Grounded Discovery Labs -- Discovery Pack

Discover: Design a system for early wildfire detection in remote forested areas that alerts within 15 minutes while minimizing false positives and maintenance burden.

Top 3 Comparison

	Featured Discovery	Bold Concept	Build-First
	Black-Carbon Aerosol Optical Mesh with Wind Consensus	Atmospheric electric-field smoke tomography mesh	Ridge-Tower Dual-Band Vision Network with Edge CNN
novelty	6	9	3
feasibility	8	4	9
economic_leverage	6	6	5
testability	9	5	9
robustness	7	3	7
constraint_fit	9	7	9
explainability	9	5	9
OVERALL	**7.7 / 10 -- Very Strong**	**5.6 / 10 -- Moderate**	**7.3 / 10 -- Very Strong**

Runner-ups

* Ridge-Tower Thermal/Visible AI with Plume Backtracking [solid-alternative] -- Solar ridge masts watch for heat and smoke geometry, using cross-view confirmation to avoid chemical false positives.
* Distributed Fiber-Optic Acoustic+Thermal Sensing Along Forest Corridors [solid-alternative] -- Buried single-mode fiber along service roads acts as a continuous DAS/DTS sensor turning every meter into a thermal+acoustic pixel.
* Slime-Mold Gossip Consensus for Sparse Fire Alerts [near-miss-alternative] -- A fault-tolerant mesh escalates from node suspicion to neighborhood quorum to ranger alert, avoiding both central servers and noisy single-node alarms.
* LoRa E-Nose Mesh with Neighbor-Voted Fire Fingerprints [solid-alternative] -- Sparse battery nodes fuse CO, NOx, VOC ratios, humidity and wind context, then ask neighbors to confirm before issuing a 15-minute wildfire alert.
* Neuromorphic polarimetric plume-eye network [solid-alternative] -- Insect-inspired event cameras watch skylight polarization flicker from nascent smoke plumes before they are obvious in normal imagery.

Featured Discovery
Black-Carbon Aerosol Optical Mesh with Wind Consensus

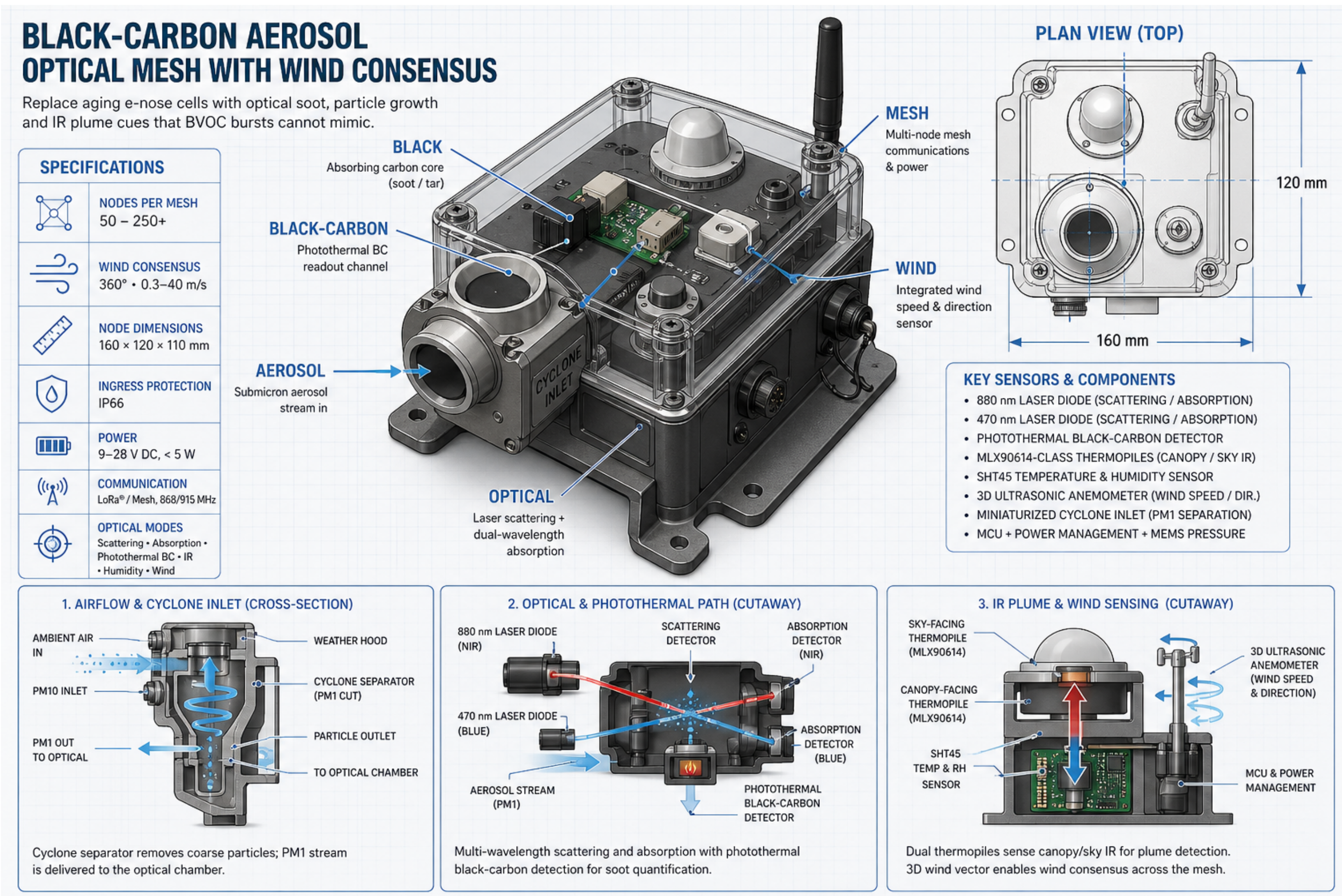
novelty: 6 | feasibility: 8 | economic_leverage: 6 | testability: 9 | robustness: 7 | constraint_fit: 9 | explainability: 9

