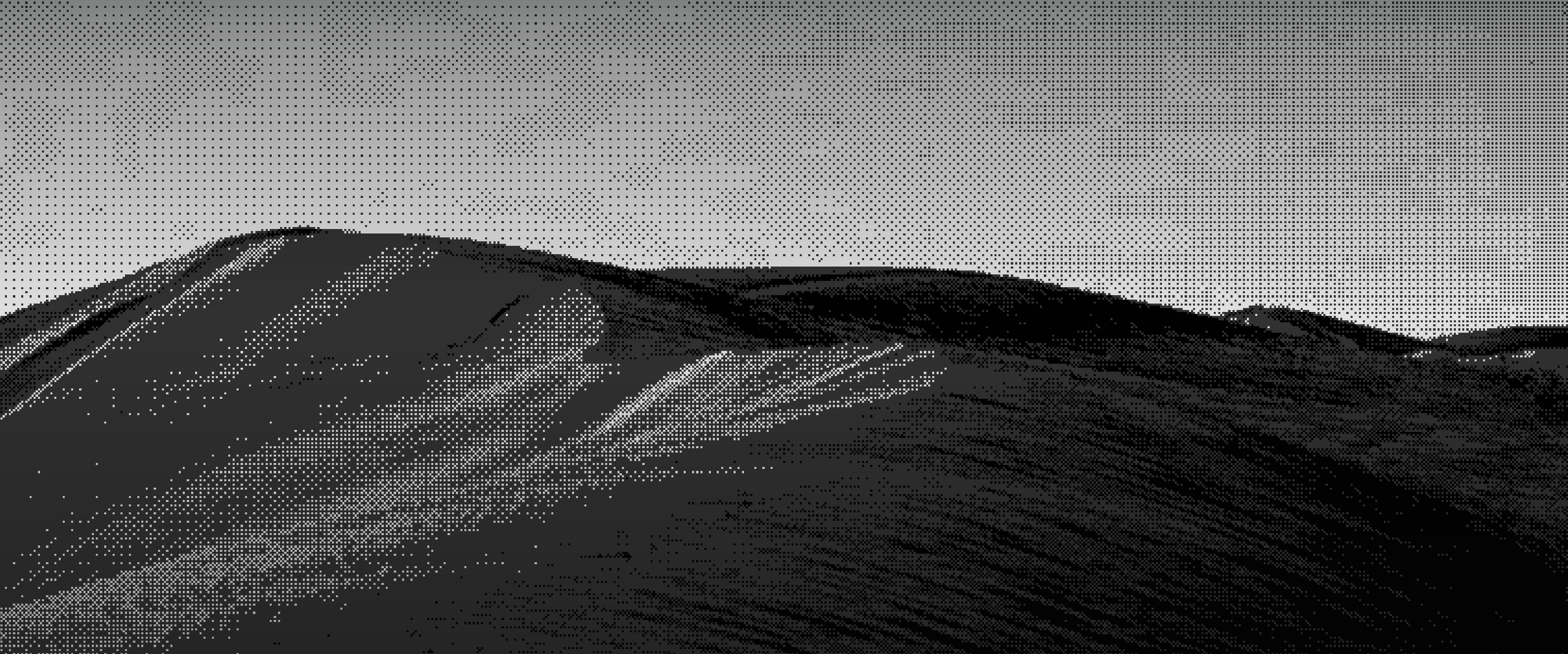


WHITE PAPER · 01

The Thinking Camera

Eight things a surveillance camera must now do — and the ninth that nobody is building

EXECUTIVE SUMMARY

For thirty years, the electro-optical industry competed on glass and detectors. Longer lenses, smaller pixel pitch, lower NETD. Those competitions are largely over. A cooled mid-wave system from any credible manufacturer will now detect a vehicle beyond twenty kilometres, and the gap between the best and the third-best is measured in percentage points that almost never decide an operational outcome.

