Eyes across the spectrum: Advancing India's EO/IR Capabilities

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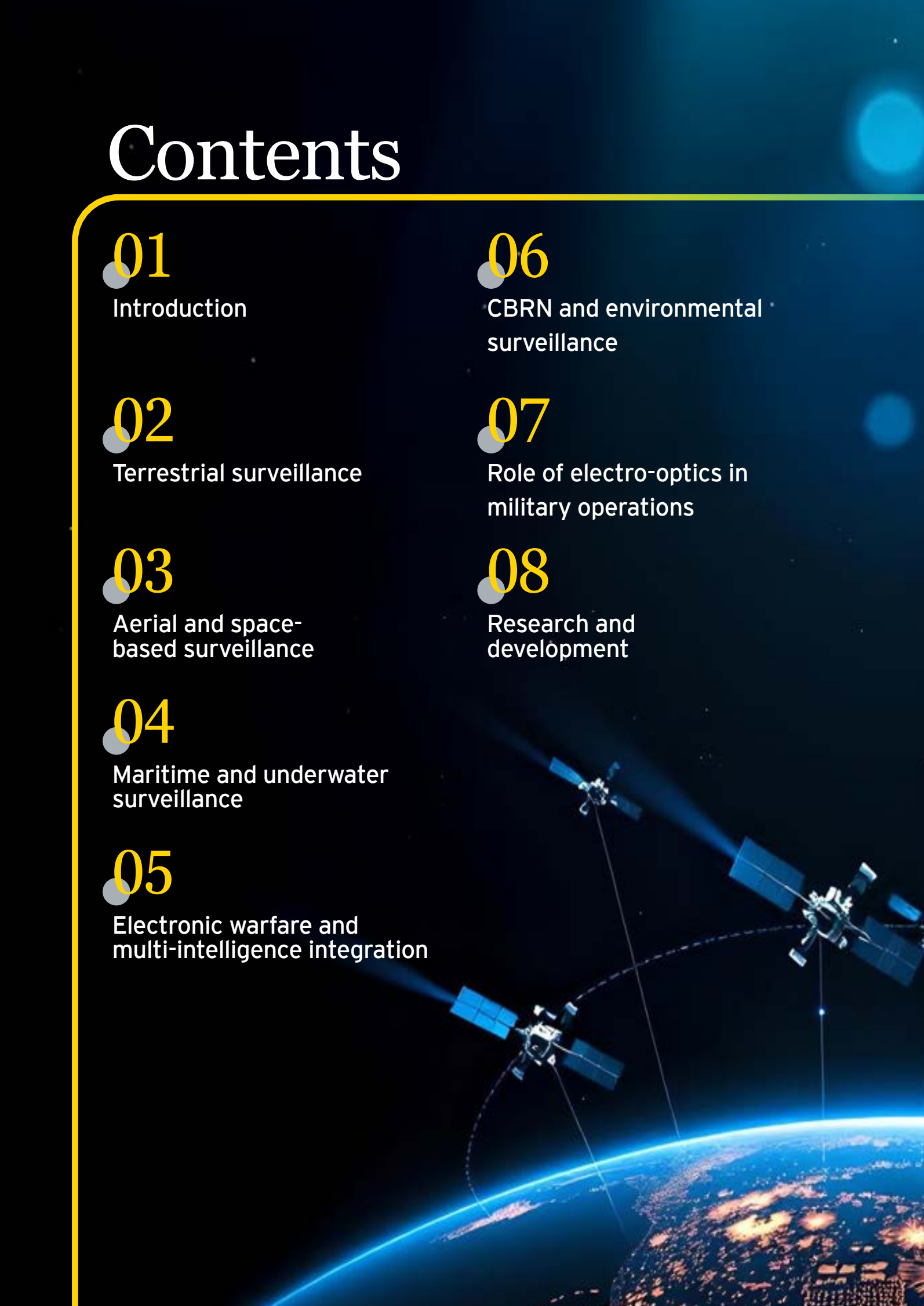

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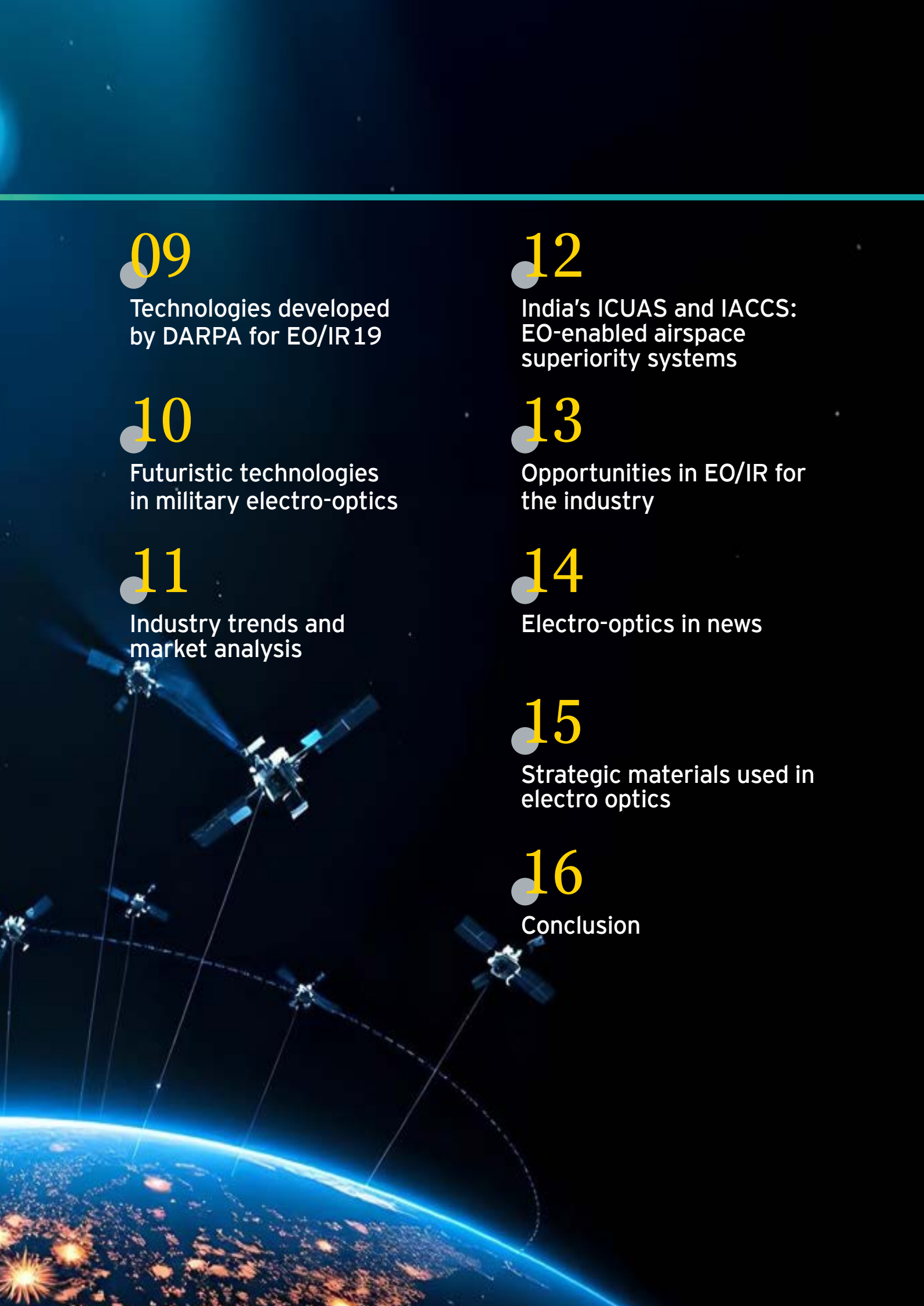

01

Introduction

In an age of rapidly evolving threats — from drone incursions and asymmetric warfare to electronic jamming and cross-domain hybrid attacks — EO/IR systems are critical to modern defence and surveillance architectures. These systems offer unmatched capabilities in day-night imaging, thermal detection, precision targeting and battlefield situational awareness.

At their core, EO/IR systems operate by detecting and interpreting infrared radiation, which is emitted by all objects above absolute zero. Unlike visible light, infrared radiation is imperceptible to the human eye but can be captured using specialized sensors and detectors. This enables EO/IR platforms to deliver real-time imagery and data, even in total darkness, adverse weather or obscured environments —scenarios where conventional optical systems often fail.

EO/IR systems typically comprise three fundamental subsystems:

Infrared detectors
Capture infrared radiation and convert it into electrical signals

Focusing optics/lens assemblies
Channel the incoming IR radiation precisely onto the detectors

Display and processing units
Translate signals into actionable imagery or tracking data

These systems are deployed across diverse platforms – including drones, satellites, armored vehicles, submarines, soldier systems and missile seekers – enabling their widespread use in land, air, sea, space, and sub-surface domains.

Despite their critical role, EO/IR systems face a series of complex design and operational challenges:

01 **Performance optimization:** Must deliver accurate data across varied environments–day/night cycles, fog, dust, snow and electromagnetic interference.

02 **SWaP constraints (size, weight, and power):** Platforms such as UAVs, soldier-borne systems, and satellites demand compact, lightweight and power-efficient EO/IR modules.

03 **System integration complexity:** EO/IR systems often require synchronization with other subsystems such as fire control, navigation, radar and AI-based decision systems.

04 **Cost and manufacturing sensitivity:** Precision optics, cryogenic cooling, and sensor fabrication are capital-intensive and require specialized infrastructure and supply chains.

05 **Testing and validation:** Calibration, range performance and ruggedization tests are critical for military-grade certification, often limited by India's testing infrastructure.