Overall: 7.7 / 10 -- Very Strong

Snapshot: sha256:6d4e3b63653ad6e3...

Constraint Compliance: Compliant (constraint_fit=9)

Wildfire smoke detection degrades when e-nose chemical cells drift and BVOC emissions create false positives; a distributed optical mesh using black-carbon absorption, scattering ratio, and IR plume signatures across three orthogonal modalities solves this by targeting physical aerosol properties that vegetation chemistry cannot replicate. Wind-consensus voting across nodes eliminates single-point false alarms and provides directional fire localization. This matters because early sub-threshold smoke detection in remote forested terrain is the critical gap between containable and catastrophic wildfire outcomes.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A distributed mesh of low-cost black-carbon (BC) optical nodes detects wildfire smoke via three orthogonal modalities and cross-node wind consensus. Each node integrates: (1) a PM2.5 sharp-cut cyclone (e.g., URG-2000-30EH-class miniaturized to ~1 L/min) followed by a stainless insect screen (200 um) and a hydrophobic PTFE-coated heated inlet (held 5 degC above ambient dewpoint via 2 W PTC heater) with condensate drain; (2) a dual-wavelength photothermal/absorption cell using 880 nm (BC-dominant) and 470 nm (BrC/BC) laser diodes

(5-20 mW) with a thermopile (e.g., Melexis MLX90614-class) detecting photothermal heating of trapped aerosol on a quartz-window pass-through cell, plus a 90deg nephelometric scatter channel (660 nm) for absorption/scatter ratio (SSA proxy); (3) an SHT45 RH/T sensor and a Sensirion SFM3000 flow sensor for self-diagnostics.
Self-checking sequence: every 15 min a solenoid switches to a HEPA zero-filter to rezero both optical channels; a mechanical shutter blocks the source for dark-current capture; a reference LED path through a sealed neutral-density coupon tracks window fouling (>10% reference loss triggers maintenance flag); flow drop >15% triggers cyclone/screen alarm. Fog/cloud rejection uses RH>95% AND single-scatter albedo >0.95 AND absent absorption rise to suppress alerts. A wildfire alert requires: BC absorption coefficient rise >2 Mm-^1 above 24 h baseline, SSA <0.85 (combustion signature), and spatial propagation -- upwind node leads downwind node by deltat consistent with local 10 m wind vector (from co-located anemometer or HRRR reanalysis) within +/-30deg. Mesh consensus (>=2 of N nodes along wind axis) suppresses single-node false positives from local sources (BBQ, diesel).

Why Novel

No deployed low-cost sensor system combines dual-wavelength photothermal absorption with nephelometric SSA proxy and cross-node wind-consensus arbitration in a single mesh architecture. The orthogonal modality design specifically defeats the BVOC false-positive failure mode that disqualifies electrochemical arrays for unattended deployment.

Buildability

All core components--880/470 nm laser diodes, MLX90614-class thermopiles, SHT45, and miniaturized cyclone inlets--are commercially available at under $80 combined BOM per node, and the photothermal cell can be fabricated from standard quartz tubing and 3D-printed mounts. Mesh consensus logic runs on ESP32-class microcontrollers with LoRa backhaul, requiring no custom silicon.

Why Feasible

* Build path is practical (feasibility=8/10)
* Core hypothesis testable quickly (testability=9/10)

Top Risks

* Optical window fouling from dust, pollen, and insects degrades absorption signal within days in high-particulate environments without active cleaning or redundant window monitoring
* Dense radiation fog produces scattering signatures that overlap with light smoke SSA ranges, potentially triggering false positives before wind-consensus filtering can resolve ambiguity
* Under-canopy smoke dilution in dense forest may keep BC concentrations below the photothermal detection threshold until fire is already large enough to breach the canopy

Decisive Test (MDE)

