Solution Brief

LATTICE SENSAI™ MULTI-OBJECT DETECTION FOR UNATTENDED GROUND SENSOR SYSTEMS

Deterministic, Low Power Edge AI for Persistent, Real-time Ground Activity Monitoring

Introduction

Unattended Ground Sensor (UGS) systems are deployed along borders, critical infrastructure, remote facilities, and perimeter security zones, where they must operate autonomously for extended periods. These small, battery-powered nodes typically fuse seismic, acoustic, passive infrared (PIR), magnetic, and imaging data, but traditional threshold-based and narrowband processing often struggle in real environments. This limitation leads to high false-alarm rates and limited ability to distinguish humans, vehicles, and animals.

The Lattice sensAI Multi-object Detection (MOD) solution addresses these challenges by bringing deterministic, low-power visual intelligence to UGS deployments. This enables nodes to classify activity, suppress false triggers, and transmit compact metadata instead of raw sensor data, improving situational awareness for operators and fusion systems while preserving power and bandwidth in remote or constrained environments. See Figure 1.

Figure 1: Multi-object Detection Deployed in a Secured Facility Environment

Integrating MOD into Modern Multimodal UGS Sensor Architectures

Modern UGS architectures combine multimodal sensing, including seismic, acoustic, PIR, magnetic, low power cameras, and optional RF or ultrasonic channels, within battery-driven, low-profile nodes arranged in mesh networks for perimeter and route monitoring. These systems generally rely on statistical or spectral methods for initial detection and rough classification, while higher-level workstations perform multi-target tracking and situation assessment using sparse, asynchronous reports.

Research shows that adding vision and pushing target detection closer to the sensor significantly improves human, vehicle, and animal discrimination while reducing false alarms caused by background noise or nonthreat activity. The Lattice sensAI MOD addresses this need by delivering a compact, edge-optimized detection pipeline suited to UGS size, weight, power, and cost (SWaP-C) constraints. Its anchor-free, multi-scale architecture with fixed 384 × 288 RGB or IR inputs provides reliable per-frame object detection within camera-enabled nodes or gateways, enhancing both local confirmation and fusion-level analytics.

KEY CHALLENGES

- High false-alarm rates driven by environmental background noise and clutter
- Limited target discrimination across humans, light vehicles, and animals
- Sparse, asynchronous sensor reporting in dense or multi-object scenes
- Severe edge SWaP-C constraints limiting compute, memory, and sensing
- Challenging RF propagation with low-rate, intermittent backhauls
- Requirement for persistent, long-life unattended field operation

LATTICE SOLUTION

- Embedded-optimized, anchor-free, multi-scale detection architecture
- Lightweight, high-utility models tailored for UGS deployments
- Deployment-accurate quantization and hardware-aligned compilation flow
- Real-world-validated performance across lighting and environmental conditions
- Sub-watt, deterministic edge inference for long-life deployments

Challenges

Fielded UGS systems face several recurring challenges in non-military security and monitoring deployments.

- **High False Alarm Rates from Background Noise**
  Seismic and acoustic sensors often trigger on environmental phenomena such as wind, rain, vegetation, small animals, and nearby machinery. These signals are difficult to distinguish from human or vehicle signatures using simple threshold-based or narrowband spectral methods.
- **Limited Target Discrimination (Human vs. Vehicle vs. Animal)**
  Many deployed nodes cannot robustly separate humans, light vehicles, and larger animals, especially at low signal-to-noise ratios or longer ranges. This leads to operator overload and reduced trust in alerts.
- **Sparse, Asynchronous Reporting and Complex Scenes**
  UGS reports arrive intermittently from distributed nodes, often with limited feature information. Higher-level tracking, including EKF, MHT, and multi-hypothesis or expert-system-based trackers, must operate with partial and noisy observations, making multi-target tracking and route reconstruction difficult.
- **Strict Power and SWaP-C Constraints at the Edge**
  Nodes are battery-powered, low-profile, and sometimes disposable. They cannot host high-power CPUs or GPUs or stream video continuously. Any edge compute must operate at milliwatt-level budgets while meeting thermal and form-factor constraints.
- **Challenging RF Environment and Limited Backhaul**
  UGS deployments often operate in cluttered RF environments with low antenna heights, ground effects, and vegetation loss, and rely on low-power, low-data-rate links. Sending full waveforms or video is impractical, so systems must prioritize compact metadata.
- **Need for Persistent, Long-life Operation**
  Border segments, remote corridors, and industrial perimeters require long unattended operation with minimal maintenance. This constrains both power consumption and algorithmic complexity.