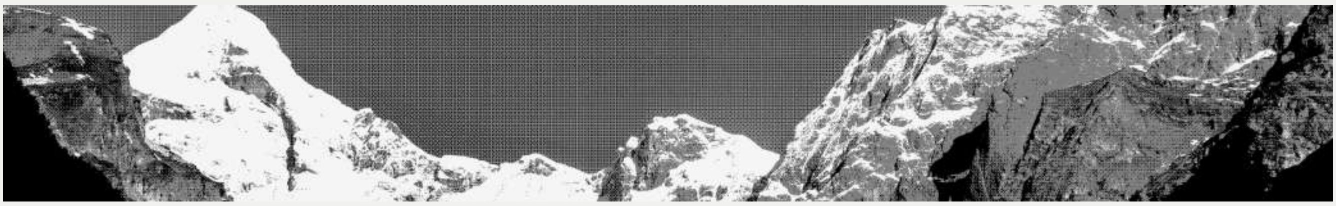
The limiting factor in a modern surveillance installation is not whether the sensor can resolve the target. It is whether anything in the system notices the target, holds onto it, understands what changed, tells the right operator at the right moment, and does so without a human watching every frame. Those are computational problems, not optical ones.

This paper sets out eight capabilities that define a competitive electro-optical system in 2026 — performance floor, compounding intelligence, sensor fusion, scene memory, prediction, operator interface, data sovereignty, and platform independence. Each of them is achievable today, and each of them is becoming a procurement expectation rather than a differentiator.

It then argues that all eight share a limitation. Every one of them makes a *single* camera smarter. None of them make *two* cameras smarter together. The systems now being installed across borders, ports, airfields and energy infrastructure are networks in cabling only: each node reasons alone, duplicates the compute of its neighbour, and hands nothing to it. The next real advance in this industry is not a better camera. It is cameras that share perception.

The paper closes with ten questions any buyer should put to an electro-optical vendor. They are designed to be uncomfortable.

The performance ceiling has moved. It now sits in software.



TERRAIN SECTOR · WIDE-AREA OBSERVATION

THE CAPABILITY INDEX

Eight capabilities that define a competitive electro-optical system in 2026

PERFORMANCE FLOOR 01

Performance is a floor, not a feature

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The next real advance in this industry is not a better camera. It is cameras that share perception.

PART I

What a camera has to do now

01 Performance is a floor, not a feature

Sixty frames per second is the first thing to establish, because everything else in this paper depends on it.

Vendors quote frame rate as a specification. Operationally it is a constraint on what is possible. At 25 or 30 frames per second, a vehicle crossing a field of view at highway speed moves a significant fraction of the frame between samples. Motion blur corrupts the features a detector relies on. A tracker loses lock during a fast pan and re-acquires as a new object, breaking the track history. Ballistic or trajectory estimation becomes coarse. And an operator slewing a pan-tilt head experiences the lag as a physical sensation — the picture arrives after the hand has moved, and precise pointing becomes guesswork.

The demanding cases are not exotic. Traffic and highway monitoring needs it. Counter-UAS needs it, because small rotary platforms change heading faster than a low-frame-rate tracker can follow. Any application involving a moving platform needs it. Perimeter monitoring of a static fence line may not — but the same product is expected to do both.

The difficulty is that 60 FPS has to be sustained *while* the system is doing everything else in this paper. Running a detector, a tracker, a fusion stage and an enhancement pass on high-resolution imagery at 60 Hz is a serious embedded engineering problem. It constrains the compute module, the memory bandwidth, the thermal design of the enclosure, and the way the inference graph is written. It is not solved by buying a faster chip; it is solved by owning the pipeline from the carrier board upward.

> This is why the frame rate question is diagnostic. A vendor who quotes 60 FPS for raw video but degrades to 12 FPS with analytics enabled has told you they bolted the AI on afterwards.

02 Intelligence that compounds

A model shipped on the day of installation is the worst model that system will ever run — or it is the only model that system will ever run. There is no third case.

Detection quality is a function of data, and data quality is a function of diversity: seasons, weather, look angles, thermal crossover conditions, local vehicle types, local clothing, local clutter. No dataset assembled before deployment covers the conditions of a site it has never seen. Synthetic data is a legitimate and increasingly effective way to bootstrap the initial model — it is now standard practice in the field, and it should not be treated as an admission of weakness. But synthetic data solves the cold-start problem. It does not solve the ongoing one.