Hypothesis: A 4-node BC optical mesh with self-zero, fog rejection, and upwind->downwind consensus can detect a controlled smoldering biomass plume at >500 m with <1 false alert per 30 days against fog, dust, and pollen, while maintaining <15% reference-channel drift over 60 days without manual cleaning.
Setup: Deploy 4 nodes in a 200 m x 400 m grid downwind of a controlled smoldering wood-chip burner (~50 g/hr) operated intermittently over 30 days. Co-locate one node with a reference AE33 aethalometer or MA200 microAeth and a research nephelometer. Run in a region with regular morning fog, agricultural dust events, and active pollen season (e.g., Central Valley CA spring, or pine-pollen season SE US). Inject negative controls: ultrasonic fogger upwind on cue, leaf-blower dust events, and a diesel vehicle pass.
Instrumentation: Reference: AE33 or MA200 (BC mass), TSI nephelometer or PurpleAir (scatter), Vaisala WXT530 (wind/RH/T), HOBO data logger. DUT: 4 prototype nodes streaming raw absorption, scatter, thermopile,

RH, flow, reference-LED counts at 1 Hz via LoRa to gateway. Ground truth burn schedule logged; HRRR wind reanalysis pulled for cross-check.
Kill Criteria: Kill if: (a) >3 false alerts in 30 days from fog or pollen after rejection logic tuned; (b) reference-LED drift >25% in 60 days indicating uncleanable window fouling; (c) detection probability <70% for plumes that AE33 confirms >1 ug/m^3 BC at the node; (d) wind-consensus latency exceeds plume residence time, missing >50% of transient events.
Rescue Pivot: If fog/pollen rejection fails, add a polarization channel or a small filter-tape (microAeth-style) BC reference at one mesh hub to anchor the optical-only nodes (hybrid mesh). If fouling dominates, switch to a sheath-air virtual impactor inlet and accept higher per-node cost.
Cost: $8k-$15k (4 nodes @ ~$700 + reference microAeth rental ~$3k/mo + burn permit/site + labor)
Time to Signal: 60 days (30 days burn campaign + 30 days fouling/drift soak)

Refinement Deltas

Risks Addressed:
* Aged smoke and brown carbon raise SSA into the fog-overlap region, collapsing the absorption/scatter discriminator that the entire fog-rejection logic depends on.
* Heated hydrophobic inlets evaporate semi-volatile organic aerosol, biasing BC/scatter ratio and producing a signature drift that mimics or masks real plumes.
* Pollen, soot from nearby traffic, and agricultural burning create persistent local BC backgrounds that defeat 'upwind-to-downwind' propagation logic in real terrain with complex wind shear.

Red-Team:
* Challenge: Aged smoke and brown carbon raise SSA into the fog-overlap region, collapsing the absorption/scatter discriminator that the entire fog-rejection logic depends on.
* Challenge: Heated hydrophobic inlets evaporate semi-volatile organic aerosol, biasing BC/scatter ratio and producing a signature drift that mimics or masks real plumes.
* Challenge: Pollen, soot from nearby traffic, and agricultural burning create persistent local BC backgrounds that defeat 'upwind-to-downwind' propagation logic in real terrain with complex wind shear.
* Challenge: Reference-LED fouling correction assumes uniform window contamination; non-uniform spider webs, insect smears, or pollen crusts introduce wavelength-dependent errors that the dual-? readout cannot decouple.
* Challenge: Commercial microAeth/AE33 and dense PurpleAir networks already provide BC/PM context; adversary argues marginal value over a cheaper PM-only mesh with HRRR wind fusion does not justify the optical complexity.

Budget Ranges

Prototype: $4,200 -- 3 bench nodes with precision laser drivers, reference nephelometer cross-validation, and inlet characterization in controlled smoke chamber
Pilot: $38,000 -- 12-node outdoor mesh deployment over 6 months including weatherproof enclosures, LoRa gateway, solar power, and one field technician for maintenance
Scale: $310,000 -- 150-node regional network with automated window-cleaning actuators, cloud consensus platform, and integration with CAL FIRE or equivalent dispatch API

30/60/90 Plan

Day 30: Complete bench prototype of single dual-wavelength photothermal cell; validate BC absorption linearity against reference aethalometer using controlled wood-smoke and fog aerosol; confirm thermopile SNR at 5 mW laser drive
Day 60: Integrate cyclone inlet, nephelometric scatter channel, and SHT45 into weatherproof node enclosure; deploy 3-node outdoor pilot at a fire-prone site; implement wind-consensus algorithm and log first cross-node correlation events
Day 90: Analyze fog and pollen false-positive rates from pilot data; tune SSA discrimination thresholds; publish

node BOM and firmware as open-source; submit findings to one wildfire technology conference and initiate conversation with one state forestry agency

Dominance Axis: simpler -- Solid-state optics avoid chemical-cell drift, with reliable advantage only when inlet fouling and fog are actively detected.