The Lattice Solution

The Lattice sensAI 8.0 solution stack delivers a highly optimized, deployment-ready MOD pipeline built around two purpose-designed models: Generic MOD and Automotive MOD. These models share a common YOLO-like, anchor-free, three-scale architecture engineered from the ground up for embedded performance. Both operate on a 384 × 288 RGB input and generate separate class and bounding-box outputs, simplifying fixed-point quantization and enabling deterministic, hardware-efficient execution.

Generic MOD is a 3.0M-parameter, general-purpose detector trained on the full 80-class COCO dataset, making it adaptable for broad UGS scenarios involving people, vehicles, and other objects.

Automotive MOD, at 2.75M parameters, focuses on eight key classes, including person, car, truck, bus, motorcycle, bicycle, traffic light, and stop sign. This provides a compact, domain-targeted model for security, perimeter, and mobility-focused deployments.

Both models have been validated on the Lattice CertusPro-NX™ System on Module (SOM), where an LFCPNX-100 CertusPro-NX FPGA performs real-time detection using an IMX219 camera. A Raspberry Pi CM5 and Lattice HUB software stream lightweight bounding-box metadata, demonstrating a complete operational pipeline from camera capture to embedded inference to low-bandwidth output.

For UGS systems, these models provide on-node visual confirmation of targets, dramatically improving classification confidence and enabling systems to transmit compact metadata rather than full video streams. This is a critical requirement for long-life, low-bandwidth field deployments.

Key Capabilities

- **Embedded-optimized Anchor-free Detection Architecture**
  Generic MOD and Automotive MOD use a three-scale, anchor-free detection head that simplifies bounding-box prediction and reduces computational overhead. The fixed 384 × 288 input aligns with FPGA memory constraints and supports consistent inference throughput.
- **Lightweight, High-utility Models for UGS**
  Generic MOD's 80-class coverage suits heterogeneous outdoor environments, while Automotive MOD's eight-class configuration is tuned for security-relevant classes and has demonstrated reliable detection ranges of up to 30 m for vehicles in outdoor tests.
- **Deployment-accurate Quantization and Compilation**
  The Lattice sensAI Neural Networks Training Environment (LATTE) and LSCQuant toolchain provide fixed-point quantization, simulation, and compilation flows that ensure model behavior observed during evaluation matches behavior on Lattice CertusPro-NX FPGAs, reducing deployment risk.
- **Real-world-validated Performance**
  Automotive MOD has been tested across indoor, outdoor sunny, and nighttime conditions, with consistent performance across its eight classes and verified minimum detectable object sizes using standard object-detection benchmarks at 8-pixel and 20-pixel localization tolerances.
- **Sub-watt, Deterministic Edge Execution**
  The compact parameter counts of Generic MOD (~3.0M) and Automotive MOD (~2.75M) enable reliable, fixed-latency inference within sub-watt power envelopes, supporting multi-year unattended deployments.

Deterministic Edge Vision MOD for UGS Systems

Lattice delivers an integrated edge-vision stack that combines optimized models, precise quantization, FPGA-friendly architectures, and production-ready hardware to enable reliable and efficient perception at the far edge. For UGS systems, this edge intelligence enables MOD to run directly within sensor-proximate nodes, delivering deterministic, low-latency classification under strict SWaP-C constraints. By tightly co-designing algorithms, quantization flows, and hardware acceleration, Lattice enables always-on MOD suitable for autonomous UGS deployments.