What solves the ongoing one is treating every deployment as a data-capture opportunity, with the framework to act on it: structured collection of hard cases, review and labelling, retraining, and a validated path back to the edge. Done properly this is not an ad-hoc service call. It is a product capability — a data pipeline that is designed, versioned and governed, with clear rules about what leaves the site and what does not.

The commercial consequence is significant and under-appreciated by buyers. A vendor with a continuous learning framework improves across an installed base; every site makes every other site better. A vendor without one ships a static binary that decays relative to the world around it. Over a seven-to-ten year asset life, those two trajectories diverge enormously. Buyers evaluate cameras on the day of the tender. They live with them for a decade.

03 Fusion: evidence, not pixels

A daylight camera sees a shape with the proportions of a person and reports a person. A thermal channel looking at the same coordinates sees no corresponding heat signature. The correct conclusion is that it is not a person — it is a mannequin, a printed target, a shadow, a scarecrow, a decoy.

Neither sensor could reach that conclusion alone. The conclusion lives in the disagreement between them.

This is the substance of sensor fusion, and it is worth being precise about it, because the term is used loosely. Fusion is not overlaying a thermal picture on a visible one and calling the blend a product. That is image blending, it is decades old, and it mainly helps a human. Fusion in the sense that matters is *evidential*: multiple independent observations of the same phenomenon, weighted by each sensor's reliability under the current conditions, combined into a single probabilistic assessment with a confidence value attached.

The principle generalises far beyond two optical channels. In counter-UAS, radio-frequency detection gives bearing and often protocol signature while electro-optics gives visual classification; either alone produces false alarms that the pair does not. In traffic and border applications, radar, lidar, inductive or RFID sensing and cameras observe the same passing vehicle, and the fused inference — class, speed, plate, lane, direction — is far more reliable than any single stream. In maritime surveillance, radar cueing plus thermal confirmation replaces continuous manual horizon scanning.

> Nobody watching a screen is seeing reality. They are seeing streams of data from which reality is being reconstructed. The quality of that reconstruction is the actual product.

Fusion is the underlying architecture of a high-performance camera, not an accessory to it — which means it must be designed into the compute and timing architecture from the beginning. Retrofitting a second sensor stream into a pipeline built for one is possible; making it time-synchronised, geometrically registered and probabilistically sound is much harder.

04 Memory: the camera that remembers the scene

This is the capability most conspicuously absent from the market, and the most straightforward to explain.

Consider a pan-tilt-zoom system covering a wide sector. It looks left, then right, then left again. On each return it re-derives the scene from scratch, as though it had never been there. Every frame is a new frame. Every object is a new object. The system has no concept of *having been here before*.

A human operator does not work this way. Having swept a sector once, a person knows there is a tree at that bearing, a building at that one, a parked vehicle at the third. They do not re-perceive the scene on each pass; they compare it to an expectation.

Two distinct capabilities follow from giving a camera the same expectation.

PERCEPTUAL CONTINUITY. If the system holds a spatial model of the scene indexed to azimuth and elevation, it can render a pan from memory and update only what has changed. The perceived smoothness of the motion is decoupled from the sensor's frame rate: the operator experiences fluid, jitter-free movement, and the sensor's job narrows to detecting difference. This is closer to how real-time graphics engines work than to how cameras traditionally work, and it is a substantial gain in usability at no optical cost.

CHANGE DETECTION. This is the greater prize. If the system recorded that a vehicle stood at a given ground reference forty minutes ago, and it is not there now, the system can report *the vehicle has left* — without having witnessed the departure, and without anyone watching that bearing at the time. The same logic reports the container that appeared, the boat now absent from its mooring, the gate that stands open, the ground disturbed since the last pass.

This changes what surveillance means. The conventional system answers "what is happening in this frame?" A system with memory answers "what is different since I last looked?" — which is almost always the question the operator actually has, and it is answerable across a period no human could have watched continuously.

Memory is also the precondition for a genuinely useful query interface, which is discussed below. A camera cannot answer questions about the past hour if it retained nothing from it.

Once a system holds a model of a scene rather than a sequence of frames, it can produce imagery that the sensor did not literally record. Three applications are already practical.