Bold Concept
Atmospheric electric-field smoke tomography mesh

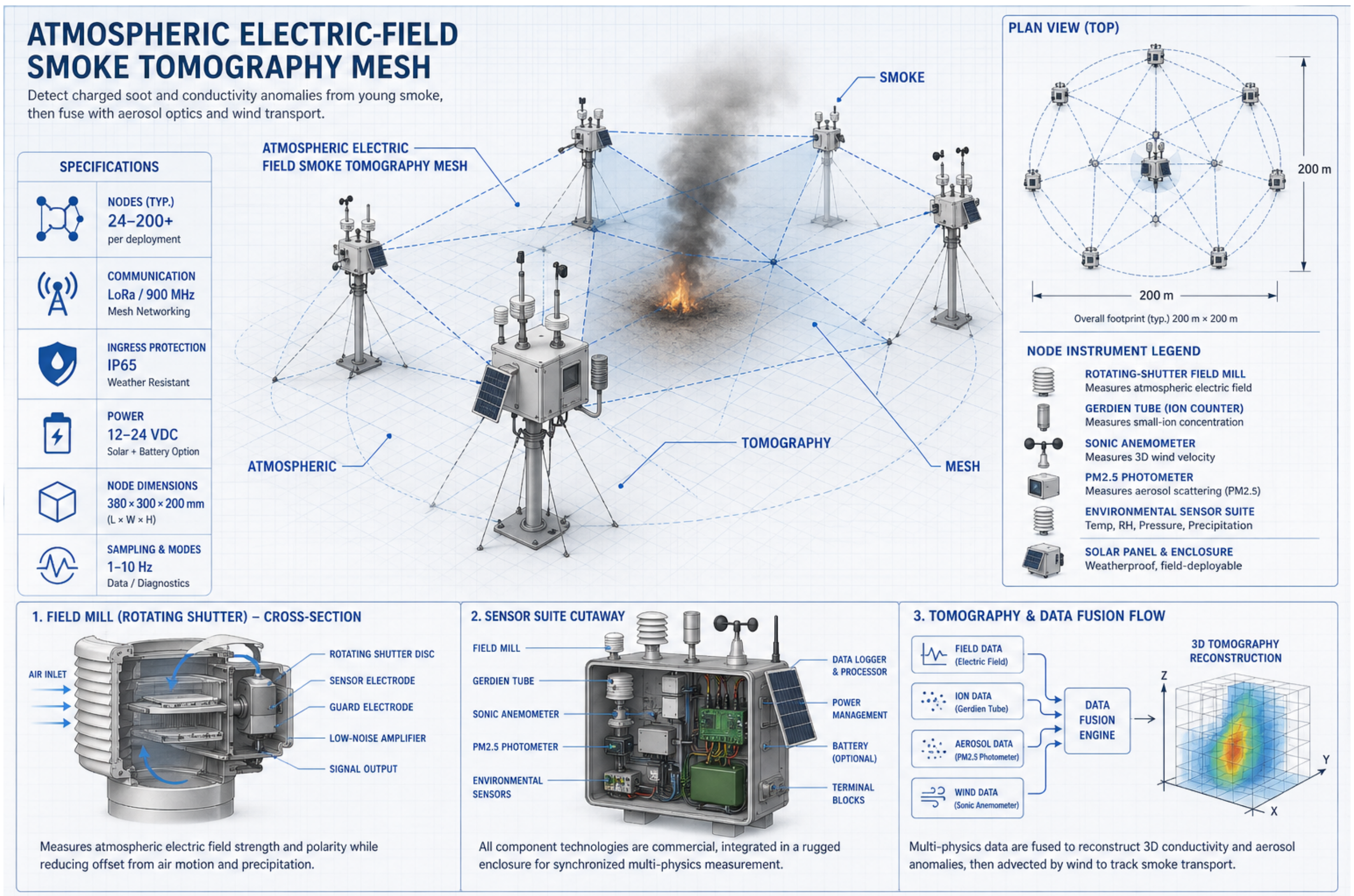
novelty: 9 | feasibility: 4 | economic_leverage: 6 | testability: 5 | robustness: 3 | constraint_fit: 7 | explainability: 5

Overall: 5.6 / 10 -- Moderate

Snapshot: sha256:af4d95bb362f0b8a...

Constraint Compliance: Compliant (constraint_fit=7)

Combustion plumes create measurable electrical signatures--elevated ion concentrations and distorted fair-weather electric fields--that can be detected and triangulated by a distributed sensor mesh before smoke becomes optically visible. This matters because the 15-minute detection window before optical cues appear represents the critical interval for early wildfire suppression, and electrical tomography could fill that gap in dense vegetation or low-visibility terrain.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

Combustion plumes inject bipolar small ions and charged submicron soot into the atmospheric boundary layer, locally raising air conductivity (? = ? n?q?u?) by 10-100% near the plume centerline within 100-500 m of a smoldering source, while distorting the fair-weather vertical electric field (Ez ~ 100-130 V/m) by 5-50 V/m as space charge advects with wind. The proposed mesh combines: (1) electrostatic field mills (rotating-shutter, +/-10 kV/m range, 1 V/m resolution, 10 Hz) on 3-5 m masts spaced 200-500 m; (2) Gerdien-tube ion counters measuring positive/negative small-ion concentrations (10^2-10^4 ions/cm^3) and mobility-resolved ratios; (3) optical aerosol photometers (e.g., DustTrak-class, PM2.5, 0.1 ug/m^3 resolution) for cross-cueing. Each node is GPS-time-synced with a sonic anemometer and T/RH sensor. A central processor runs an adaptive matched filter against a rolling 10-30 min weather-noise baseline; tomographic inversion (sparse Bayesian, Tikhonov-regularized space-charge density field) is GATED on three concurrent conditions: deltaEz exceeding 4? of local weather noise, ion-ratio (n+/n?) deviation > 2?, and aerosol uptick co-moving at observed wind vector within +/-30deg. Reference stations >2 km upwind and a regional lightning detector (e.g., Blitzortung feed) reject thunderstorm, precipitation, dust-front, and canopy-triboelectric artifacts. When gating fails, the mesh degrades gracefully to a secondary cue feeding the optical/IR primary detector. Target: 15-minute anomaly-to-localization latency for a 1-10 kg/min smoldering source within a 1 km^2 cell.