Spectrum of EO/IR technologies in defence surveillance

Technology	Primary application
IR cameras	Night vision, thermal imaging for border and base surveillance
Laser rangefinders	Precision target acquisition and fire control
SAR	High-resolution imaging in all weather, often integrated with EO for multi-spectral fusion
EO/IR multi-sensor pods	Mounted on UAVs, aircraft, and vehicles for 360° surveillance and targeting
LiDAR	Terrain mapping, obstacle detection and autonomous navigation support
Multispectral and hyperspectral cameras	Detect camouflage, disturbed soil and chemical signatures
Underwater electro-optics	Submarine detection, sonobuoy systems and underwater robotics
Space-based EO systems	High-resolution imaging, real-time ISR, missile tracking and disaster response

The following sections provide an in-depth overview of domain-specific EO/IR applications.

02

Terrestrial surveillance

India's land-based surveillance architecture is evolving rapidly to counter threats such as infiltration, smuggling, cross-border terrorism and hybrid warfare. Key terrestrial surveillance technologies include:

- **Electro-optical surveillance systems:** These are multi-sensor systems that integrate daylight cameras, thermal imagers (MWIR/LWIR), and laser rangefinders. They are mounted on towers, masts, vehicles, and personal protection systems. Examples: DRDO's EO Node, BEL's IPSS, and Tonbo Imaging's ARGUS family, MKU Netro.

- **Battlefield surveillance radars:** These are portable X-band and L-band radars used by the Indian Army and BSF. They detect human movement up to 10 to 15 km and vehicle movement up to 25 km. Some examples include the BFSR-SR developed by BEL and DRDO.

- **Multi-sensor surveillance systems:** These platforms combine EO, acoustic, seismic, and radar sensors for 360° awareness. They include AI-based fusion software and deployed at high-altitude locations along international borders.

- **Long-range observation systems:** These are mounted EO systems (pan-tilt-zoom cameras with 20+ km detection range), integrated with command-and-control networks and primarily used by the ITBP, BSF and Assam Rifles.

- **Smart fencing systems (e.g., CIBMS):** The Comprehensive Integrated Border Management System integrates EOSS, intrusion detection, AI analytics and ground radars. Examples include smart fences along the international border in J&K.

- **Unattended ground sensors:** These sensors have nodes embedded in soil that detect vibrations, sound, temperature and movement. EO modules enable visual cueing to confirm threats.

- **Man-portable surveillance devices:** These include EO binoculars and thermal imagers for tactical units, snipers and forward observers. India currently deploys BEL's TI 3000 series and imported Elbit LORROS systems for surveillance at mountain posts.

Key applications

1. **Border surveillance and infiltration detection:** This system is deployed extensively across Jammu and Kashmir, Punjab, Rajasthan and Eastern Ladakh. It is used to detect cross-border tunnel activity, smuggling and UAV infiltration.

2. **Critical infrastructure protection:** EO systems monitor perimeters of military bases, airfields, oil refineries and nuclear plants.

3. **Counter-terror and CI/CT operations:** EO binoculars and MSSS are used by Rashtriya Rifles, NSG, and CAPFs for night operations and urban warfare.

4. **Disaster management and humanitarian assistance:** EO surveillance aids NDRF and Army teams in landslide, flood and avalanche response. Visual intelligence enables victim localization and terrain navigation.

Indigenous progress

India is steadily advancing the indigenization of terrestrial electro-optical (EO) technologies, with contributions across government R&D, public sector manufacturing, and private innovation. These include:

1. **DRDO developments:** The Defence Research and Development Organisation has developed the EO Node, a mast-mounted EO sensor suite that uses artificial intelligence for real-time threat detection and classification. Another key product is the BFSR-SR[1], a compact battlefield surveillance radar that now features extended range and improved electronic counter-countermeasures (ECCM) capabilities for robust field performance.

2. **BEL systems:** Bharat Electronics Limited has deployed its Integrated Perimeter Security System (IPSS) across army camps and sensitive border posts, enhancing perimeter monitoring. The company also supplies thermal imager sights customized for use with sniper rifles[2], main battle tanks[3], and light machine guns, offering night-fighting capability to frontline units.

3. **Private sector innovation:** Tonbo Imaging makes fusion imagers with AI detection[4]. ideaForge provides EO payloads on UAVs[5] for border patrol. Gurutvaa builds custom EO systems for CUAS Systems[6].

Challenges and gaps

Terrain and climate constraints: EO systems struggle in snow, dust storms, fog and heavily forested areas. Siachen, Eastern Arunachal and parts of Chhattisgarh and Odisha—with their heavily forested terrain pose line-of-sight and power issues.

Power and communication bandwidth: High energy consumption of cooled IR sensors is unsustainable at remote posts. Limited communication pipes delay real-time EO data transmission.

Import dependency: Critical optics, IR detectors (InSb, MCT, VOx), and high-precision gimbals are largely imported from France, Germany, Israel, and the US.

Sensor fusion complexity: Integrating radar, seismic, EO and RF sensors in real time remains an evolving technical challenge.

Future outlook

- **AI-native surveillance platforms:** Systems will use AI to automate threat classification (e.g., human vs. animal) using convolutional neural networks and send real-time alerts with image or video tags.
- **Swarm-deployed UGS and EO beacons:** Low-cost sensors will monitor unmanned gaps without the need for recovery.
- **Integrated soldier systems:** Night vision EO systems will link to AR headsets and command tablets.
- **Solar-powered EO towers and camouflaged sentries:** Energy-autonomous surveillance masts will adjust to weather and light conditions using AI.
- **Plug-and-play EO nodes for rapid deployment:** Modular EO systems can be air-dropped and activated remotely in contested zones.

03

Aerial and space-based surveillance

Aerial and space-based surveillance form the strategic apex of India's multi-tiered ISR architecture. These platforms offer persistent, wide-area coverage and early warning capabilities that are critical for high-tempo operations, strategic deterrence, and disaster response.

Technologies and platforms

A. Aerial surveillance systems

- **HALE/MALE UAVs:** Platforms like the MQ-9B SeaGuardian and indigenous Tapas-BH-201 are equipped with EO/IR payloads and SAR. They can operate continuously for 24 to 40 hours, ideal for persistent surveillance over land and maritime zones.
- **Aerostats and tethered balloons:** Aerostats carry EO/IR and radar payloads at altitudes of 1 km to 3 km, ideal for surveillance of mountain passes or coastline gaps. Examples include DRDO's Akashdeep[7] and Israel's SkyStar 180. Start-up Airbotix[8] is also developing an Aerostat.
- **Manned ISR aircraft:** Platforms like EMB-145 AEW&C (with IAF Netra) and Gulfstream-based SIGINT aircraft house long-range EO/IR sensors, ELINT, and COMINT systems. Used for battlefield surveillance, radar cueing, and strike support.
- **Helicopter EO pods:** Lightweight stabilized EO pods with day/night cameras, thermal imagers, and laser designators are integrated into ALHs, Rudras, and Apache helicopters for target tracking and CAS missions.

B. Space-based surveillance systems

- **Earth observation satellites[9]:** India's Cartosat, RISAT, and EMISAT series deliver high-resolution EO imagery with day/night and all-weather capabilities. These satellites support tactical troop monitoring, road and infrastructure tracking and surveillance of adversarial airbases.
- **Hyperspectral and multispectral imaging satellites:** Enable detection of camouflaged assets, disturbed terrain, underground bunkers, and mineral signatures. ISRO's HySIS and private player Pixxel's satellites are advancing Indian hyperspectral capabilities.
- **Private LEO constellations and dual-use satellites:** Start-ups like GalaxEye, and SatSure are building high-resolution EO satellites for both civilian and defence use[10]. Skyroot is developing launch vehicles that put these satellites in orbit. Dual-use imaging is being leveraged by the MoD through commercial partnerships for rapid revisit.

Strategic applications

- **Early warning and threat tracking:** HALE UAVs and RISAT satellites detect enemy force buildup, ballistic missile launches, or naval movement. Cross-domain ISR helps verify adversaries' deployments.
- **Real-time battlefield visualization:** EO data from UAVs and AEW&C platforms supports strike aircraft in precision engagements. UAV-based EO streaming assists forward air controllers and artillery fire correction.
- **Disaster management and environmental monitoring:** ISRO's Cartosat, INSAT, and IRS systems offer rapid EO-based mapping during floods, cyclones, and forest fires. UAVs deliver visual feeds to NDRF during natural disasters.
- **Grey-zone conflict monitoring:** Continuous EO surveillance from HALE UAVs over sensitive regions helps detect intrusions, balloon activity, and unusual patterns in adversary deployments.

Indigenous progress

ISRO's RISAT and Cartosat programs

- **Cartosat-3:** Offers sub-meter (0.25 m) resolution EO imaging—one of the highest among commercial remote sensing satellites—enabling identification of small objects and changes in infrastructure.
- **RISAT-2BR1 and successors:** Provide SAR imaging combined with EO payloads, ensuring day-night, all-weather surveillance crucial for monitoring adversarial activities on international borders.

DRDO's Netra series

- A fleet of mini-UAVs equipped with EO/IR sensors.
- Used for airfield perimeter monitoring, base protection, and tactical surveillance during national events.
- Offers real-time video feeds to mobile ground stations, enabling quick response during asymmetric threats.

DRDO's AWACS program (A320 conversion)

- India is converting Air India's A320 airframes into advanced AEW&CS.
- These platforms are being integrated with long-range EO/IR systems, radar arrays, and ESM.
- Adds to the current fleet of Netra EMB-145 AEW&C systems, with significantly higher payload and endurance.
- EO sensors on board are to support battlefield visualization, target verification, and strike coordination in real time.

Private sector initiatives

- **Pixxel:** India's first commercial player in hyperspectral EO satellite technology. Its EO constellations serve both defence ISR and environmental monitoring applications.
- **GalaxEye:** Developing India's first fusion imaging satellite—"Drishti"—which combines EO and SAR payloads for true multi-sensor space surveillance.
- **TATA Advanced Systems:** Converting a business jet into a HALE surveillance UAV[11], featuring EO/IR payloads, autonomous flight systems, and satellite communications. This marks a significant milestone in India's private-sector-led unmanned surveillance ecosystem.
- **High altitude pseudo satellites[12]:** NSRT, VEDA Aeronautics[13] and CSIR-NAL are developing solar-powered HAPS drones for persistent EO coverage. Focus on ISR, communications relay, and disaster monitoring. Use for dual-use EO operations with modular payloads (EO/IR, LIDAR, SAR).