05 Prediction: seeing what the sensor did not capture

OCCLUSION PERSISTENCE. A tracked person walks behind a tree and emerges two seconds later. Conventional trackers drop the track and initialise a new one, breaking the identity chain and, in a counting or alerting application, generating a duplicate. A predictive tracker maintains the hypothesis through the occlusion, renders the outline at the estimated position, and re-associates cleanly on re-emergence.

LOW-LIGHT RECONSTRUCTION. Traditional night vision amplifies the photons that arrive, with the noise and bloom that implies. Learned enhancement instead reconstructs the most probable scene given a very sparse signal and a strong prior about what scenes look like. The image is inferred rather than measured — and for the purpose of *seeing what is there*, this is now frequently the better image. It requires no image intensifier tube and no illuminator, which means no emissions and no consumable.

SUPER-RESOLUTION. Learned upscaling extends usable magnification past the optical limit of the lens. It does not conjure detail that was never sampled, and any vendor claiming otherwise should be treated with suspicion. What it does is exploit temporal information across frames and learned priors about structure to produce a reconstruction materially more useful than naive interpolation.

Each of these deserves an honest caveat, and the honesty is itself a differentiator. Predicted imagery is inference, not evidence. A well-designed system marks it as such in the interface, so an operator always knows whether they are looking at something the sensor saw or something the system believes. Vendors who blur that line are storing up a problem for their customers.

EDGE INFERENCE · LOW-LIGHT RECONSTRUCTION

06 Two interfaces, not one

Almost every product in this category ships a single user interface. This is a design error, because the two dominant use cases have irreconcilable requirements.

DESIGN FOR AWARENESS. One operator, ten or twenty camera feeds, a stadium perimeter or a port or a city sector, an eight-hour shift. The failure mode is not that the system missed something — it is that the system displayed it and the human did not register it. Attention, not detection, is the scarce resource.

The design objective here is direction of attention. The system must decide what deserves a human, and make that decision legible: which feed, which region of which feed, why, and how confident it is. Everything else must recede. This is fundamentally an editorial problem — the interface is deciding what matters — and it is best judged by a metric almost nobody measures: how long does it take a cold operator to understand what the system is telling them?

DESIGN FOR COMBAT. One operator, one feed, extreme stress, degraded fine motor control, tunnel vision, and a decision measured in seconds. Every design instinct from the awareness case is now wrong. Density is wrong. Configurability is wrong. Anything requiring a menu is wrong. What is needed is a single unambiguous frame, the one number that matters, high-contrast marking that survives peripheral vision, and controls operable without looking at them. A product that ships one interface has, in practice, chosen one of these users and quietly failed the other.

LANGUAGE AS AN INTERFACE. Beyond the visual layer, the interaction model itself is changing. Small models running at the edge make it reasonable to ask a camera a question in natural language and get an answer — not as a novelty, but as the natural interface to scene memory. *How many vehicles crossed this line in the last two hours? Show me everything that changed on the north face since 0600. Was there a boat at that mooring last night?* These are event queries against a structured record of detections, each with a timestamp, a classification and a ground reference, and they replace the current alternative, which is a human scrubbing video.

Voice, touch, and physical controls each have their place — a joystick remains the correct instrument for precise pointing under stress, and no touchscreen has ever improved on it. The requirement is that the system supports several interaction modes rather than assuming one.

07 Sovereignty of the data path

Surveillance systems observe people, facilities and activity that customers are legally and often politically obliged to protect. The architecture has to make that protection demonstrable rather than promised.

Three properties matter.

INFERENCE AT THE EDGE. Analytics that run on the device do not require imagery to leave the site. This is a privacy and compliance property before it is a latency property, and under European data protection regimes it is frequently the difference between a deployable system and an undeployable one. It also removes the dependency on connectivity that makes cloud-analytics products fragile in exactly the environments that need them most.

A DEFENSIBLE TRANSPORT LAYER. Fibre-optic transport (SFP/SFP+) between sensor and control room is immune to electromagnetic interference, carries no radiated signal to intercept, and cannot be tapped without detectable disturbance. For fixed installations it should be the default rather than an option, and copper or wireless should be the compromise that is justified, not the baseline that is assumed.