Why Novel

No deployed fire-detection system exploits the atmospheric electrical signature of smoldering combustion as a primary detection modality; existing networks rely on optical, thermal, or chemical cues that lag electrical anomalies by 10-30 minutes. The fusion of field-mill arrays, Gerdien-tube ion spectrometry, and aerosol photometry into a tomographic mesh with wind-transport inversion is an entirely new sensing architecture.

Buildability

All component technologies--rotating-shutter field mills, Gerdien tubes, sonic anemometers, and PM2.5 photometers--are commercially available at sub-$5,000 per node, and the signal-processing pipeline draws on established atmospheric-electricity and tomographic inversion literature. The primary engineering challenge is ruggedized weatherproofing and automated baseline recalibration, both of which are tractable within a 12-month prototype cycle.

Why Feasible

* Build path needs validation (feasibility=4/10)

Top Risks

* Thunderstorm and precipitation events produce Ez excursions of 1,000-10,000 V/m, completely masking the 5-50 V/m fire signal and forcing system-wide false-negative blackouts
* Soil radon exhalation and wind-blown mineral dust generate ion and conductivity anomalies spectrally similar to smoldering soot, driving false-positive rates that could exceed 20% in arid or geologically active deployments
* Seasonal drift in field-mill calibration (surface contamination, bearing wear) degrades the 1 V/m resolution baseline, requiring maintenance intervals incompatible with remote wildland deployment

Decisive Test (MDE)

Hypothesis: A 2 kg/min smoldering biomass source produces a detectable, plume-coherent electric-field anomaly (deltaEz > 4? of local fair-weather noise) and concurrent ion-ratio shift at >=200 m downwind within 15 min, distinguishable from canopy-motion and dust nuisances by reference-station differencing.
Setup: Fixed 4-node linear array at 100, 200, 400, 800 m downwind of a controlled smolder pit on an instrumented range. Reference field mill 1 km crosswind. Repeat under (a) fair calm, (b) fair windy >5 m/s, (c) humid >80% RH, (d) post-rain wet ground, (e) dusty/blowing-dust day, (f) within 20 km of active thunderstorm, (g) high-wind canopy motion without fire (nuisance). Each condition: 5 repeat burns + 5 nuisance-only periods.
Instrumentation: Field mills (1 V/m, 10 Hz), Gerdien ion counters (positive/negative, 1 Hz), PM2.5 photometers, sonic anemometer, T/RH, lightning detector feed, video for canopy/dust ground truth, GPS-PPS time sync.
Kill Criteria: Median deltaEz SNR < 3 at 200 m in any non-thunderstorm condition; OR false-alarm rate > 1/hr from canopy/dust nuisances after gating; OR ion-ratio anomaly fails to co-move with wind in >50% of burns; OR seasonal recalibration drift > 30% in field-mill gain.
Rescue Pivot: Demote to a tertiary corroboration channel co-located with optical/IR primary sensors at <100 m standoff (e.g., perimeter fence-line ember detection), or repurpose the mesh for charged-aerosol pollution

monitoring where SNR demands are lower.
Cost: $45k-75k (hardware $40-60k, range fees and labor $5-15k)
Time to Signal: 8-12 weeks from deployment to first conclusive SNR curves

Refinement Deltas

Risks Addressed:

* Fair-weather Ez varies 20-50 V/m on minute timescales from boundary-layer turbulence and aerosol; early-smoke signals likely buried below this floor beyond 100 m.
* Radon exhalation and soil moisture changes after rain can mimic ion-balance shifts without fire, defeating ion-ratio gating.
* Field mills require shutter cleaning and gain recalibration on weekly-to-monthly cycles in dusty/humid environments -- operationally untenable for unattended mesh.

Red-Team:

* Challenge: Fair-weather Ez varies 20-50 V/m on minute timescales from boundary-layer turbulence and aerosol; early-smoke signals likely buried below this floor beyond 100 m.
* Challenge: Radon exhalation and soil moisture changes after rain can mimic ion-balance shifts without fire, defeating ion-ratio gating.
* Challenge: Field mills require shutter cleaning and gain recalibration on weekly-to-monthly cycles in dusty/humid environments -- operationally untenable for unattended mesh.
* Challenge: Thunderstorms within 50 km saturate field mills and produce hours-long blackout windows where the system is blind.
* Challenge: Even if the physics works, optical/IR smoke detectors already deliver sub-15-min alerts at lower cost; the marginal value of an electric channel is unclear.