Challenges and gaps

- **Revisit rate and latency:** Traditional satellites have limited passes over a region; delays of 6 to 12 hours for revisit unless in LEO constellations. Real-time video from satellites is still underdeveloped in India.
- **Weather limitations:** EO systems degrade in cloud cover, fog, and haze. SAR complements EO but requires complex signal processing. Spectrum and Bandwidth Constraints. Downlink of high-resolution EO imagery is constrained by limited bandwidth and encryption needs.
- **System survivability:** UAVs and ISR aircraft face jamming, spoofing, and air-to-air threats in contested airspace.

Future outlook

- **Real-time cloud-based EO analytics:** Edge processing onboard satellites and UAVs to enable live threat detection (e.g., tank movements, convoy analysis). Uses onboard AI to flag anomalies without sending full video.
- **CubeSats and swarm EO constellations:** Dozens of small satellites deployed rapidly for regional conflict surveillance or disaster response. Indian Space Policy 2023 enables such dual-use constellation launches via NSIL and IN-SPACe.
- **International collaboration and data sharing:** Indo-US cooperation through the Indo-Pacific Maritime Domain Awareness Initiative includes EO satellite data exchange. QUAD aims to build EO infrastructure for joint disaster and threat monitoring in the IOR.

04

Maritime and underwater surveillance

Given India's 7,500 km coastline, 1,300+ offshore islands, and critical sea lanes in the IOR, maritime and underwater surveillance are vital pillars of national security. EO technologies—integrated with radar, sonar, and acoustic systems—play a decisive role in real-time tracking of maritime threats, coastal security, ASW, and naval operations.

Key technologies

A. Surface and aerial EO systems

- **Electro-optical fire control systems:** Integrated into naval guns and CIWS. Examples: DRDO's EO-NAV and BEL's EOS-500 used for 360° tracking of surface and aerial targets.
- **Shipborne EO/IR surveillance pods:** Mounted on corvettes, frigates, and destroyers for day-night visual tracking. Systems include daylight cameras, thermal imagers, and laser rangefinders.
- **Maritime Patrol Aircraft (MPA):** P-8I Poseidon, Do-228, and Sea Guardian UAVs carry advanced EO/IR sensors for ISR missions, sub-hunting, and surface ship detection.
- **Coastal Surveillance Systems (CSS):** A network of EO/radar towers (e.g., BEL's Coastal Surveillance Network – CSN) monitors strategic coastal chokepoints and harbors. Integrated with Automatic Identification System (AIS) and Indian Navy's Information Management & Analysis Centre (IMAC).

B. Subsurface and underwater EO systems

- **Unmanned Underwater Vehicles (UUVs):** Equipped with electro-optical (EO) sensors for port security, hull inspection, mine detection, and seabed mapping. Indian examples include DRDO's Autonomous Underwater Vehicle (AUV) and NIOT-developed gliders. EO cameras aid in visual navigation and object classification in relatively clear waters.
- **Remotely Operated Vehicles (ROVs):** Deployed by the Indian Navy and scientific agencies for underwater infrastructure inspection, salvage operations, and explosive ordnance disposal. EO cameras enable precise visual identification and maneuvering in turbid environments.
- **Laser-based imaging systems (LIDAR / BLUE LIDAR):** Used for shallow water bathymetry, reef surveys, and underwater object detection. These systems rely on light-based imaging and are effective in clear, shallow waters where sonar may underperform.
- **Sonobuoys (Non-EO system – acoustic sensing):** While not electro-optical, sonobuoys are critical for underwater surveillance, particularly for anti-submarine warfare (ASW). They use active or passive sonar to detect, localize, and track submarines or underwater vehicles. Deployed by air or ship platforms, sonobuoys transmit acoustic data to command centers or airborne assets in real time.

Strategic applications

- **Maritime Domain Awareness (MDA):** EO sensors fuse with radar, satellite, and acoustic data to track illegal fishing, smuggling, and vessel movements in the IOR. The National Command Control Communication and Intelligence (NC3I) network processes these feeds in real time.
- **Anti-piracy and law enforcement:** EO pods on patrol vessels and UAVs help track and interdict pirate vessels in the Gulf of Aden and off Lakshadweep. Helps identify small boats not emitting AIS signals (dark vessels).
- **Port and harbor protection:** EO/IR systems on harbor towers, buoys, and floating barriers help monitor naval installations (e.g., Mumbai, Karwar, Vizag). Essential for early detection of swimmer delivery vehicles (SDVs), small boats, and sabotage threats.
- **Submarine detection and ASW support:** EO-equipped UUVs scan seabeds for acoustic anomalies and visual confirmation. Support ASW missions via thermal imaging of wake turbulence or oil leaks.
- **Island surveillance:** EO sensors deployed on Andaman and Nicobar, and Lakshadweep islands help track Chinese naval movements and monitor Exclusive Economic Zones (EEZ).

Indigenous Developments

- **BEL's Coastal Surveillance Network (CSN):** 46+ EO/radar towers deployed across India's coastline and island territories. The second phase includes integration with Bangladesh, Sri Lanka, Maldives, and Seychelles under regional MDA initiatives.
- **DRDO's Naval EO systems:** EO-NAV and integrated mast systems combining electro-optics, radar, and electronic support measures (ESM) for deployment on frontline Indian Navy warships.
- **Private sector contributions:** Alpha Design, VizExperts, and L&T are developing modular EO systems for surface vessels and autonomous maritime platforms. Aadyah Aerospace is building stabilized EO/IR pods for deployment on naval UAVs.
- **NIOT's UUV and sensor tech:** The National Institute of Ocean Technology (NIOT) is advancing indigenous underwater gliders and seabed surveillance units with embedded EO sensors for ISR and marine environment monitoring.

- **BDL–Ultra Maritime JV for Sonobuoys[14]:** Bharat Dynamics Ltd (BDL) and Ultra Maritime have partnered to co-develop and manufacture sonobuoys in India. These acoustic and EO-enabled systems are critical to anti-submarine warfare. The collaboration aims to bring into India both passive and active sonobuoy capabilities, enhancing indigenous production under the Aatmanirbhar Bharat initiative. The sonobuoys will be produced to US Navy standards, ensuring interoperability with platforms like the P-8I, MH-60R, and MQ-9B Sea Guardian aircraft. Production is set to commence in 2027 at BDL's Visakhapatnam facility, with efforts focused on optimizing acoustic performance for the unique environment of the Indian Ocean, including the development of bespoke multi-static active solutions.
- **Adani–Sparton partnership[15]:** Adani Defence has entered into a strategic collaboration with US-based Sparton to locally manufacture next-generation sonobuoys. The partnership will enhance India's underwater surveillance capability by producing both passive and active sonobuoys with embedded EO and signal processing modules.

Challenges and gaps

- **Low visibility and sea conditions:** EO performance is degraded by fog, salt spray, and heavy rain; fusion with radar and sonar required for reliability.
- **Bandwidth constraints at sea:** Live EO feed transmission from ships and offshore platforms requires high-bandwidth satcom or LOS links—often unreliable in combat.
- **Saltwater degradation and fouling:** EO lenses and housings corrode over time in maritime environments, reducing image quality and sensor life.
- **Underwater EO limitations:** Water absorbs and scatters light rapidly; EO systems are limited to clear, shallow waters. Sonar still remains primary for deep-sea ISR.
- **Import dependency:** EO domes, sapphire windows, and underwater imaging chips are largely imported, especially from US, France, and Israel.

Future outlook

- **EO-equipped Autonomous Surface Vessels (ASVs):** ASVs with mast-mounted EO/IR sensors to patrol harbors, chokepoints, and shipping lanes autonomously.
- **Swarm UUV surveillance:** Networked underwater drones equipped with EO and sonar for persistent seabed ISR and anti-mine operations.
- **AI-driven threat detection:** AI-enabled EO systems on naval platforms to identify, classify, and track suspicious vessels in cluttered maritime environments.
- **EO-linked satellite backhaul:** Maritime EO feeds to be streamed via satellite (e.g., GSAT-7 series) to IACCS and IMAC nodes in real time.
- **LIDAR-on-drones for littoral ops:** UAVs equipped with LIDAR to survey shallow waters, coral reefs, and coastal terrain—valuable for amphibious planning and anti-infiltration.

05

Electronic warfare and multi-intelligence integration

As the electromagnetic battlespace becomes increasingly contested, electro-optics (EO) is emerging as a critical enabler in complementing and fusing electronic warfare (EW), Signals Intelligence (SIGINT), and multi-intelligence (Multi-INT) streams. India is steadily building toward a synergistic ISR architecture that converges EO, radar, acoustic, and electronic data for faster and more accurate decision-making.

Key technologies

A. Surface and aerial EO systems

- **SIGINT systems (COMINT and ELINT):** Passive receivers and direction-finding antennas intercept enemy radio (COMINT) and radar (ELINT) signals. Systems like DRDO's Himshakti and Samyukta intercept battlefield communications and radar emissions in border areas. EO assets provide visual confirmation once a signal source is geo-located.

- **EO-enhanced electronic surveillance and jamming:** EO sensors support jamming operations by identifying exact emitter locations visually, especially in urban and mountainous terrain. Integrated EO cameras on EW vehicles (e.g., BEL's DLRL-EW suite) assist in line-of-sight confirmation of RF targets.
- **Radar-EO hybrid platforms:** Systems like DRDO's Divya Drishti combine radar and EO imaging for dual-mode surveillance, useful against stealth UAVs and masked ground targets. EO helps confirm radar tracks in low-RCS environments.
- **Direction-finding and target acquisition networks:** EO systems are used to cue directional antennas or triangulate the source of enemy emissions. Real-time video assists in threat classification (e.g., distinguishing enemy communication towers from civilian telecom infrastructure).
- **AI-based sensor fusion for threat response:** Neural networks fuse EO video, radar feeds, RF intercepts, and acoustic detections to create a coherent Recognized Threat Picture (RTP). Enables near-instantaneous alerts and prioritization for engagement by air defence, EW, or kinetic assets.

