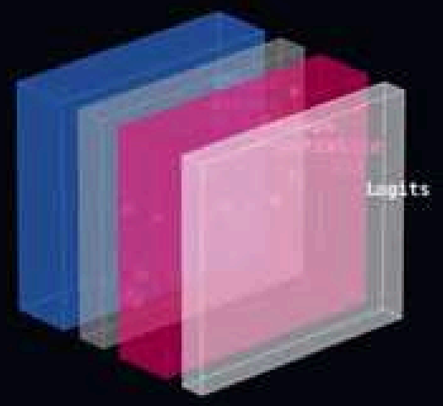
TECHNOLOGIES

- IoT
- IMAGE PROCESSING
- EXPLAINABLE AI
- REINFORCEMENT LEARNING
- DEEP LEARNING
- WEB DEVELOPMENT
- DATA ANALYSIS

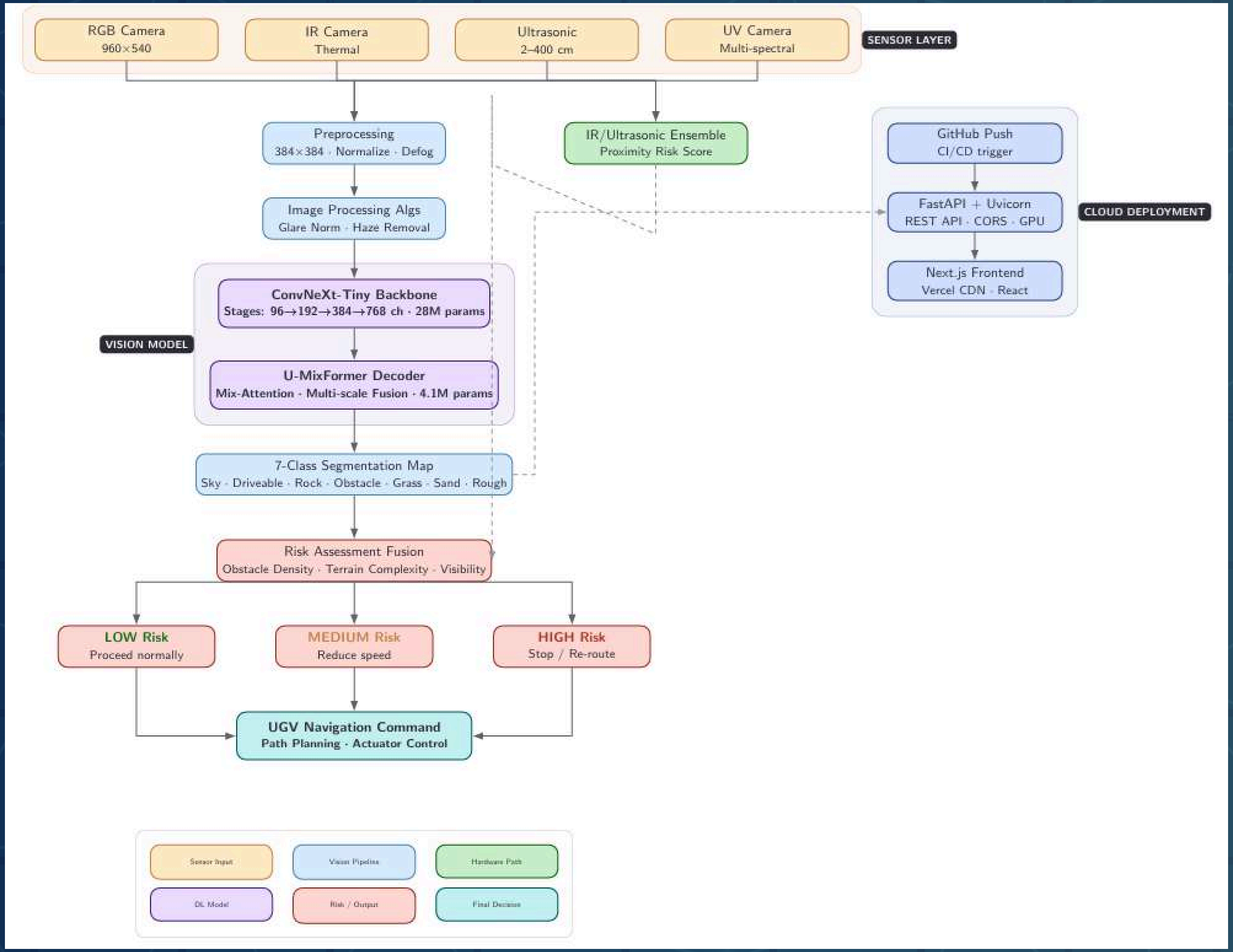
Linear Head · 1×1 Conv baseline

Simplest possible head. One 1×1 conv directly maps
each patch token to class logits. No spatial context.

▸ Reshape → Conv2d



MODEL ARCHITECTURE



Why our Solution?

1. Usage of IoT

We are using one of India's first Made in India boards, Vicharak Shrike Lite along with ultrasonic and infrared sensors to calibrate the terrain

2. Practical Considerations

We created a custom image algorithm that removes fog and dust from an image

3. Tests with Real World Data

Digital twins give ideal images. For testing, we developed a custom image generation model that adds dust, mist and haze and makes images realistic

4 Desert-specific Perception

Most autonomous systems are trained on urban datasets; our U-MixFormer is purpose-built for sandy, arid terrain with 7 off-road classes that urban models completely miss

Image Processing Algorithm

Physical channel-aware dehazing: Unlike standard fog removal, this algorithm treats sand, dust, and mist as distinct degradation types — applying separate transmission estimates per color channel (R/G/B) and correcting for the yellow-red color cast caused by Mie scattering, which generic methods miss entirely.

Multi-stage perceptual restoration pipeline: After haze removal, the image is progressively refined through adaptive gamma correction in LAB color space, luminance-only contrast enhancement (CLAHE), and edge-coherence-gated sharpening — ensuring detail is recovered without introducing artifacts or unnatural colors.

OUR CODE ON EDGE

- Dual-sensor fusion — IR reflectivity + temperature-compensated ultrasonic ranging on Shrike Lite's GPIO, polled every 10ms for real-time terrain awareness
- On-device online learning — RLS adapter updates model weights in-place directly on the Shrike Lite; no cloud, no retraining — the UGV gets smarter in the field
- Kalman-filtered outputs — Adaptive spike detection halves the gain on noisy readings, giving smooth, glitch-resistant predictions even in harsh desert vibration conditions
- Cold-start ready — Physics-derived synthetic priors pre-loaded into a feedback ring buffer so the model is immediately deployable the moment the board powers on
- False-positive hardened — Triple-confirmation gates + 4s cooldown timers ensure alerts only fire on sustained, consistent detections — not sensor glitches

TECH DEMOS

Start


THANK
YOU!