Benefits

- **Co-engineered Models and Hardware Flow**
  Generic MOD and Automotive MOD are co-designed with Lattice's quantization tools, neural-network compiler, and ML IP blocks. This unified approach ensures the models map cleanly onto Lattice CertusPro-NX resources with consistent, deterministic timing, which is critical for UGS alerting and fusion logic.
- **Ready-to-deploy SOM Platform**
  The Lattice CertusPro-NX SOM provides a fully validated implementation, including the FPGA, camera interface, firmware, metadata streaming, and runtime tools. This reduces development time and simplifies integration for UGS designers.
- **Model Interchangeability for Mission Flexibility**
  Generic MOD and Automotive MOD share the same backbone architecture and compilation flow, allowing teams to switch between 80-class and 8-class models without any hardware redesign. This supports rapid adaptation to different operational requirements, agency needs, or deployment environments.
- **Predictable FPGA Inference for Edge Reliability**
  FPGA execution delivers fixed latency and deterministic behavior, enabling more stable alerting and more reliable coordination with acoustic, seismic, or radar triggers in UGS sensor-fusion pipelines.
- **Engineered for Long-life Field Installations**
  The Lattice CertusPro-NX FPGA delivers low power, a compact form factor, long-term availability, and robustness for multi-year unattended UGS deployments in remote or harsh environments.

Why Traditional UGS Sensors Fall Short

UGS systems deployed across defense, border security, and critical-infrastructure environments rely on a range of sensing technologies. Each plays an important role in detection, but all have well-known limitations in classification accuracy, environmental robustness, and false-alarm performance.

- **Seismic Sensors**
  These detect ground vibrations from footsteps and vehicles and are effective in low-visibility conditions. However, they are highly sensitive to soil composition and environmental noise, which often results in false alarms.
- **Acoustic Sensors**
  Acoustic systems capture sound signatures for detection and coarse identification. Their reliability is reduced by wind, echoes, and background noise, making consistent target discrimination difficult.
- **Passive Infrared Sensors**
  Passive infrared sensors sense heat-based motion and are extremely power-efficient, but they operate only at short ranges and cannot identify target type.
- **Magnetic Sensors**
  Magnetic systems detect disturbances caused by ferrous objects and are useful for identifying vehicles or weapons. However, they cannot detect unarmed personnel and function only within very limited distances.
- **Ultrasonic / Micro-doppler Sensors**
  These use Doppler-based motion analysis to sometimes distinguish humans from animals, but short range and occlusion sensitivity limit their effectiveness in complex terrain.
- **Radar Sensors**
  Radar enables all-weather detection at longer ranges but typically requires more power and still struggles with fine-grained classification in cluttered outdoor environments.
- **EO/IR Cameras**
  Optical and thermal cameras provide rich visual information, but without onboard intelligence they often require high bandwidth or human review. This limits their usefulness in unattended, low power deployments.

Together, these sensing modalities form a strong foundation for UGS deployments, but visual confirmation at the edge remains difficult to achieve using conventional approaches. Today, UGS systems typically rely on high-power camera processors or off-node video streaming to validate detections, both of which exceed battery budgets and consume valuable bandwidth.

The Lattice sensAI MOD solution addresses this gap by enabling true on-node visual intelligence within a sub-1 W power envelope. Battery-operated UGS nodes can classify people and vehicles locally and transmit only compact bounding-box metadata instead of full video. This delivers immediate, reliable confirmation of detected activity, significantly reduces false alarms, and makes UGS networks more efficient, more accurate, and easier to deploy in remote or bandwidth-constrained environments.

Conclusion

Unattended Ground Sensor networks play a critical role in monitoring remote borders, industrial perimeters, and key infrastructure. However, systems that rely solely on seismic, acoustic, or PIR sensing remain limited in their ability to accurately classify detected activity. Adding compact, low-power visual detection directly at the node significantly improves a system's ability to distinguish humans, vehicles, and benign motion.

The Lattice sensAI MOD solution is purpose-built to address UGS constraints, delivering deterministic, sub-watt inference, compact metadata generation, and long-life operation in small-form-factor nodes. By enabling reliable object detection at the edge, MOD reduces false alarms, strengthens operator confidence, and improves the quality of data passed to sensor-fusion systems, all while maintaining strict power and bandwidth limits.

For UGS programs seeking to modernize without increasing system size, thermal load, or power consumption, the Lattice sensAI solution stack offers a practical and scalable path forward. It delivers just enough compute for real-time ground-activity monitoring, allowing customers to enhance sensing performance while preserving the deployment characteristics these systems depend on.

Ready to Learn More?

To learn more about Lattice low power FPGA-based solutions for industrial, automotive, communications, computing, and consumer applications, visit **www.latticesemi.com** or contact us at **sales@latticesemi.com**.