06

CBRN and environmental surveillance

Chemical, Biological, Radiological, and Nuclear (CBRN) threats demand precision surveillance and early warning. EO-based systems are increasingly being used for detection, assessment, and containment planning—especially in urban warfare, disaster response, and border security contexts.

Key technologies and platforms

System / technology	Application	Function
IR gas detectors	Detection of invisible gas leaks (e.g., chlorine, ammonia)	Uses thermal imaging to detect temperature gradients and spectral absorption
Hyperspectral sensors	Remote identification of chemical signatures	Analyses atmospheric particles across multiple spectral bands
UV fluorescence systems	Detection of radioactive contamination	Captures characteristic emissions from radioactive particles
Atmospheric LIDAR systems	Tracking chemical and biological aerosol dispersion	EO-guided LIDAR maps plume spread in real-time
Mobile LIDAR platforms (truck/UAV-mounted)	Early warning in battlefield or industrial zones	Deployed by CBRN teams for on-the-move detection
CBRN surveillance UAVs	Remote atmospheric sampling	Combines EO/IR, LIDAR, and chemical sensors
Dual-use pandemic response sensors	Health monitoring in CBRN or pandemic scenarios	Uses EO thermal screening and bio signal analytics

07

Role of electro-optics in military operations

Electro-optical (EO) systems have attained strategic importance in modern warfare, evolving from specialized night vision applications to ubiquitous integration across all operational phases, encompassing reconnaissance, targeting, and battle damage assessment. The integration of EO systems across platforms (UAVs, missiles, satellites, vehicles, and ships) has transformed battlefield transparency, targeting accuracy, and survivability.

Operational capabilities enabled by EO systems

Application area	Key capabilities and use cases
Enhanced vision and real-time monitoring	Day/night, all-weather situational awareness; thermal imagers detect heat through fog/smoke/darkness; live EO feeds enable real-time ISR for ground troops, UAVs, and pilots.
Persistent observation	Long-endurance EO coverage using HAPS (e.g., NewSpace) and aerostats over forward areas; tethered EO drones aid CAPFs in perimeter and riot surveillance.
High-resolution imaging	Sub-meter EO imagery from RISAT, Cartosat, Pixxel, etc., used for detecting infrastructure buildup, strike assessments, and identifying launch pads.
Multispectral targeting	Fusion of visible, IR, SWIR, UV bands to detect camouflaged or obscured targets; used by UAVs, loitering munitions, and manned platforms for precise target classification.
Laser designation and LGB guidance	Laser rangefinders/designators (e.g., DRDO LDP) mark targets for LGBs and missiles like Sudarshan and HELINA; integrated into EO pods on Mirage-2000, Jaguar, etc.
Fire control systems	EO enables thermal and optical sights in tanks, APCs, and warships for tracking, range finding, and auto-lock (e.g., DRDO thermal sights on Arjun, T-90 tanks).
CUAS and anti-drone ops	EO detects low-RCS drones missed by radar; enables visual verification, jamming, and kill confirmation via CUAS systems like BEL's D4 System[16], Zen's CUAS and Grene Robotics' Indrajaal[17].
Terrain mapping and urban ISR	EO drones generate 3D terrain maps for high-altitude zones (Ladakh, Sikkim); urban ISR includes facial recognition, motion tracking, and crowd analytics.
Pilot vision enhancement	Helmet-mounted EO displays (e.g., MKU helmets) provide fused day/night visuals and HUD integration for enhanced situational awareness in low-visibility flight.
Optical jamming and countermeasures	EO dazzlers and laser jammers (DRDO, PSUs) neutralize optics of drones, missiles, and sniper scopes; key for convoy protection and asymmetric warfare.
Camouflage detection	Multispectral EO sensors detect anomalies like disturbed soil, synthetic camouflage, and heat patterns; vital for locating hidden camps in forests/mountains.
AI and sensor fusion	EO feeds processed via AI/ML for intrusion detection, threat classification, and spoofing detection; fused with radar, acoustic, and SIGINT under IACCS/ICUAS networks.
Unmanned and autonomous EO platforms	EO modules embedded in drones, UGVs, USVs for independent ISR; critical for swarm drone autonomy and GPS-denied missions using vision-based navigation.
Space surveillance and missile defence	EO sensors in satellites provide missile/troop movement alerts; EO seekers in BMD systems (e.g., PDV, AD-1/2) guide interceptors toward incoming threats.

Why EO/IR now?

The increasing complexity of today's threat environment has underscored the operational necessity of robust surveillance systems across all domains of warfare. Surveillance is no longer a tactical luxury but a strategic imperative, especially as adversaries employ diverse warfare models—conventional, hybrid, and asymmetric—each demanding tailored intelligence solutions.

- **Conventional threats:** In conventional threats, surveillance plays a critical role in tracking organized military movements, force build-ups, and aerial or naval intrusions. For example, the Russia-Ukraine conflict has highlighted the importance of real-time ISR (Intelligence, Surveillance, and Reconnaissance) for both offensive targeting and defensive posturing. Satellite imagery, EO/IR sensors, and UAVs have been used to monitor troop concentrations, assess damage, and coordinate artillery strikes—giving an edge to whichever side can "see" better and faster.
- **Hybrid threats:** Hybrid threats pose a more complex challenge. These combine regular military forces, insurgent tactics, and cyberwarfare. EO systems, thermal cameras, border surveillance radars, and cyber ISR tools become vital to detect hidden threats, track irregular combatants, and intercept communications.
- **Asymmetric threats:** The most elusive are asymmetric threats which involve exploiting the vulnerabilities of more sophisticated forces. EO payloads mounted on drones, ground-based sensors, and networked data-sharing platforms help in identifying subterranean activities, tracking irregular fighters, and preventing surprise attacks in densely populated urban zones.

Surveillance systems, therefore, act as the first line of defence in all forms of conflict—detecting early indicators, denying adversary surprise, and guiding precision response. The dynamic threat landscape mandates a multi-domain surveillance strategy that integrates electro-optics, signals intelligence (SIGINT), space-based ISR, and AI-driven analysis to remain one step ahead of evolving hostilities.

AI-enabled next-generation sighting systems for small arms

As warfare evolves, infantry soldiers need real-time, intelligent, and precise visual augmentation. AI-enabled electro-optical sighting systems for small arms are revolutionizing infantry capabilities by providing soldiers with advanced battlefield awareness, automated targeting assistance, and networked engagement intelligence—effectively turning the rifle into a smart combat node.

Core capabilities and technologies

AI-enabled sights go beyond traditional optical scopes or thermal imagers by integrating onboard processors, neural networks, and digital overlays. Key features include:

- **Automatic target detection and tracking:** AI algorithms identify and lock onto human figures, vehicles, drones, or suspicious movement in real-time.
- **Ballistic correction and reticule adjustment:** The sight auto-adjusts for bullet drop, wind, angle, and range—improving first-round hit probability under pressure.
- **Thermal and visible spectrum fusion:** Multispectral image fusion allows soldiers to see through fog, smoke, or darkness, blending thermal and visible views.
- **Facial and object recognition (Optional):** Advanced sights can identify individuals or objects of interest in counter-terror and VIP protection scenarios.

- **Integrated rangefinders and laser designation:** Embedded LRFs calculate exact distance and highlight targets for teammates or drones.
- **Networked fire sharing:** AI sights transmit real-time visual feeds and tagged targets to commanders or fellow troops via BMS/C2 networks.

Advantages in the battlefield

- **Reduced reaction time:** Targets are highlighted and tracked automatically, helping the soldier focus on decision-making, not detection.
- **Improved accuracy:** Dynamic reticule adjustments ensure hits even under complex terrain, movement, or wind conditions.
- **Enhanced night and urban combat performance:** Multispectral fusion ensures visibility through visual obstructions, giving Indian soldiers an edge in jungle, mountain, or riot-prone zones.
- **Situational awareness:** Shared visual data and AI-aided classification help differentiate between combatants, civilians, and decoys.

Global benchmarks

- **SMARTSHOOTER (Israel):** AI-enabled SMASH sights used to shoot down drones with assault rifles; integrates target tracking and fire control.
- **IVAS (US):** Microsoft's military HoloLens with AI vision, GPS overlay, and BMS integration.
- **Elbit SmartSight™ (Israel):** Compact fire control with facial recognition and object tracking.

Electro-optics in DEWs

Electro-optics (EO) play a crucial role in the operation, targeting, and effectiveness of Directed Energy Weapons (DEWs)—such as high-energy lasers (HELs), microwave weapons, and dazzlers. EO systems provide precision tracking, beam control, real-time feedback, and kill confirmation.