KNOWING WHAT IS INSIDE. A customer should be able to establish what software is running on a device, who wrote it, what it communicates with, and under whose jurisdiction its supply chain sits. Systems assembled from third-party analytics SDKs, third-party video stacks and third-party radio modules cannot answer that question completely, because no single party knows the whole answer.

08 One intelligence, many platforms

The perception stack is the expensive asset. The housing it sits in is not.

The same detection, tracking, fusion and memory capability should be deployable on a fixed pan-tilt pedestal, on a ground vehicle or rover, on a mast or aerostat for wide-area persistent observation, and on a vessel. The requirements differ in stabilisation, power, environmental sealing and mounting — not in perception.

Vendors who build each configuration as a separate product line end up with divergent software, staggered feature parity, and a matrix of variants that nobody can support. Vendors who treat the perception stack as the product and the platform as an integration target ship improvements everywhere at once. For a buyer, the practical test is simple: does a capability announced for the flagship reach the rest of the range, and how quickly?

PART II · THE MISSING DIMENSION

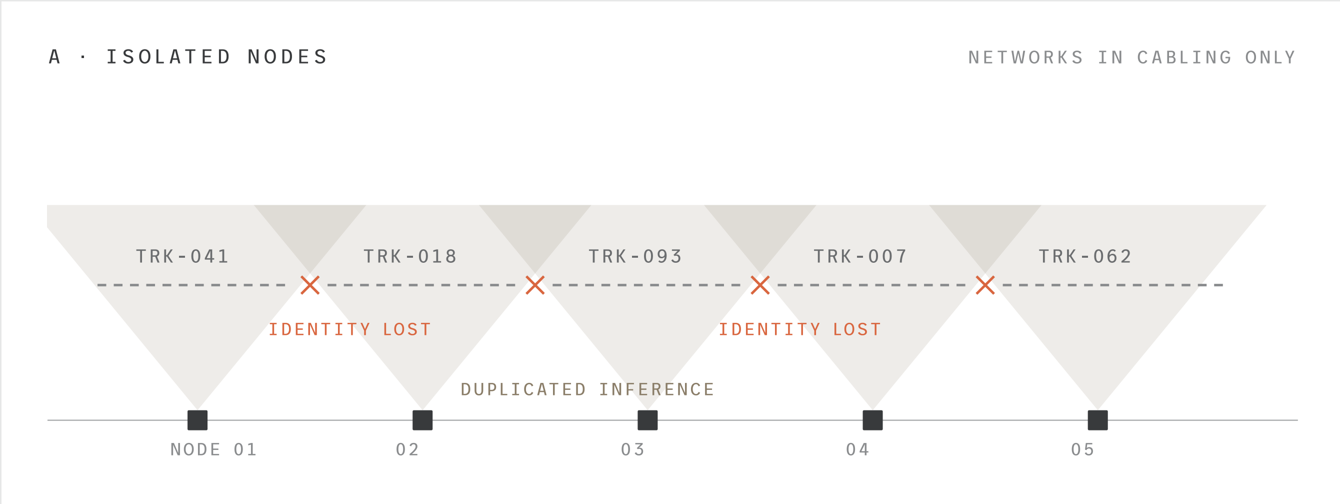
Cameras that share perception

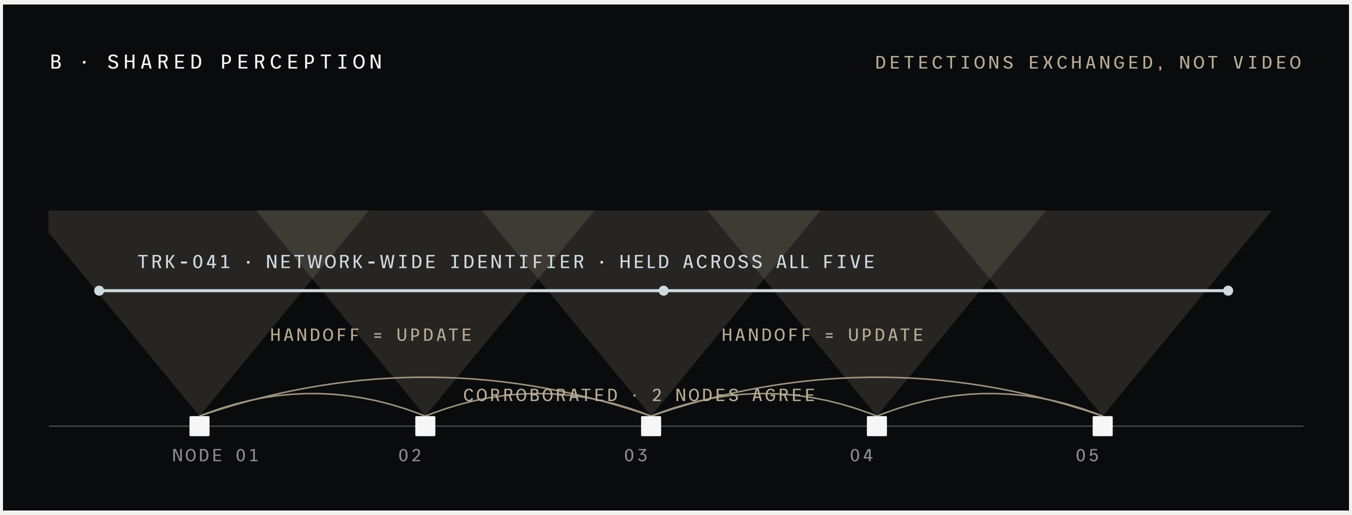
Everything in Part I improves an individual camera. Read the list again with that in mind. Faster processing: one camera. Continuous learning: one model, however widely deployed. Fusion: multiple sensors, but one node. Memory, prediction, interface, sovereignty, portability: all properties of a device.

Now consider what is actually installed at a real site. Twelve, forty, two hundred sensors across a border sector, a port, an airfield, an energy corridor. Each one intelligent. Each one alone.

SAME SENSORS, TWO ARCHITECTURES

A track crossing five nodes — as isolated devices, and as one network





DISTRIBUTED CORRELATION

Agreement raises confidence; disagreement is a signal in itself.

CONTINUOUS IDENTITY

History survives geography.

BANDWIDTH

Several orders of magnitude below streaming.

09 The isolation problem

Independent nodes produce four costs, and they compound with the size of the installation.

DUPLICATED INFERENCE. Two cameras with overlapping coverage each run a full detection stack against the same object. The compute is spent twice and the second result adds nothing.