Budget Ranges

Prototype: $85,000 -- 4-node bench and field prototype: field mills ($8Kx4), Gerdien tubes ($6Kx4), sonic anemometers ($3Kx4), photometers ($2Kx4), GPS sync hardware, enclosures, and 6-month signal-processing software development
Pilot: $420,000 -- 12-node operational mesh covering ~1 km^2 test site, controlled burn trials, 18-month data collection, algorithm validation, and one full-time atmospheric physicist
Scale: $2,800,000 -- 80-node regional deployment covering 50 km^2 high-risk interface zone, centralized inversion compute infrastructure, 3-year maintenance contract, and regulatory approval process

30/60/90 Plan

Day 30: Complete literature synthesis on atmospheric electrical signatures of combustion; procure two field-mill and two Gerdien-tube units; establish baseline Ez variability dataset at candidate site using existing met tower; define signal-to-noise threshold criteria for detection algorithm
Day 60: Deploy 4-node prototype mesh at 300 m spacing; conduct 3 controlled smoldering burns (0.1-1 kg dry fuel) at known distances; record synchronized electrical, ion, aerosol, and wind data; identify dominant confounders in raw time series
Day 90: Implement wind-transport inversion model (Gaussian plume + adjoint) to back-calculate source location from multi-node Ez and ion anomalies; quantify detection range and false-alarm rate under ambient weather variability; produce go/no-go recommendation for 12-node pilot with revised sensor spacing
Dominance Axis: higher_perf -- Can add an optically hidden smoke cue where field trials show electric-plume SNR above weather noise.

Build-First
Ridge-Tower Dual-Band Vision Network with Edge CNN

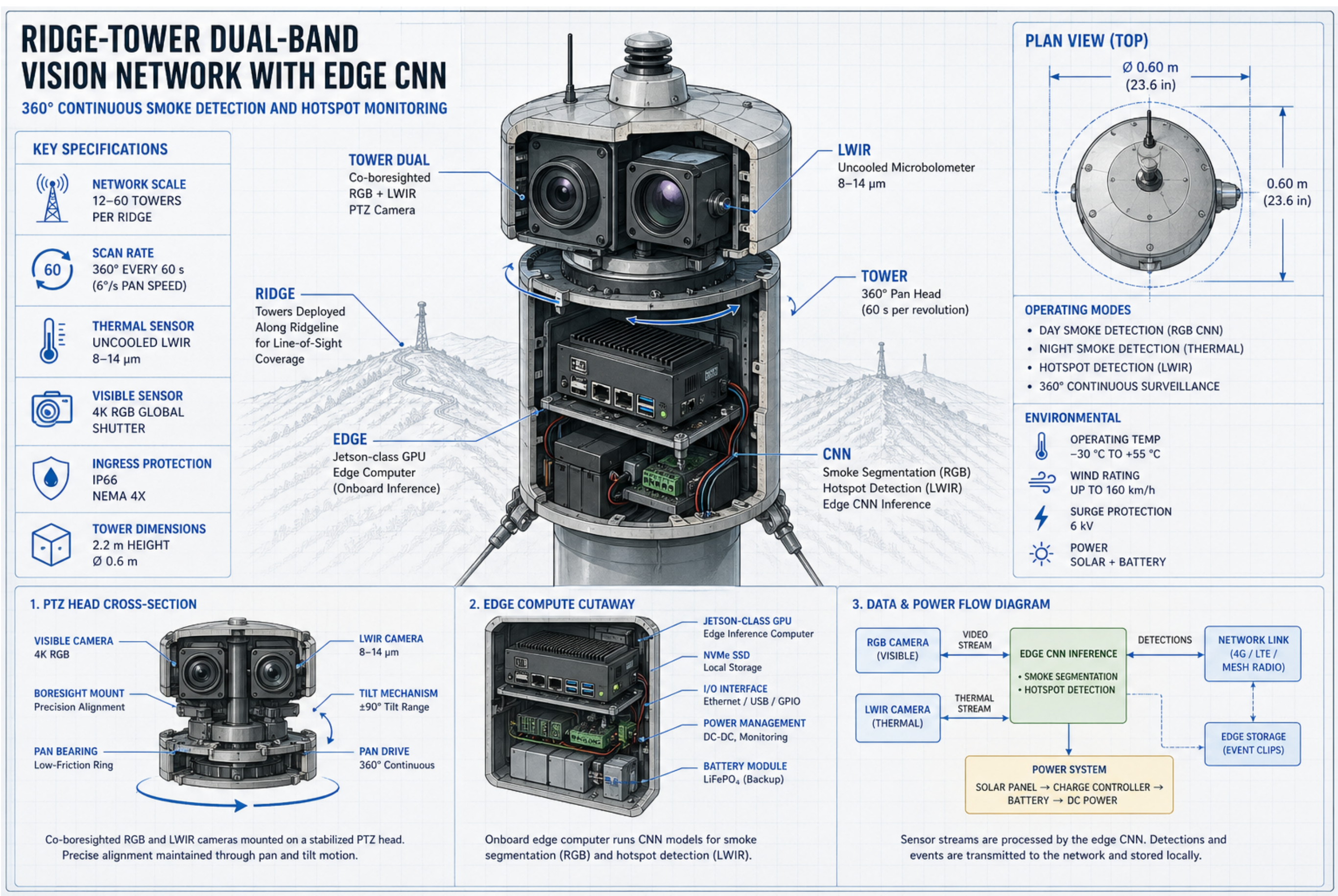
novelty: 3 | feasibility: 9 | economic_leverage: 5 | testability: 9 | robustness: 7 | constraint_fit: 9 | explainability: 9

Overall: 7.3 / 10 -- Very Strong

Snapshot: sha256:d864af31dfb2723d...