Function	Component/technology	Role	Use case
Target detection and acquisition	▪ Infrared (IR) cameras ▪ Visible-spectrum day cameras ▪ Short-Wave Infrared (SWIR) sensors ▪ Multispectral imagers	Uses thermal imaging to detect temperature gradients and spectral absorption	Detecting swarm drones or incoming RPGs before laser engagement using thermal/movement cues
Tracking and beam steering	▪ Infrared (IR) cameras ▪ Visible-spectrum day cameras ▪ Short-Wave Infrared (SWIR) sensors ▪ Multispectral imagers	▪ Detect heat signature ▪ Enable optical verification ▪ See through haze/ camouflage ▪ Discriminate targets via spectral data	Detecting swarm drones or incoming RPGs before laser engagement using thermal/movement cues

Function	Component/technology	Role	Use case
Tracking and beam steering	▪ Gimballed EO tracking pods ▪ Laser rangefinders ▪ Optical sensors with AI trackers	▪ Stabilize aim ▪ Measure distance accurately ▪ Maintain lock-on amid clutter/jamming	Locking onto a drone's propulsion unit for precision targeting
Beam quality monitoring and feedback	▪ High-speed optical sensors ▪ Adaptive optics ▪ Thermal/focal plane sensors	▪ Monitor beam integrity ▪ Correct beam distortions ▪ Evaluate heat on target	Maintaining laser focus during atmospheric distortion over terrain like deserts or the sea
Target effect verification (BDA)	▪ Thermal imagers ▪ High-resolution video ▪ Spectral sensors	▪ Confirm damage or neutralization ▪ Provide visual evidence ▪ Detect chemical/ structural impact	Confirming UAV destruction (e.g., engine fire) before shifting aim to another target

Payloads, systems and subsystems of a surveillance satellite

1. **Payload (Mission-specific subsystems):** This is the heart of the satellite—the components that perform the actual surveillance. These vary depending on the type of surveillance:

System type	Key components	Primary functions/use cases
Electro-Optical/ Infrared (EO/IR) Systems	▪ High-resolution optical cameras (panchromatic, multispectral, hyperspectral) ▪ Infrared sensors (thermal/night imaging) ▪ Telescopes and mirrors ▪ Image stabilization systems	▪ Day/night surveillance ▪ Target detection and identification ▪ ISR operations ▪ Terrain mapping and tracking in degraded environments
Synthetic Aperture Radar (SAR)	▪ Radar antennas (deployable/fixed) ▪ Transmit/receive modules ▪ AESA arrays ▪ SAR processors	▪ All-weather, high-resolution imaging ▪ Ground/sea surface monitoring ▪ Detection through clouds, foliage, and camouflage
Signals Intelligence (SIGINT) / Electronic Intelligence (ELINT)	▪ Wideband antennas ▪ RF receivers ▪ Signal processors ▪ Direction finding and geolocation systems	▪ Day/night surveillance ▪ Target detection and identification ▪ ISR operations ▪ Terrain mapping and tracking in degraded environments
Hyperspectral sensors[18]	▪ Optical dispersion systems to split light into 100s of narrow bands ▪ Specialized imaging sensors ▪ Spectral signature libraries	▪ Detection of materials based on spectral signatures ▪ Identification of camouflage, minerals, explosives, or chemical/biological agents ▪ Environmental and defence use

2. **Satellite Bus (supporting subsystems):** These are essential to support the payload and overall satellite operations:

Subsystem	Key components	Primary functions/use cases
Power subsystem	Solar arrays, battery packs, Power Distribution Unit (PDU)	Generates and stores power, ensures continuous operation during eclipse, manages power flow to all onboard systems
Attitude determination and control system (ADCS)	Star trackers, sun sensors, gyroscopes, reaction wheels, magnetorquers, thrusters	Determines spacecraft orientation, enables precise sensor pointing for imaging, communication, and maneuvering
Thermal control system	Radiators, heat pipes, MLI - heaters	Maintains operational temperature range, prevents overheating/freezing of sensitive components
Command and data handling (C&DH)	Onboard processors/computers, SSD-based memory units, fault-tolerant autonomous software	Executes onboard commands, stores sensor data, manages system health and autonomous operations
Communication subsystem	High-gain antennas, transceivers, modems, Uses X-band, Ka-band, or S-band frequencies	Transmits data to ground stations, receives commands from mission control, enables real-time or store-and-forward communication

3. **Propulsion subsystem (optional in LEO; common in GEO):** For orbit correction or station-keeping. Types: monopropellant (hydrazine), electric propulsion (ion thrusters)

4. **Structural subsystem:** Primary and secondary structures to mount all components. Designed to withstand launch loads and space environment.

5. **Ground segment (Critical for surveillance missions)**
Though not part of the satellite, this is indispensable:

- Ground control stations (for commanding and telemetry)
- Downlink stations (to receive data)
- Data processing centers (for image correction, AI/ML analysis, target recognition)
- Tasking systems (to reorient satellites as per user priority)

6. **Emerging technologies**

- **AI-based onboard processing:** For real-time object detection and prioritizing data transmission
- **Laser communication terminals:** Faster, secure data downlinks
- **CubeSats with distributed sensing:** For persistent low-cost surveillance
- **Quantum sensing/ RF mapping**

08

Research and development

India's vision of achieving sovereign capability in surveillance and electro-optics (EO) is increasingly shaped by a multi-tiered R&D ecosystem, spanning public laboratories, defence PSUs, private start-ups, and academia. As the operational demands for multi-spectral imaging, persistent ISR, AI-integrated targeting, and stealth detection accelerate, the nation's research infrastructure is racing to match global benchmarks.

Emerging technology frontiers in EO R&D

1. **India's defence surveillance innovation is anchored in several disruptive EO technology domains:**

- **Multispectral and hyperspectral imaging:** Enables material-level threat detection across invisible spectra—e.g., camouflage nets, disturbed terrain, and underground bunkers—crucial for both tactical and strategic reconnaissance.
- **Quantum imaging and electro-optics:** Research on quantum dots and single-photon avalanche diodes (SPADs) for ultra-sensitive, low-light imaging. Ideal for GPS-denied, obscured, or contested environments.
- **MEMS-based EO payloads:** Micro-electro-mechanical systems allow miniaturized, rugged EO sensors (<500g) suitable for nano-UAVs, loitering munitions, and wearable soldier systems.

- **EO–AI convergence:** Onboard deep learning analytics enabling automatic target recognition, anomaly detection, and threat classification in real-time. This includes edge-AI accelerators integrated into UAVs and soldier kits.
- **Short-Wave Infrared (SWIR) EO:** Penetrates haze, smoke, and camouflage; vital in maritime, jungle, and urban combat zones.
- **Optical jamming and counter-camouflage:** EO systems that blind adversary optics or detect IR/polarization distortions from stealth platforms and synthetic covers.

2. Leading Indian R&D institutions and projects

India's strategic EO research is spearheaded by multiple government and private actors. These include:

- **DRDO – CHESS and DEAL labs:** Developing EO seekers, thermal imagers, cooled IR focal plane arrays (FPAs), and laser targeting modules for UAS, missiles, and armored vehicles.
- **ISRO's sensor payload units:** Advancing high-resolution hyperspectral EO satellites (e.g., HySIS, Cartosat) for military, disaster response, and dual-use ISR applications.
- **iDEX and TDF programs:** Funding over 20+ EO-focused start-ups with grants up to INR25 crore, promoting AI-integrated EO processing, modular sensors, and battlefield vision systems.
- **CSIR, IITs, and IISc:** Partnering with defence start-ups on adaptive optics, nanophotonics, and AI-driven EO algorithm development for edge computing.

3. Private sector innovation in EO R&D

India's vibrant private sector is now at the forefront of EO innovation. Below table showcases the country's focus in research and development:

Company	R&D focus
Tonbo Imaging	Fusion EO/thermal modules, AI-based target classification, global exports to 25+ countries
Gurutvaa Systems	MEMS-based EO payloads, smart gimbals, ruggedized ISR units for UAVs and mobile platforms
IdeaForge	AI-enhanced EO drones (e.g., Switch), battlefield-ready ISR solutions for Army and CAPFs
Aadyah Aerospace, Paras Defence, VizExperts	Indigenous EO manufacturing, optical test infrastructure, software-defined payloads for multi-platform integration

4. Collaboration and tech transfer ecosystem

R&D momentum is accelerated by strategic collaboration, including:

- **Academia–industry–government trifecta:** IITs and IISc co-develop sensors, software, and subsystems with private players and PSUs under DRDO-led programs.
- **International technology transfers:** Critical EO subsystems like stabilization gimbals, cooled FPAs, and optical glass benefit from licensed know-how from Israel, France, and the US, especially under offset obligations and JV structures.

5. Challenges and bottlenecks

Despite progress, India's EO R&D faces structural gaps, namely:

- **Sensor fabrication dependence:** High-end IR sensors (MCT, InSb, InGaAs) and optics (Germanium, ZnSe) remain largely imported.
- **Testing and calibration infrastructure:** India lacks dedicated EO testing ranges, high-temperature IR calibration facilities, and standardized evaluation benchmarks.
- **IP and commercialization gaps:** Weak patenting norms and long public procurement cycles disincentivize rapid R&D commercialization.
- **TRL/MRL mismatches:** Many EO innovations stagnate at TRL 4–5 due to lack of funds for user trials, documentation, and certification required to scale.

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Technologies developed by DARPA for EO/IR[19]

DARPA has developed several advanced **Electro-Optical/Infrared (EO/IR) technologies** for military and intelligence applications. Here are some notable programs:

Program name	Key features and technologies
Extreme Optics and Imaging (EXTREME)	▪ Utilizes metamaterials-based optics for next-gen imaging systems ▪ Enables smaller, lighter, and more efficient lenses ▪ Allows advanced manipulation of light to reduce optical aberrations and improve resolution
Seeker Cost Transformation (SECTR)	▪ Develops low-cost EO/IR seekers for air-launched weapons ▪ Optimized for GPS-denied navigation ▪ Designed to be modular, reconfigurable, and scalable for multiple missions
Video Synthetic Aperture Radar (ViSAR)	▪ EHF-band radar-imaging sensor that penetrates clouds, smoke, and fog ▪ Produces full-motion, high-resolution video imagery ▪ Tracks moving ground targets in poor visibility

These technologies enhance surveillance, targeting, and intelligence capabilities, making EO/IR systems more effective in complex environments.

