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REVIEW PAPER

Thermal (Infrared) Imaging Sensors

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ABSTRACT

Recent developments in improved type of infrared detector technologies focal plane arrays, signal processing techniques, and innovative optical designs have enabled thermal imaging technology to undergo revolutionary advancement, leading to realisation of high performance and compact thermal cameras for surveillance, target acquisition, tracking, and guidance. Instruments Research and Development Establishment (IRDE), Dehradun, has designed and developed a variety of thermal imaging sights for different ongoing programmes/projects. In the present paper, an overview of thermal imaging systems, different generations and classification of thermal imaging systems is described. The paper also presents salient features/specifications of thermal imaging systems developed by IRDE together with the images recorded in actual field trials.

Keywords: Thermal imaging, focal plane arrays, IR sensors, long-wave infrared, medium-wave infrared

1. INTRODUCTION

Present day scenario of low-intensity conflict, internal security, counter insurgency, and counter terrorism has resulted in rapid technological advancements in the development of electro-optical (EO) sensors for both visible and infrared (IR) spectrum which has been a major thrust of military systems for the last three decades.

All conditions vision is rapidly emerging as an increasingly important operational requirement of all the three Services. To fulfill their tasks, these must be able to exploit a large field of view (FOV) for enhanced mobility, high sensitivity for efficient observation, and a good resolution to identify their targets before firing. The technologies in the night vision field have progressed to the point that while true all conditions vision has not yet been achieved, night vision devices already offer capabilities far exceeding the unassisted human eye.

Thermal IR imaging sensor[1] works in a completely passive manner by utilising the thermal contrast of targets against its background and is independent of prevailing light conditions. It generates extensive ranges for detection and recognition of targets in day and night conditions.

In addition, long-wave IR (LWIR) (8-12 μm/ 3-5 μm) can penetrate mist and fog considerably better than visible/near-IR light. Artificial smoke screening of targets is relatively ineffective during observation through thermal imagers. But thermal imaging technology is much more complex compared to image intensifiers in terms of IR detector and cryogenics, opto-mechanics, and advanced signal processing requirements. Figure 1 shows the regions

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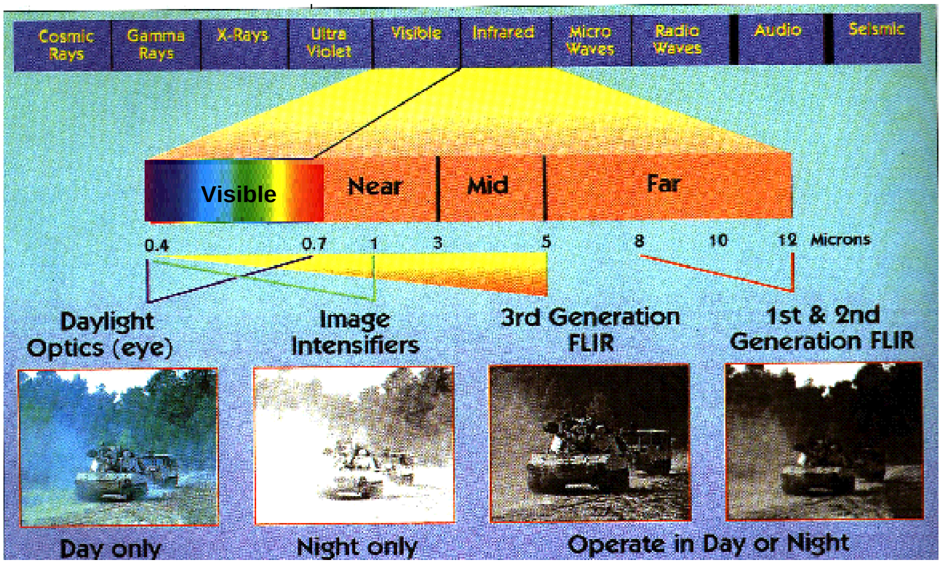

Figure 1. Electro-magnetic spectrum and types of imaging sensors.

of electromagnetic spectrum where electro-optical imaging sensors are operating and improvements in image quality of IR thermal images compared to image intensifiers.

2. OVERVIEW

Infrared sensors are used for a wide variety of military purposes. These include night vision for ground, air, and naval applications, surveillance, airborne reconnaissance, infantry and AFVs, fire control and sighting systems, forward observation, air defence warning systems, and missile seekers. Practical infrared imaging systems first appeared in the 1960s particularly on airborne platforms where these were subsequently used in Vietnam, Operation Desert Storm, and extensively used in Iraq war. Early systems were bulky. The current systems in service are generally lighter and more compact while giving much better performance in sensitivity and picture quality.

The introduction of the capability for night vision using thermal imagers is one of the major technological advances in the armament sector over the last three decades and emerged as the real force multiplier.