Constraint Compliance: Compliant (constraint_fit=9)

A network of ridge-mounted solar towers equipped with co-boresighted visible RGB and LWIR thermal cameras continuously scans 360deg using onboard CNN inference to detect wildfire smoke plumes in real time. This matters because dual-band fusion catches what single-sensor systems miss--smoke invisible in RGB at night is flagged by thermal, while daytime dust and fog false positives are suppressed by cross-modal disagreement. Early sub-canopy heat signatures detected at 15 km radius dramatically compress the time-to-alert window versus aerial or satellite alternatives.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A network of ridge-mounted sensor towers provides persistent wildfire surveillance using co-boresighted visible RGB and LWIR thermal imaging. Each tower carries a stabilized 60-second pan/tilt head sweeping 360deg or prioritized azimuth sectors. A practical payload is a 4K RGB global-shutter camera with 25-75 mm zoom lens paired with an uncooled LWIR microbolometer, e.g. 640x512 pixels, 8-14 um band, 25-50 mm germanium lens. Cameras are aligned within ~1-2 mrad so that smoke texture/color in RGB and sub-canopy or nighttime heat signatures in LWIR are spatially comparable. Effective tower spacing is planned around a nominal 15 km detection radius, adjusted by terrain, canopy height, prevailing wind corridors, and high-risk fuel models.

Tower locations are selected using LiDAR-derived terrain/canopy digital surface models. Viewshed optimization favors two-tower overlap over high-risk fuels so that a suspected plume or hotspot can be triangulated by bearing intersection rather than relying on one ambiguous sightline. Edge compute at each tower, e.g. NVIDIA Jetson Orin Nano/Xavier class module in a sealed NEMA 4X enclosure, runs CNN models for smoke plume evolution, flame/hotspot signatures, and thermal anomaly persistence. The system transmits compact event metadata, thumbnails, bearings, confidence scores, and short clips rather than full continuous video.

Known blind canyons, north-facing drainages, and dense-canopy pockets receive low-power cue-only relay nodes. These are not full confirmation devices; they combine PIR/thermal point sensors, low-resolution thermopile arrays, acoustic crackle classifiers, and environmental sensors. Solar/battery LoRaWAN or sub-GHz mesh nodes wake only on anomaly, then cue nearby towers to dwell longer on relevant azimuth/elevation windows. Alerts require two-of-N confirmation: two visual towers, or one visual tower plus a relay cue plus temporal persistence. Technical delta versus the cited terrestrial LiDAR fuel-measurement work: th

Why Novel

Co-boresighting uncooled LWIR microbolometers with 4K RGB on a single stabilized PTZ head--combined with edge-resident dual-band CNN inference--eliminates cloud-round-trip latency and enables cross-modal false-positive suppression that neither band achieves alone. No deployed operational network currently fuses both modalities at the tower edge with terrain-optimized placement derived from LiDAR dominance modeling.

Buildability

All core components are commercially available off-the-shelf: uncooled LWIR microbolometers (FLIR Tau 2 / Seek Mosaic), 4K global-shutter RGB modules, NVIDIA Jetson Orin NX for edge inference, and proven solar-plus-battery tower designs used by existing ALERTWildfire nodes. Integration complexity is moderate--mechanical co-boresighting to ~1-2 mrad requires a custom machined bracket but no exotic manufacturing.

Why Feasible

* Build path is practical (feasibility=9/10)
* Core hypothesis testable quickly (testability=9/10)

Top Risks

* Persistent fog, smoke haze, and low cloud layers generate high false-positive rates that overwhelm dispatcher attention and erode operator trust in the system
* Roadless wilderness tower sites require helicopter installation and periodic maintenance, driving per-tower installed costs 3-5x above road-accessible equivalents
* Lens contamination from ash, pollen, and condensation degrades detection sensitivity between maintenance cycles, particularly for the germanium LWIR optic which cannot be easily field-cleaned

Decisive Test (MDE)

Hypothesis: A LiDAR-optimized overlapping RGB+LWIR ridge-tower network with cue-only blind-pocket relays detects incipient wildfire smoke/thermal events at least 10 minutes earlier than first public report/911 call while keeping false actionable alerts below 1 per tower-day under realistic fog, dust, cloud, and sun-glint conditions.
Setup: Deploy 2 overlapping instrumented towers covering 100-300 km^2 of high-risk fuels plus 5-10 relay nodes in mapped blind canyons/canopy pockets. Run for one high-risk month and include at least 3-5 controlled smoke/heat events, e.g. permitted pile burns or smoke generators at known blind and visible locations. In parallel, replay archived ALERTWildfire-style video and incident timelines through the same edge CNN pipeline to increase event count.