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Futuristic technologies in military electro-optics

Technology theme	Key features	Use case
Quantum electro-optics	▪ Quantum imaging with entangled photons ▪ Single-photon detectors (SPDs) ▪ Quantum dots for enhanced IR/SWIR detection	Nighttime sniper detection, obscured-visibility urban ops, next-gen missile seekers
AI-native electro-optics	▪ Onboard AI image analytics ▪ EO-AI fusion engines for adaptive retasking ▪ Behavioral pattern recognition (e.g., hostile UAV vs bird)	Counter-UAS systems, swarm threat detection, real-time urban ISR
Multispectral and hyperspectral EO	▪ Hyperspectral detection of material/chemical signatures ▪ Fusion of visible, IR, SWIR, UV bands ▪ High target discrimination in complex environments	Camouflage detection, WMD facility monitoring, smart seekers in PGMs

Technology theme	Key features	Use case
Cognitive EO sensors	▪ Smart adaptive sensors with context-based adjustments ▪ Energy-efficient, event-triggered activation	Soldier-wearable EO helmets, low-power UAV ISR, persistent border surveillance
EO in directed energy systems	▪ EO-cued high-energy lasers ▪ EO-assisted beam steering for real-time tracking	Laser-based anti-drone systems, cruise missile interception
EO in stealth and counter-stealth	▪ IR/thermal masking via materials for stealth ▪ EO sensors for stealth detection using multispectral analysis	Detection of stealth UAVs and jets, IR signature management for survivability
Miniaturized EO for swarm drones	▪ MEMS-based lightweight EO payloads ▪ Distributed EO swarms with composite imaging	Nano-drone ISR, tunnel inspections, urban battlefield monitoring
EO jamming and countermeasures	▪ EO jammers and dazzlers ▪ IR spoofing to mislead guided munitions	Soft kill protection for armored vehicles, ships, airbases
EO in space-based ISR	▪ EO sensors on CubeSats for short revisit ISR ▪ EO-GIS fusion for terrain-aware intelligence	Border monitoring, strategic strike preparation, cross-domain ops planning
EO in next-gen platforms	▪ EO-enhanced 6th-gen fighter cockpits ▪ AI-driven EO seeker drones and UCAVs	AMCA, loitering munitions, AI-enabled PGMs, adaptive fighter vision

AI-driven surveillance and sensor fusion

AI and Machine Learning (ML) have transformed ISR systems from passive image collectors to autonomous threat evaluators. Modern EO/IR surveillance platforms now incorporate AI models for real-time target detection, classification, and threat prioritization. Sensor-cued ISR—where one sensor (e.g., radar) automatically cues another (e.g., EO/IR turret or hyperspectral imager)—is central to this transformation. The following table outlines key components and benefits of this integrated approach.

Component	Function	Example	Benefit
Real-time multi-spectral fusion	Combines EO/IR, radar, and hyperspectral inputs to create unified threat tracks	Sensor fusion in the Lockheed Martin F-35[20] fighter aircraft	Increased accuracy, all-weather capability
AI/ML for target recognition	Automatically identifies and classifies military assets or threats	Edge AI for UAVs[21]	Faster decisions, lower operator workload
Sensor-cued ISR	One sensor alerts and triggers others for confirmation or zoomed-in analysis	Raytheon's Multi-Sensor Targeting System (MTS-C)[22]	Reduces blind spots and optimizes resource allocation

India-specific R&D directions

- **DRDO** is working on quantum EO sensors and cryo-cooled mid-IR detectors.
- **Start-ups like Tonbo Imaging, GalaxEye, and Optimized Electrotech** are experimenting with AI-edge fusion and multispectral miniaturization.
- **ISRO** is advancing hyperspectral payloads and compact EO constellations for near-real-time surveillance

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Industry trends and market analysis

Rising demand across surveillance segments

India's threat matrix—spanning disputed borders, asymmetric terrorism, maritime security, and climate-linked disasters—has catalysed investment in layered surveillance architectures. Key domain-specific drivers include:

- **Terrestrial:** Border EO towers, radar–thermal fusion systems, and motion detection sensors such as BEL's IPSS and DRDO's EON dominate deployments across international borders.
- **Aerial and space:** Tactical UAVs (e.g., ideaForge SWITCH, TAS Nimble-i) and high-altitude pseudo-satellites (e.g., NewSpace Research) enable persistent EO coverage. ISRO's Cartosat and RISAT series complement this from orbit.
- **Maritime:** The Indian Navy and Coast Guard integrate EO/IR with radar chains for blue water domain awareness, leveraging systems from BEL and newer players like Optimized Electrotech.
- **Underwater:** DRDO and NIOT are developing EO payloads for unmanned gliders and ROVs for seabed surveillance and port security.
- **CBRN/environmental:** EO-LIDAR drones by Dhaksha, Enord, and others now monitor chemical plumes, toxic leaks, and environmental hazards.

Key trends in the electro-optics ecosystem

1 EO + AI fusion

- Start-ups like **Enord, Skylark Drones,** and **Tonbo Imaging** are embedding AI into EO feeds to classify threats, automate image recognition, and reduce operator burden.
- **Enord's AI Pilot™** offers autonomous GPS-denied EO surveillance, ideal for contested or dense urban zones.

2 Miniaturization and modularity

- Platforms like **TAS Nimble-i, Fligen Eagle 1.0,** and **DroneAcharya drones** feature compact EO payloads for soldier-portable drones and vehicle-mounted ISR kits.
- Tonbo Imaging's Arjun sighting systems demonstrate a modular fusion of thermal and visible imaging.

3 Multispectral and thermal imaging

- Companies like **Optimized Electrotech** and **SFO Technologies** offer EO modules with LIDAR, SWIR, and thermal bands for use in UAVs, naval platforms, and armored vehicles.
- MKU integrates thermal cameras and fused vision modules in soldier-wearables and combat helmets.

4 Persistent and stratospheric surveillance

- **VEDA Aeronautics, NAL and NewSpace Research's** HAPS drones and **GalaxyEye** satellites signify the move toward 24/7 EO surveillance from stratosphere and LEO.
- These systems serve ISR roles and disaster management missions with EO data fusion.

5 EO in logistics and urban monitoring

- Drones by **TSAW, Skye Air, and ideaForge** integrate EO to enhance urban crowd surveillance, smart city mapping, and disaster response logistics.

Market players and capabilities (illustrative)

Company	Core EO/IR competency
MKU	Night vision devices, fused EO helmet displays, integrated EO soldier systems
Optimized Electrotech	Dual-use EO payloads for UAVs, naval, and vehicle platforms; indigenous sensor fusion tech
Tonbo Imaging	Thermal sights, fusion cameras, AI-driven EO modules for >25 export markets
SFO Technologies (NeST Group)	EO modules for aerospace, naval EO/IR systems, custom imaging payloads
HFCL, Vindhya Telelinks, Aksh Optifibre, Finolex Cables	Supply EO system backbone via fibre optic connectivity for perimeter and smart surveillance
BraveCore Surveillance & Tactical	EO/IR camera systems with integrated gimbal stabilization.

Company	Core EO/IR competency
M-Core Industries	Manufactures optoelectronic components including thermal lenses and EO gimbals (B2B)
Sterlite Technologies	Integrates EO-enabled smart city surveillance with 5G-ready fibre and command centre backbones
Dixon Technologies	Expanding into EO-enabled smart surveillance systems for police modernization projects
Eagle Photonics, Relemac Technologies, Fiber Optic Services (FOS)	Provide EO sensor cabling, optical interfaces, and ruggedized connectors used in border systems
GKB Optic Technologies	Optical glass, lenses, and IR windows used in thermal scopes and EO sensor modules
Optic Electronic (India) Pvt. Limited	Electro Optics and NVDs for small and medium calibre arms. Combined sight for UBGL and assault rifle.
HP Instrument	Supplier of photonic and EO testing/calibration equipment for PSU and private labs
Defsys Solutions Pvt. Ltd.	EO/IR payloads for ground vehicles, automated intruder detection systems, cooled/ uncooled thermal cameras
Paras Defence & Space Technologies	Multi-sensor EO surveillance systems for land, air and sea platforms, thermal imagers, gimbals
TATA Advanced Systems	Thermal imagers, electro-optic payloads for UAVs, tanks, and special forces
Eon Space Labs	High-performance IR payloads for maritime ISR, Buho225 infrared camera series
Lotus Advanced Technologies Pvt Ltd	EO/IR systems for small-medium naval platforms, Sea MiniPOP observation systems
Bharat Electronics Ltd (BEL)	EO Fire Control Systems (EOFCS), Thermal Imager-based Sights, and Multi-Sensor EO Pods for tanks, aircraft, and naval vessels
India Optel Limited	Day vision devices, image intensifier tubes, laser range finders, thermal imaging systems, and sight units for infantry and armored platforms
Zetatek Industries	EO tracking systems and simulators, R&D in real-time electro-optical evaluation systems
IdeaForge Technology	Integrated EO/IR payloads on tactical UAVs for border, urban and forest surveillance
Skylark Drones	AI-integrated EO systems for industrial, infrastructure, and emergency response use cases
Aadyah Aerospace	EO sensors for loitering munitions, tactical ISR UAVs
Gurutvaa Systems	Ruggedized EO systems for drones and ground robots with onboard analytics
Alpha Design Technologies	EO modules for electro-optical fire control, border surveillance systems
VizExperts India Pvt Ltd	EO-enabled battlefield visualization and command centre integrations

Global companies	Country	Specialization	Key products
Lockheed Martin	US, UK	EO/IR targeting systems for military aircraft	Sniper Advanced Targeting Pod, IRST systems
Raytheon Technologies	US, UK	Multi-spectral imaging and infrared tracking systems	MTS-A EO/IR sensor, FLIR targeting systems
Thales Group	France	EO/IR solutions for naval, airborne, and land-based applications	Catherine thermal imagers, Sophie handheld EO/IR devices
Northrop Grumman	US, UK	High-resolution EO/IR sensors for ISR and targeting	LITENING targeting pod, EO/IR surveillance systems
BAE Systems	UK	EO/IR systems for armored vehicles and fighter jets	AN/AAR-57 Common Missile Warning System
Teledyne FLIR	US	Thermal imaging and infrared surveillance solutions	FLIR Ranger HDC, airborne EO/IR cameras
Rheinmetall AG	Germany	EO/IR systems for battlefield reconnaissance and fire control	Vingmate fire control systems, thermal imaging sights
Thirdeye Systems	Israel	EO/IR analytics and drone detection systems	AI-enabled perimeter monitoring, vehicle-mounted detection systems
IAI (Israel Aerospace)	Israel	EO/IR surveillance systems for air and naval applications	Multi-sensor payloads for UAVs, mission pods
Elbit Systems	Israel	EO/IR imaging systems for drones and ground forces	XACT th64 thermal sights, UAV imaging pods, smart weapon optics
General Dynamics	US, UK	EO/IR surveillance and precision targeting systems	EO/IR mission systems for armored vehicles and aircraft
Dassault Systèmes	France	EO/IR simulation and digital twin tools	Virtual mission planning and optics simulation software
L3Harris Technologies	US	EO/IR targeting pods, weapon sights, night vision and laser systems	WESCAM MX-Series, AN/PAS-13 thermal sight, NVGs, PEQ laser modules
Meprolight (SK Group)	Israel	Small arms electro-optics: red dot, thermal, and night sights	Mepro M5, Mepro MOR, Mepro TIGER thermal weapon sight
Aimpoint AB	Sweden	Military-grade red dot sights for rifles, carbines, and DMRs	CompM4, Micro T2, PRO Patrol Rifle Optic
Trijicon Inc.	US	Advanced combat optics, reflex sights, ACOGs, night vision	ACOG, RMR Type 2, VCOG 1-8x, Trijicon IR Hunter