UNCORRELATED FALSE POSITIVES. A single node's false alarm rate is an irreducible property of that node. But a false positive is, by definition, something only one sensor believes. Two nodes observing the same volume from different angles have the information needed to discard it — and no channel through which to compare notes. The industry's usual answer is to raise confidence thresholds, which suppresses false alarms by also suppressing real detections. Cross-node agreement suppresses false alarms without that cost.

BLIND HANDOFF. A target leaves camera A's field of view and enters camera B's. In an isolated architecture, camera A loses a track and camera B gains an unrelated new one. The continuous history — where it came from, how long it has been present, what it did earlier — is destroyed at every boundary. On a long perimeter with dozens of boundaries, coherent tracking becomes impossible.

FRAGMENTED AWARENESS. The command position receives a collection of feeds and alerts rather than a situation. Assembling those into a picture is left to a human, at the exact moment they have least capacity to do it.

None of these are sensor problems. All four are network problems, and all four are solved in software.

10 The node, not the endpoint

The architectural change is to treat each device as a participant in a shared perceptual model rather than a producer of a stream. Several things follow.

DISTRIBUTED CORRELATION. Detections are exchanged as structured messages — classification, confidence, ground reference, timestamp, observing node — not as video. Where multiple nodes observe the same ground coordinate, their assessments are compared. Agreement raises confidence; disagreement is a signal in itself. The network reaches conclusions no individual node could reach, and it does so on a bandwidth budget several orders of magnitude below streaming.

CONTINUOUS IDENTITY. A track carries a network-wide identifier. Handoff between nodes becomes an update to an existing object rather than the death of one and the birth of another. History survives geography.

SHARED MEMORY. The scene memory described in Part I need not be per-camera. A change observed by one node is available to all — the vehicle logged by the eastern node is known to be missing by the western one, and the site holds one model of itself rather than forty disjoint ones.

CUED ATTENTION. A detection at one node becomes a cue at another: slew, look here, confirm. This is routine practice between radar and electro-optics; it is conspicuously rare between electro-optical nodes themselves, and there is no technical reason for that.

