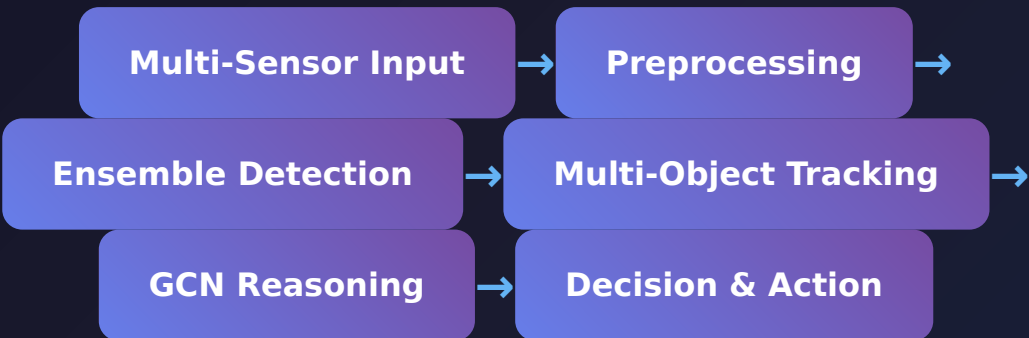


Graph-Enhanced Ensemble Vision System (GEEVS)

Comprehensive System Architecture for Real-Time
Human Tracking in Search-and-Rescue Operations

System Data Flow Pipeline



1 Input Layer & Sensor Fusion

RGB Camera System

- 4K resolution at 30fps minimum
- Optical image stabilization
- Auto-exposure and white balance
- Wide-angle lens (120° FOV)
- Low-light performance optimization

Thermal Imaging System

- FLIR Boson 640×512 resolution
- LWIR spectrum (8-14μm)
- Temperature range: -40°C to +330°C
- Thermal sensitivity: <50mK
- Synchronized with RGB stream

LiDAR Integration (Optional)

- Velodyne VLP-16 or equivalent
- 360° horizontal scanning
- ±15° vertical FOV
- 100m range capability
- Point cloud generation

Sensor Synchronization

- Hardware timestamp alignment
- Spatial calibration matrix
- Multi-modal data fusion
- Real-time stream management
- Quality assessment metrics

2 Preprocessing & Enhancement

Image Enhancement

- Adaptive histogram equalization (CLAHE)
- Gaussian blur for noise reduction
- Contrast and brightness normalization
- Color space conversion (RGB→HSV)
- Dynamic range compression

Frame Stabilization

- Motion vector estimation
- Affine transformation correction
- Rolling shutter compensation
- IMU data integration
- Temporal frame alignment

Multi-Scale Processing

- Image pyramid generation (5 levels)
- Scale-invariant feature extraction
- Resolution adaptive processing
- Bandwidth optimization
- Memory efficient scaling

Buffer Management

- Circular buffer (5-frame window)
- Temporal consistency checking
- Frame interpolation capability

- Memory pool optimization
- Thread-safe operations

3 Ensemble Detection Framework

YOLOv8 Detector

- Real-time branch (>30 FPS)
- Anchor-free detection
- Multi-scale feature fusion
- TensorRT optimization
- Dynamic batch processing

Faster R-CNN Detector

- High-precision branch
- Region Proposal Network (RPN)
- Feature Pyramid Network (FPN)
- ROI Align for accuracy
- Selective processing (every 3rd frame)

Thermal Specialist Network

- Custom thermal-trained model
- Temperature-based features
- Thermal signature recognition
- Low-light optimization
- Thermal-RGB alignment

Ensemble Fusion Engine

- Dynamic confidence weighting
- Bayesian model averaging
- Non-Maximum Suppression (NMS)
- Weighted Box Fusion (WBF)
- Consensus-based validation

4 Multi-Object Tracking System

DeepSORT Tracker

- Kalman filter motion prediction
- Deep appearance descriptor
- Hungarian algorithm assignment
- Track management system
- Occlusion handling

ByteTrack System

- Association-based tracking
- Low-confidence detection recovery
- Simple online tracking
- Robust to detection noise
- Minimal parameter tuning

Re-Identification Network

- Person re-ID across occlusions
- Appearance feature extraction (512-dim)

- Metric learning optimization
- Cross-camera matching
- Temporal feature consistency

Track Quality Assessment

- Confidence score calculation
- Track stability metrics
- Motion consistency analysis
- Appearance reliability scoring
- Adaptive threshold management

5 Graph Convolutional Network Reasoning

Graph Construction

- Dynamic node creation (detected persons)
- Spatial proximity edges
- Temporal relationship modeling
- Interaction pattern analysis
- Hierarchical graph structure

Node Feature Engineering

- Visual appearance embeddings (512-dim)
- Motion vectors and velocity
- Spatial coordinates and bounding box
- Temporal presence history
- Interaction frequency metrics

Spatial-Temporal GCN

- Multi-layer GCN architecture (3 layers)
- Residual connections
- Attention mechanism
- Temporal convolution layers
- Graph pooling operations

Contextual Reasoning

- Crowd behavior analysis
- Trajectory prediction (5-second horizon)
- Occlusion anticipation
- Group movement detection
- Anomaly behavior identification

6 Decision Engine & Action Layer

Target Prioritization

- Risk assessment algorithm
- Vulnerability scoring (age, isolation)

- Tracking confidence weighting
- Mission parameter integration
- Dynamic priority adjustment

Path Planning

- RRT* path planning algorithm
- Obstacle avoidance system
- Dynamic re-planning capability
- Optimal viewing angle maintenance
- Energy-efficient navigation

Communication System

- Real-time operator alerts
- GPS coordinate transmission
- Video stream relay
- Emergency protocol activation
- Multi-agent coordination

Data Logging

- Complete tracking history
- Decision audit trail
- Performance metrics logging
- Incident report generation
- Post-mission analysis data

Hardware Requirements

Computing Unit: NVIDIA Jetson AGX Orin 64GB

GPU: 2048-core Arm Cortex-A78AE

Memory: 64GB LPDDR5 RAM

Storage: 1TB NVMe SSD

Power: 60W TDP maximum

I/O: USB 3.2, GigE, CAN, GPIO

Software Stack

Framework: PyTorch 2.0 + TensorRT

Computer Vision: OpenCV 4.8, Detectron2

Graph Processing: PyTorch Geometric, DGL

Robotics: ROS 2 Humble

Communication: ZeroMQ, WebRTC

Optimization: ONNX, TensorRT, CUDA

Network Architecture

Detection: YOLOv8n/s/m variants

Classification: Faster R-CNN ResNet-50

Re-ID: OSNet with Triplet Loss

GCN: GraphSAGE with 3 layers

Fusion: Attention-based ensemble

Optimization: Mixed precision training

Target Performance Metrics

95%+

Detection mAP@0.5

80%+

MOTA Score

30+

FPS Real-time

<100ms

End-to-end Latency

<5%

ID Switch Rate

45W

Power Consumption

Key Innovations

Adaptive Ensemble Weighting

Dynamic model fusion based on environmental conditions and detection confidence, automatically adjusting to optimize performance in real-time.

Hierarchical Graph Construction

Multi-level graph representation capturing both local interactions and global scene context for enhanced tracking consistency.

Predictive Trajectory Modeling

GCN-based future path prediction enabling proactive tracking and improved handling of temporary occlusions.

Multi-Modal Sensor Fusion

Intelligent combination of RGB and thermal imaging for robust detection across diverse environmental conditions.

Architecture Legend

Core Processing Layers

■ Component Modules

■ Performance Metrics

■ Innovation Highlights