Global companies	Country	Specialization	Key products
Steiner Optik	Germany	Thermal and optical weapon sights, binoculars, and laser systems	T-Series thermal optics, M830r LRF binoculars, DBAL-A3 laser module
Steiner eOptics (Beretta)	US	Military-grade lasers and fire control for small arms	DBAL, CQBL-1, LAS/TAC series
Hensoldt AG	Germany	EO systems for infantry and armored platforms, thermal weapon sights	NSA80 thermal sight, Spotter 60+, ZF 4-16x56 targeting scope
Raytheon ELCAN	Canada	Precision optics for rifles and MGs	Specter DR 1-4x, Specter TR 1-3-9x tactical optics
Beretta Defence Tech	Italy	Integrated optics with firearms, smart fire control for assault rifles	Smart battle rifles with EO sights and embedded fire-control optics
Thales Angénieux	France	Thermal weapon sights and handheld optronics for dismounted soldiers	Sophie-U LT, MINIE-DIR, IR 1000-B handheld IR devices
Vortex Optics (Vortex Defence Division)	US	Tactical scopes and LPVOs used in military applications	Razor HD Gen III 1-10x, Spitfire HD Prism, AMG UH-1 Gen II
Nocturna Ltd.	UK	Night vision and IR weapon sights for soldiers and vehicles	Sentinel night vision sight, IRIS thermal viewer
FLIR Systems (Teledyne)	US	Thermal weapon sights, rugged soldier EO systems	FLIR ThermoSight Pro, Breach PTQ136, FLIR RS8500 pod
Wilcox Industries	US	EO accessory integration for helmets and firearms	RAID-Xe IR laser, NVG mounts, FUSION helmet sensor
GSCI Advanced Photonics	Canada	Rugged thermal scopes, night vision monocular for defence	TI-GEAR-C core, QUADRO-S multi-sensor fusion optics
Brolis Defence	Lithuania	Clip-on thermal scopes and soldier-borne EO gear	BROLIS Clip-On Thermal Imagers (COTI)
Rafael Advanced Defence Systems	Israel	Integrated EO fire control and targeting for infantry and AFVs	Fire Weaver, SPIKE optics integration, Toplite EOS

EO surveillance market valuation and outlook

India's evolving threat matrix has catalysed significant investment in layered surveillance architectures. Domestically, the surveillance market is currently valued at approximately USD 4.3 billion, with projections suggesting it will surpass USD 15 billion by 2029. Globally, the electro-optical/infrared (EO/IR) surveillance market is valued at USD 11.09 billion as of 2025, and is expected to grow at a CAGR of 2.46%, reaching USD 13.15 billion by 2032.

Key catalysts

- UAV proliferation in defence and civilian sectors
- Integration of EO with AI, edge computing, and cloud
- Demand from MoD, CAPFs, Smart Cities, and disaster response

Notable insights

- EO payloads form **~40% to 45% of the cost structure** of tactical UAVs in Indian military tenders.
- Indian EO/IR exports (e.g., **Tonbo, Optimized Electrotech)** are now penetrating markets in Israel, the UAE, and Southeast Asia.

Challenges

1. Import dependence on core components

- India still imports key technologies such as cooled IR detectors (e.g., InSb, MCT), high-performance gimbals, and focal plane arrays (FPAs).
- High-cost components from the US, France, and Israel restrict domestic value addition.

2. Export regulation bottlenecks

- SCOMET and Wassenaar Arrangement requirements limits export of high-resolution thermal and multispectral EO/IR equipment.
- Requires complex end-use certifications and export compliance, hindering Indian OEMs.

3. Lack of interoperability and standardization

- Specifications vary across services (Army, Navy, Air Force) causing procurement delays.
- No unified testing framework or TRL/MRL benchmark specific to EO/IR payloads.

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India's ICUAS and IACCS: EO-enabled airspace superiority systems

Surveillance and electro-optics (EO) are now fundamental to the Indian Air Force's dual-tiered airspace defence architecture, specifically through the **Integrated Counter-UAS Grid (ICUAS)** and the **Integrated Air Command and Control System (IACCS)**[24]. While ICUAS focuses on decentralized detection and neutralization of hostile low-RCS threats, IACCS serves as the centralized brain of India's layered air defence network. Together, they form the backbone of India's sovereign, AI-driven, EO-integrated air defence doctrine.

1. EO in the Integrated Counter-UAS Grid (ICUAS)

The ICUAS Grid was developed in response to rising threats from drones, UAV swarms, and low-flying stealth targets. EO/IR systems are central to its three-phase kill chain: detection, classification, and engagement.

A. Engagement and damage assessment

- **EO-aided interceptors:** EO modules on loitering munitions or quadcopters allow visual target locking in kinetic kill.
- **Kill confirmation:** EO footage is used post-engagement to confirm hits, monitor debris dispersion, and assess secondary threats or follow-on strikes.

B. Detection and tracking

- **EO/IR sensors on PTZ towers:** These sensors detect low-altitude threats in sectors where radar coverage is impaired due to terrain masking or low RCS.
- **Thermal imagers:** Critical for night-time or poor weather detection—infrared payloads mounted on EO towers identify heat signatures from drones or munitions.
- **Passive, jam-resistant EO systems:** Unlike radar, EO systems are immune to electronic jamming, making them ideal for deployment in dense urban and electronic warfare-prone areas like airbases and other zones of national significance.

C. Classification and threat verification

- **AI video analytics:** AI algorithms analyze EO video in real time to distinguish quadcopters from birds, decoys from armed drones, and balloons from weather probes.
- **Zoom and visual confirmation:** EO cameras offer high-resolution zoom to visually verify flagged threats, minimizing false positives.
- **Thermal differentiation:** Hot engines or moving bodies are classified using thermal gradient mapping.

D. ICUAS EO deployment components

Component	Core EO/IR competency
Gimballed EO/IR towers	24x7 visual surveillance and threat confirmation
UAV-mounted EO payloads	Layered detection and tracking
Handheld EO viewers	Used by QRTs for mobile response
AI video analytics software	Autonomously classifies, flags and escalates threats

2. EO in the Integrated Air Command and Control System (IACCS)

The IACCS is India's airspace command-and-control backbone. EO/IR sensors embedded across platforms provide the critical visual truth layer for multi-sensor fusion, enabling fast and reliable air defence decision-making.

A. Real-time multi-sensor fusion

- **Data integration:** EO feeds from aerostats, AEW&CS aircraft, ICUAS towers, and satellite surveillance are fused with radar (e.g., Ashwini, Rohini) and ELINT data.
- **Reduced sensor ambiguity:** EO confirmation helps distinguish between a friendly fighter and a cruise missile, or between a decoy and a live threat.

B. Target recognition and engagement prioritization

- **In saturation attack scenarios, EO data enables:**
  - Visual ID of drone types (ISR vs. armed)
  - Prioritization of threats based on movement, signature, and formation
  - Enhanced SAM deployment efficiency

C. Base and asset protection

- **Perimeter EO cameras:** Integrated into IACCS for automatic alerts on unauthorized UAS entry, base takeoffs/landings, and movement monitoring.
- **Runway safety:** EO ensures real-time surveillance of aircraft taxiways, logistics zones, and perimeter roads.

D. Joint ops and tactical awareness

- During tri-service operations, EO feeds from Army and Navy are incorporated into IACCS to enhance the **Recognized Air Picture (RAP),** offering a common operating picture (COP) for joint command.

EO's role in ICUAS vs. IACCS

Capability	ICUAS Grid	ACCS System
Low-RCS drone detection	EO/IR sensors	EO-aided fusion
Visual confirmation	On-target video	RAP clarity
AI-driven threat classification	Swarm differentiation	Threat prioritization
Base perimeter security	EO towers + UAV patrols	Integrated with IACCS camera feeds
Engagement and kill confirmation	EO lock and post-strike video	EO-guided interceptor missions

The ICUAS and IACCS represent India's shift toward autonomous, electro-optically enabled airspace defence. EO systems serve as the visual backbone of India's kill chain — seeing what radar misses, verifying what RF sensors suspect, and guiding precision responses faster than ever before.