Around the world, several first-generation thermal imagers are being phased out and replaced by second- or third-generation thermal imagers. Military users of these devices are also becoming more and more familiar with thermal imager system capabilities and limitations. As such, user demand for higher and higher target acquisition and engagement range, large FOV, and compact weight/volume has resulted in rapid growth in thermal imager system technologies.

3. THERMAL IMAGING

3.1 Thermal Imager Generations

First-, second-, and third-generation[2] thermal imagers are used to describe different developmental stages of thermal imagers which are primarily based on IR detector configuration/geometry and means of scanning and read-out electronics techniques. Thermal imager family can be grouped as shown in Fig. 2.

3.2 Thermal Imager classification

In addition to the detector generation, thermal imagers are sometimes classified on the basis of spatial resolution and range performance, and also on the basis of spectral response.

3.2.1 Long-range Thermal Imagers

- Spatial resolution or instantaneous field of view (IFOV) better than 0.1 mrad

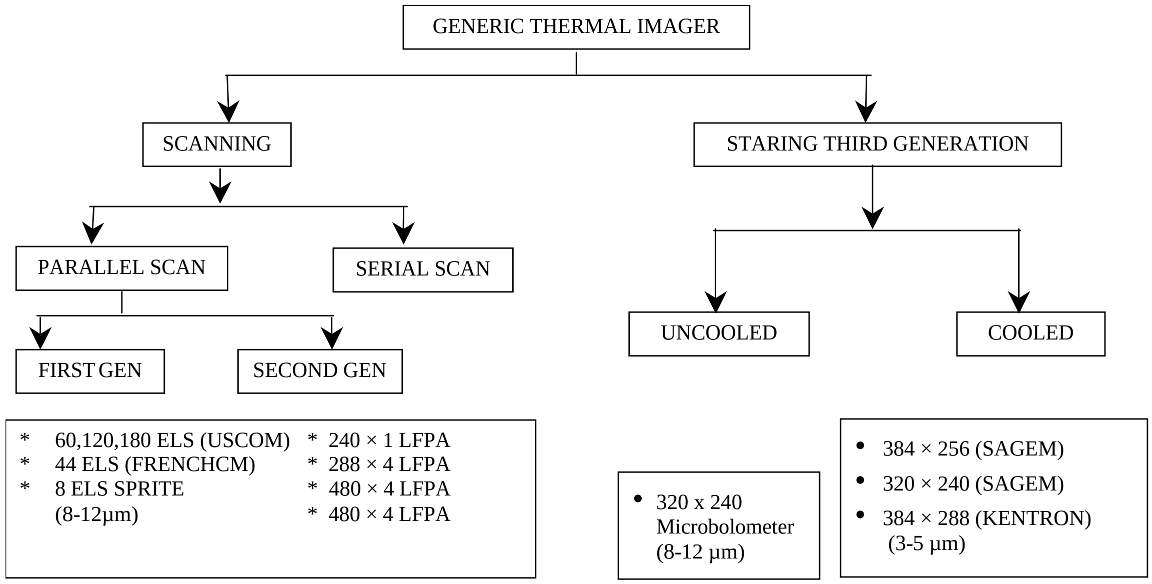

Figure 2. Thermal imaging family tree

- Recognition ranges better than 4 km against NATO tank size targets
- Used as target acquisition system for anti-tank guided missiles (ATGMs)

3.2.2 Medium-range Thermal Imagers

- Spatial resolution of IFOV better than 0.15 mrad
- Recognition ranges better than 3 km against NATO tank size used as part of integrated fire control system for MBTs

3.2.3 Hand-held Thermal Imagers

- Spatial resolution of IFOV better than 0.20 mrad
- Recognition ranges better than 2 km against NATO tank size targets and men-movements
- Used as tripod-mounted or hand-held for infantry or artillery role.

These systems exploit the two infrared spectral windows, i.e., 3–5 µm and 8–12 µm that are termed as medium-wave infrared (MWIR) and LWIR and atmosphere is transparent in these windows (Fig. 3). The atmosphere affects the system performance. The atmospheric transmission varies in MWIR and LWIR under different climatic conditions.

3.3 Subsystems of Thermal Imaging Systems

Thermal imaging process is defined as conversion of heat (infrared) energy into a real-time picture and a thermal image is a pictorial representation of temperature differential across the target relative to its background. In contrast to visible system, where reflection and reflectivity differences determine the image contour, in thermal imaging, the temperature and emissivity difference of targets in the scene determine the contrast and contour of what imager sees.

The essential components of a thermal imaging sensor (Fig. 4) and their functions are:

Optical system (Telescope): It collects the IR radiations and focuses them onto the detector array.

Opto-mechanical scanning system: It moves the IR image of the scene across the detector, type of scanning mechanism is directed by the type of detector array configuration.

Detector and cryogenics: It converts IR radiation into electrical signal. A typical detector is an array of small sensitive *InSb*/*HgCdTe* elements and cooled to 77 K.