11 Designing the traffic

Networks under stress are defined by what they drop. A network that treats all messages equally will delay a critical alert behind a video frame, which is the wrong outcome in every operational scenario. Traffic must therefore be tiered explicitly by consequence, not by size or by order of arrival:

CRITICAL — sub-10 ms
alerts, emergency signals, safety-relevant state. Always transmitted first, always small, always able to pre-empt.

HIGH — sub-100 ms
live imagery of an active engagement, track updates, cue messages.

ROUTINE — sub-second
command oversight feeds, correlation results, recommendations.

BACKGROUND — seconds
diagnostics, network health, learning data.

Under bandwidth pressure the lower tiers degrade and the top tier does not. This is a design decision that has to be made before the protocol is written; it cannot be added later by tuning quality-of-service settings.

12 Degrading well

A networked system that fails worse than an isolated one is not an improvement. Three properties are non-negotiable.

SELF-HEALING TOPOLOGY. Nodes fail, links drop, obstacles move. The mesh must re-route without operator action and without a central coordinator whose loss takes the network with it. A realistic target is continued function with a substantial fraction of nodes lost.

GRACEFUL DEGRADATION. A node that loses the network must continue to work as a complete standalone camera — full local detection, tracking, recording and interface — and rejoin without intervention when connectivity returns. Networking must be an enhancement layered over an independently sufficient device, never a dependency.

EMISSIONS DISCIPLINE. In many environments radio transmission is itself a risk. Fixed installations should carry network traffic over the fibre backbone rather than the air. Mobile nodes should be able to operate silently, and to choose when they speak.

Across the applications that matter in Europe, the practical differences are concrete rather than theoretical.

13 What it changes

At a **border or long perimeter**, overlapping sectors eliminate the coverage seams that are otherwise the obvious approach route, and a track survives the entire length of the line instead of resetting at every camera boundary.

At an **airport, port or energy site**, a single site-wide model of what is present and what has changed replaces forty separate feeds, and the false alarm rate — the reason most such systems end up with their analytics disabled — falls because nodes corroborate one another.

In **counter-UAS**, a small aircraft is detected by whichever node happens to have the angle, and tracked continuously as it transits the coverage of many, with radio-frequency and optical evidence fused across the network rather than within a single device.

In **maritime and coastal surveillance**, contacts hand off between shore nodes and vessel-mounted nodes without loss of identity, and the shore picture and the ship picture are the same picture.

COASTAL SECTOR · SHORE AND VESSEL NODES PLATE 03

In every case the individual device is unchanged. The capability comes from the fact that it is no longer alone.

Why this is a software problem

The argument of this paper is that almost everything determining the value of a modern electro-optical system — frame rate under load, model quality and its trajectory over time, fusion, memory, prediction, interface, security posture, portability, and networking — is decided in software.

That has an uncomfortable implication for how this industry is organised.

The prevailing model is integration. A manufacturer sources a detector from one supplier, optics from another, a gimbal from a third, a compute module from a fourth, an analytics SDK from a fifth, and a radio from a sixth, then assembles them into an enclosure. It is a rational way to build a camera. It is a poor way to build a system, for reasons that only surface later:

Frame rate under load cannot be optimised across boundaries nobody owns. Fusion requires time synchronisation and geometric registration across components procured independently. Continuous

learning requires a data path through a model somebody else trained and will not expose. Networking requires a protocol layer beneath three separate vendors' abstractions. Security posture cannot be attested when no single party knows the whole bill of materials. And a capability shipped as an update can only reach as far as the code you control.

The alternative is to own the stack: the carrier board, the embedded layer, the perception models, the control software, the interface, and the network protocol. It is materially harder and slower to reach a first product. It is the only structure in which the capabilities in this paper can be delivered as a coherent system rather than a set of features that half-work together.

14 Where FieldX stands

FieldX is a robotics and applied-AI company. The electro-optical product line exists because building the software required building the hardware underneath it.