IACCS structure

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Opportunities in EO/IR for the industry

EO and IR technologies offer a wide spectrum of opportunities in the Indian and global defence ecosystem—not only at the platform level but also through modular systems and sub-systems. Here is a structured breakdown of these opportunities:

1. Platforms-level opportunities

These are integrated EO/IR systems on military platforms:

A. Unmanned systems

- **EO/IR payloads for UAVs, UGVs, and USVs** (e.g., stabilized gimbals, thermal cameras and laser rangefinders)
- **Miniaturized EO modules** for tactical drones (swarming, loitering, logistics)

B. Armored vehicles and MBTs

- Gunner and commander sights with **thermal imaging and day/night fusion**
- Fire control EO systems with **automatic target recognition**

C. Fighter jets and helicopters

- **Targeting pods** (e.g., FLIR, IRST, EO-SAR hybrid)
- **Pilot vision enhancement systems** (e.g., helmet-mounted EO cues)

D. Naval vessels

- EO fire-control **systems for surface and air threat tracking**
- **360° IR maritime surveillance suites** for littoral security

E. Space-based platforms

- **EO satellites and CubeSats** for tactical ISR and disaster monitoring
- **Multispectral satellite imaging** for grey-zone and long-range surveillance

2. Systems-level opportunities

Comprehensive EO systems integrated with other technologies:

A. EO + radar fusion systems

- Battlefield surveillance systems combining EO and synthetic aperture radar (SAR)
- Coastal and border command centers using **EO-radar fusion towers**

B. EO in Counter-UAS (CUAS)

- EO tracking and discrimination units for drone detection
- EO kill confirmation and threat classification modules

C. C4ISR systems

- EO video feeds integrated into **real-time command networks (IACCS)**
- AI-based fusion of **SIGINT, IMINT, and EO/IR inputs** for target prioritization

3. Sub-system and component-level opportunities

Critical building blocks of EO/IR devices

A. Sensors and FPAs

- **Indigenous development of focal plane arrays (FPAs):** MCT, InSb, VOx, InGaAs
- High-sensitivity thermal detectors for cooled and uncooled systems

B. Lenses and optical materials

- Military-grade **Germanium, Sapphire, and ZnSe optics**
- Precision optical coatings for IR transparency and durability

C. Gimbals and stabilization units

- Lightweight, vibration-resistant gimbals for UAVs and handheld systems
- **Dual-axis and tri-axis stabilization** with inertial navigation integration

D. AI and edge computing modules

- Embedded AI chipsets for **object detection, facial recognition and target tracking**
- Software-defined EO payloads with plug-and-play modularity

E. Cooling systems

- Cryo-coolers for mid-wave IR (MWIR) detectors
- **Compact thermal management systems** for EO pods in UAVs and missiles

4. Export and civil dual-use opportunities

- Internal security (e.g., CAPFs, airport security and smart cities)
- Disaster management (flood, fire and landslide surveillance)
- Industrial monitoring (pipeline, oil and gas, mining, and solar farms)
- Defence exports of EO payloads, subsystems, and test equipment to friendly nations under **Line of Credit (LoC)** frameworks

Major AoNs, RFIs and RFPs

Product	Type
2500 TI-Based Driver Night Sights for BMP-2/2K, AAT and CMT	RFI
Night Sight (TI) for 84mm Rocket Launcher	AoN
Night Sight (Thermal Imaging) for 84mm Rocket Launcher	RFI
Digital Night Vision Goggles	RFI
Indian Navy RFI for Fast Interceptor Craft (FIC-I)	RFI
Night Sight (TI) for 84mm RL	RFI
TI-Based Driver Night Sight (DNS) Systems	RFI

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Electro-optics in news

Company/Entity	News/developments
Tonbo Imaging	Launched 360° EO/IR systems (Wolfpack IRST, Atlas) for land, air, and naval platforms with AI fusion
DRDO	Upgraded D4 anti-drone system with EO/IR sensors, AI-based threat classification, and laser neutralizers
Paras Defence & MicroCon (Israel)	Signed MoU for co-developing EO/IR seekers and ISR payloads for drones in India
Origin Robotics (Latvia)	Unveiled BLAZE man-portable C-UAS integrating radar, EO/IR, and AI-driven visual tracking
Indian Air Force (IAF)	Issued RFI for ISTAR systems with SAR and EO/IR payloads, including SATCOM and data links
High Point Aerotechnologies (US)	Debuted Sawtooth C-UAS with layered EO/IR, radar, RF detection, and jamming capabilities
Solar Industries (India)	Revealed Bhargavastra anti-drone system integrating EO/IR, radar, AI, and micro-missiles
Aurora Flight Sciences	Tested EO/IR payload on Centaur OPA for ISR missions in degraded weather conditions
Estonian Firm (EIRSHIELD)	Launched autonomous EO/IR-based air defence system on Bv206 platform for drone protection
NAL	Announced development of 150 kg indigenous loitering munition UAV with EO/IR gimbal and Wankel engine
Hensoldt	Partnered with Raphe mPhibr (MIMO radars) and Samtel Avionics (EO-based Cavi Sight for UAVs)
Paras defence	Announced INR12,000 crore investment in India's first Optics Park for EO/IR manufacturing in Maharashtra

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Strategic materials used in electro-optics

Strategic materials are the **critical enablers** behind performance, reliability and sensitivity of **surveillance and electro-optic (EO) equipment,** including sensors, optics, imaging systems and tracking modules. These materials influence factors like image resolution, detection range, night vision capability, sensor miniaturization and thermal performance.

Material	Application	Remarks
Indium Antimonide (InSb)	Mid-wave infrared (MWIR) focal plane arrays (FPAs)	High sensitivity; needs cryogenic cooling
Mercury Cadmium Telluride (MCT)	Long-wave IR (LWIR) detectors	Used in cooled IR detectors for thermal sights
Vanadium Oxide (VOx)	Uncooled thermal imagers (UAVs, handheld systems)	Cost-effective; common in soldier and drone EO systems
Amorphous Silicon (a-Si)	Microbolometers for uncooled IR	Cheaper alternative for mass production
Quantum Dots	Next-gen IR and SWIR sensors	Under R&D; higher photon conversion efficiency
Germanium (Ge)	Infrared lenses and windows	High IR transmittance, especially for LWIR systems
Zinc Selenide (ZnSe)	IR optical elements in thermal sights	Used in high-power laser optics as well

Material	Application	Remarks
Chalcogenide Glasses	Rugged IR optics for harsh environments	Emerging substitute for Ge
Sapphire	EO window material; scratch resistant	High strength; used in missile domes and sensors
Calcium Fluoride (CaF)	UV and IR lenses	High clarity, low dispersion optics
Fused Silica / Quartz	Visible light optics and satellite optics	Used for high-stability optics in ISR satellites
Gallium Arsenide (GaAs)	High-speed EO electronics and laser diodes	Used in radar-EO hybrid modules
Indium Gallium Arsenide (InGaAs)	SWIR imaging detectors	Detects lasers, heat, smoke—used in smart munitions and surveillance
Silicon (Si)	Visible-light CMOS/CCD sensors	Universal base for visible EO sensors
Silicon Carbide (SiC)	EO focal plane substrates; radar apertures	High thermal and mechanical resistance
Gallium Nitride (GaN)	EO radar signal processing and power electronics	Also used in laser warning systems (LWS)
Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG)	Rangefinders and target designators	Produces high-energy IR laser pulses
Lithium Niobate (LiNbO)	Electro-optic modulators	Controls laser beams; used in fire-control EO systems
KTP (Potassium Titanyl Phosphate)	Frequency doubling (IR to visible) in laser systems	Used in compact EO targeting lasers
Beryllium	Lightweight EO mirror structures	High stiffness; used in space optics and UAV payloads
Titanium Alloys	EO pod structural housing	Strength-to-weight optimization
Carbon Fiber Reinforced Polymer (CFRP)	EO gimbal mounts and UAV EO housings	Lightweight and vibration-resistant
Aluminum Nitride (AIN)	Thermal management in EO modules	Conductive but electrically insulating; helps with cooling

Criticality for India

Many of the above are **import-dependent**, placing surveillance and EO capabilities at risk during prolonged conflict. Especially:

- **IR FPA materials (MCT, InSb, InGaAs)** are not fully indigenized
- **Optical-grade Germanium and ZnSe** are imported (mostly from China, Germany, or US)
- **Sensor chip fabrication** (e.g., a-Si, VOx arrays) is limited due to the absence of dedicated fab facilities in India

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Conclusion

Electro-optical and infrared (EO/IR) technologies have become indispensable to India's defence and surveillance architecture, enabling precision, persistence and real-time situational awareness across land, air, sea and space domains. From border surveillance towers and smart munitions to satellite-based ISR and AI-enabled EO fusion, these systems underpin India's multi-layered response to both conventional and asymmetric threats. With growing indigenous innovation — from EO-equipped UAVs and loitering munitions to thermal sights and hyperspectral satellites — India is steadily reducing its import dependence. However, gaps remain in high-end sensor fabrication, strategic materials, and testing infrastructure. Going forward, synergistic R&D, defence–industry collaboration and AI-integrated EO platforms are vital to achieving self-reliance and operational superiority. In a future shaped by drone swarms, hybrid warfare, and electromagnetic battlespaces, EO/IR capabilities serve not just as tools of surveillance but as enablers of strategic dominance.

List of abbreviations

Acronym	Full form
ADA-O	Adaptive Defence Antenna - Open
AEW&CS	Airborne Early Warning and Control System
ASW	Anti-Submarine Warfare
BFSR	Battlefield Surveillance Radar
CIWS	Close-In Weapon System
COMINT	Communications Intelligence
EHF	Extremely High Frequency
ELINT	Electronic Intelligence
EO	Electro-Optical
EOS	Earth Observation Satellites
EOSS	Electro-Optical Surveillance System
ESM	Electronic Support Measures
FLIR	Forward Looking Infrared
FPA	Focal Plane Array
GIS	Geographic Information System
HAPS	High Altitude Pseudo Satellite
HALE	High Altitude Long Endurance
IACCS	Integrated Air Command and Control System
ICUAS	Integrated Counter-Unmanned Aerial System
InGaAs	Indium Gallium Arsenide
InSb	Indium Antimonide
IPSS	Integrated Perimeter Security System
IOR	Indian Ocean Region

Acronym	Full form
ISR	Intelligence, Surveillance and Reconnaissance
LiDAR	Light Detection and Ranging
LOROS	Long Range Reconnaissance and Observation System
LWIR	Long Wave Infrared
MALE	Medium Altitude Long Endurance
MCT	Mercury Cadmium Telluride
MEMS	Micro Electro-Mechanical Systems
MSSS	Multi Sensor Surveillance System
MWIR	Mid Wave Infrared
PTZ	Pan-Tilt-Zoom
RCS	Radar Cross Section
RISAT	Radar Imaging Satellite
SAR	Synthetic Aperture Radar
SIGINT	Signals Intelligence
SWIR	Short Wave Infrared
TSAW	Technit Space and AeroWorks
Vox	Vanadium Oxide
ZnSe	Zinc Selenide

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