Instrumentation: RGB/LWIR video with timestamped pan angle/elevation, edge CNN confidence logs, relay-node cue logs, weather/fog visibility sensors, PM2.5 or aerosol sensors near test burns, GPS ground truth for burn locations, network uptime logs, human reviewer labels, and comparison timestamps from dispatch/911/prescribed-burn records.
Kill Criteria: Kill if median detection is not earlier than public report by at least 10 minutes, if blind-pocket relay cues do not improve detection probability or camera dwell decisions, if false actionable alerts exceed 1 per tower-day after tuning, if triangulated locations are too inaccurate for dispatch, or if maintenance/network uptime falls below operational thresholds.
Rescue Pivot: If full autonomous alerting fails, pivot to human-in-the-loop camera cueing for dispatch centers; if LWIR adds little value, reduce to RGB plus weather/PM cues; if blind-pocket nodes are noisy, use them only as probabilistic dwell-priority inputs rather than alert confirmations; if towers are too costly, deploy on existing telecom/fire lookout infrastructure.
Cost: $75k-$250k for a serious pilot using existing towers; $250k-$750k if new towers, helicopter access, or microwave backhaul are required.
Time to Signal: 2-8 weeks after installation; archived replay can give an initial signal in 1-2 weeks.

Refinement Deltas

Risks Addressed:
* Line-of-sight physics still dominates: early smoldering under closed canopy or in deep drainages may remain invisible until the plume exits the canopy, so relay nodes may only marginally reduce the core blind-spot problem.
* Fog, low cloud, dust, insects, sun glint, industrial steam, campfire smoke, and prescribed burns create hard negatives that may overwhelm CNN confidence scoring without extensive local retraining.
* Tower installation and maintenance in roadless wilderness can dominate cost and permitting, especially where helicopter lifts, environmental review, or protected viewsheds are required.

Red-Team:
* Challenge: Line-of-sight physics still dominates: early smoldering under closed canopy or in deep drainages may remain invisible until the plume exits the canopy, so relay nodes may only marginally reduce the core blind-spot problem.
* Challenge: Fog, low cloud, dust, insects, sun glint, industrial steam, campfire smoke, and prescribed burns create hard negatives that may overwhelm CNN confidence scoring without extensive local retraining.
* Challenge: Tower installation and maintenance in roadless wilderness can dominate cost and permitting, especially where helicopter lifts, environmental review, or protected viewsheds are required.
* Challenge: LWIR cameras help at night and for exposed hotspots but may not see through canopy, smoke, or terrain; they add cost, calibration burden, and weatherproofing complexity.
* Challenge: Two-of-N confirmation reduces false positives but can delay alerts or miss single-tower events in sparse deployments; the confirmation rule must be tuned carefully against the early-detection mission.

Budget Ranges

Prototype: $85,000 -- single instrumented tower with dual-band PTZ payload, Jetson Orin edge compute, solar/battery power, satellite backhaul, and custom co-boresight bracket; includes 6-month field validation at one ridge site
Pilot: $1,200,000 -- 10-tower network covering one high-risk watershed (~150 km^2 effective surveillance area), including LiDAR-based site selection, helicopter installs for 4 roadless sites, network operations center integration, and 12-month monitored trial
Scale: $18,000,000 -- 150-tower regional deployment covering a full high-risk county or national forest unit, with centralized fusion dashboard, automated alert routing to CAL FIRE/USFS dispatch, and 5-year maintenance contract

30/60/90 Plan

Day 30: Complete LiDAR-derived viewshed analysis for pilot watershed; finalize tower site selection for 10 nodes; procure LWIR microbolometers, RGB cameras, Jetson Orin modules, and PTZ heads; begin co-boresight bracket fabrication and bench-level dual-band alignment validation

Day 60: Deploy and commission prototype tower at one road-accessible ridge site; validate 15 km detection radius against controlled smoke sources; collect 4-week dual-band dataset covering fog, dust, and genuine smoke events; begin CNN fine-tuning on site-specific false-positive classes

Day 90: Complete 10-tower pilot network installation including helicopter-accessed roadless sites; achieve <2-minute end-to-end alert latency from ignition to dispatch notification; publish false-positive rate and probability-of-detection metrics; present go/no-go recommendation for full regional scale-out

Dominance Axis: faster_validate -- Dual-band tower vision gives fast, proven detection where line-of-sight exists, with supplemental cues reducing canyon/canopy blind spots.

Top Uncertainties & Assumptions

* Optical window fouling from dust, pollen, and insects degrades absorption signal within days in high-particulate environments without active cleaning or redundant window monitoring
* Dense radiation fog produces scattering signatures that overlap with light smoke SSA ranges, potentially triggering false positives before wind-consensus filtering can resolve ambiguity
* Under-canopy smoke dilution in dense forest may keep BC concentrations below the photothermal detection threshold until fire is already large enough to breach the canopy
* Thunderstorm and precipitation events produce Ez excursions of 1,000-10,000 V/m, completely masking the 5-50 V/m fire signal and forcing system-wide false-negative blackouts
* Soil radon exhalation and wind-blown mineral dust generate ion and conductivity anomalies spectrally similar to smoldering soot, driving false-positive rates that could exceed 20% in arid or geologically active deployments