Every FX-Ground variant runs on a carrier board of our own design, built around NVIDIA Jetson Orin compute, with our own detection, classification, tracking and fusion models, our own control server and operator interface, and integrated mesh radio — with fibre-optic (SFP/SFP+) video and control as the standard backbone. Standards support — ONVIF, RTSP, H.264/H.265, STANAG 4609 — is implemented in our own stack rather than inherited from a third party, which is what makes integration into existing command systems predictable.

The range spans uncooled long-wave systems for infrastructure, urban and industrial use through to cooled mid-wave systems for long-range, counter-UAS and maritime roles, with vehicle detection from four kilometres to beyond thirty-five depending on variant. The optical specifications are in the product literature and they are competitive. They are not the reason to choose the system.

The reason is that one team owns the path from the sensor to the operator's eye — and can therefore keep changing what happens along it. The capabilities in Part II are where that path leads.

ON ORIGIN. FieldX designs and builds in India. For a European buyer this is worth stating plainly rather than obscuring. India's software and embedded engineering base is deep, mature and globally proven — it is the reason a very large share of the world's critical software is built there — and it is the base this product line draws on. The commercial consequences are a cost structure that is difficult to match from Western Europe or North America at equivalent capability, engineering capacity that can be scaled against a roadmap rather than rationed, and a supply chain outside ITAR and comparable export-control regimes, which materially simplifies procurement, re-export and end-user documentation for European customers and their own downstream markets.

COMPUTE	MODELS
Own carrier board · NVIDIA Jetson Orin	Detection, classification, tracking, fusion
BACKBONE	STANDARDS
Fibre SFP/SFP+ · integrated mesh radio	ONVIF · RTSP · H.264/H.265 · STANAG 4609

Ten questions to ask any electro-optical vendor

These are written to be difficult to answer well. Vague responses are themselves informative.

- [ ] 01 **What is your sustained frame rate with all analytics enabled, at full sensor resolution?**
  Not the raw video figure. The number under load, measured, with the analytics running. Ask what degrades first when the system is saturated.

- [ ] 02 **Who wrote the detection models, and can they be retrained for my site?**
  If the answer involves a third-party SDK, capability is capped at what that vendor chooses to expose, on their timetable.

- [ ] 03 **What is the process by which the system gets better after installation?**
  Ask for the mechanism, not the intention. How are hard cases captured? Who reviews them? How often are models updated? How do updates reach a deployed unit? What leaves my site, and under what agreement?

- [ ] 04 **Is your fusion evidential or visual?**
  Blending a thermal image over a visible one is not fusion. Ask whether independent sensor observations are combined into a single confidence-weighted assessment, and ask to see a case where the two sensors disagreed.

- [ ] 05 **Does the system retain a model of the scene between passes?**
  Then: can it tell me what changed since a given time without a human reviewing footage? This one question separates most of the market.

- [ ] 06 **Where does inference run, and what leaves the device?**
  Edge or cloud. What is transmitted, to whom, under which jurisdiction, and what happens to every capability if the uplink is cut for a week.

- [ ] 07 **Show me the interface a stressed operator uses at three in the morning.**
  Not the demonstration interface. Ask how long it takes an untrained operator to correctly interpret an alert, and whether anyone has ever measured it.

- [ ] 08 **Can two of your cameras corroborate a detection?**
  If a target is visible to two units, does either know? Can a track pass between them and keep its identity and history? If not, you are buying isolated devices connected only by cable.

- [ ] 09 **What happens when a node loses the network?**
  The correct answer is that it continues as a complete standalone system and rejoins automatically. Any dependency of basic function on connectivity is an availability risk.

- [ ] 10 **Which parts of this system did you build, and which did you buy?**
  Everything above depends on the answer. It also determines whether the roadmap you are being shown is one the vendor can actually deliver, or one they are waiting on someone else for.

The industry has spent a long time making cameras that see further. The problems customers actually have — too many feeds, too few operators, too many false alarms, tracks that break at every boundary, and no way to ask what changed — are not solved by seeing further.

They are solved by systems that understand what they are looking at, remember what they saw, and tell each other about it.

The first eight capabilities in this paper are becoming table stakes; within a few years a system without them will not be competitive. The ninth — machines that share perception — is where the next decade of this industry will actually be decided, and it is being built now.

FieldX

AI-enabled electro-optical surveillance systems

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THE FUTURE IS AUTONOMOUS