Signal processor: It includes the pre-amplifier, post-amplifier, multiplexing and single O/P is fed to display device.

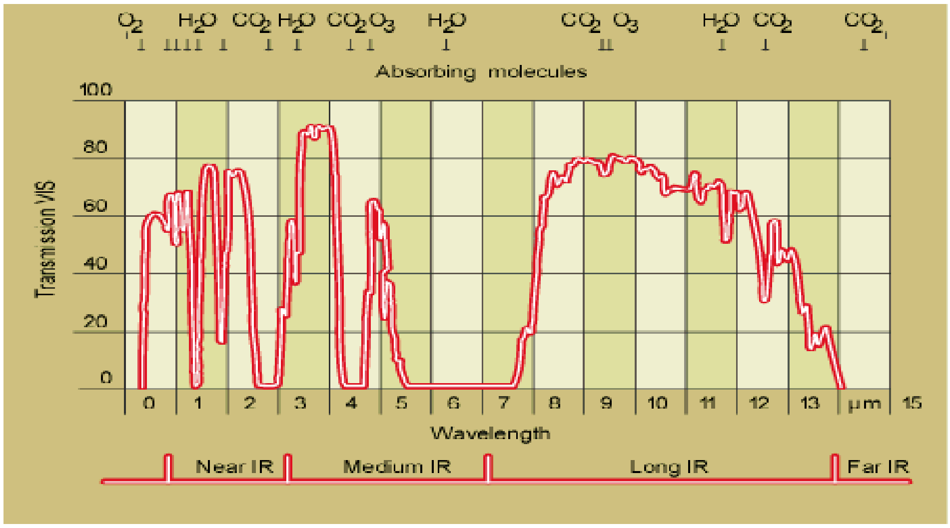

Figure 3. Atmospheric transmission.

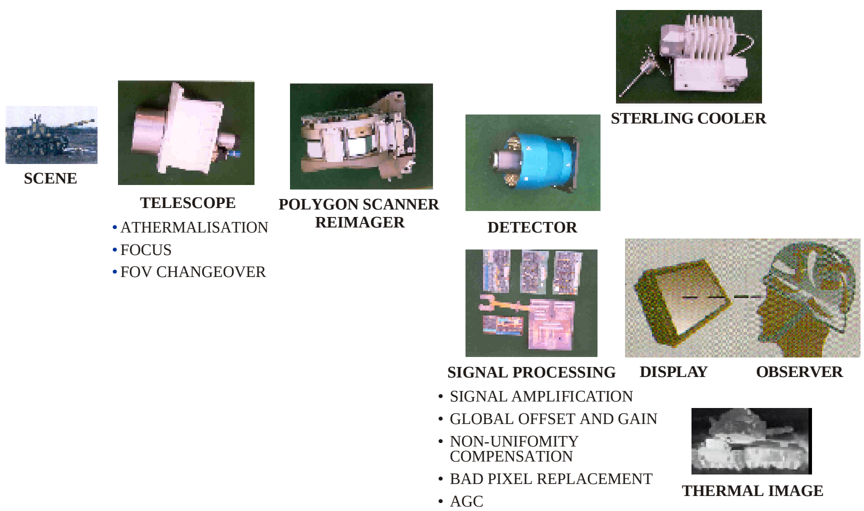

Figure 4. Subsystems of a thermal imaging system.

Output device: It includes: (i) display monitor using CRT, organic LED (OLED), LCD panel, and (ii) a recorder for data storage.

4. THERMAL IMAGING SYSTEMS DEVELOPED AT IRDE

Instruments Research and Development Establishment has developed and successfully field tested, first-generation thermal imagers based on 60-element linear mercury cadmium telluride (MCT) photoconductive arrays and 100-element linear MCT photovoltaic arrays. Subsequently, first-generation linear array detectors are being phased out, first-generation thermal imager sights were replaced by second-generation 288 x 4 MCT linear focal plane array-based systems.

4.1 First-generation Thermal Imager for Tank Fire Control System

As a part of tank fire control system (TFCS), a thermal imager based on 60-element linear array MCT detector was designed and developed, which was successfully field tested with users participation. This thermal imager operates on the principle of parallel scan with 4:1 interlace. It utilises 60-element linear array MCT detector encapsulated in a dewar and cooled to 77 K by a split stirling engine cooler. A rotating eight-sided polygon scanner provides the complete 2-D coverage of the total FOV. The system has two FOVs. The detailed specifications are given in Table 1. The thermal imager developed is shown in Fig. 5.

Table 1. Specifications for thermal sight for tank fire control system

Spectral range	8 – 12 µm
Optics diameter	110 mm
Detector	60-element linear MCT
Cooler	Split stirling (1/4 W)
FOV	
WFOV	4.2° (El) × 10.8° (Az)
NFOV	1.4° (El) × 3.6° (Az)
Range (Tank target) (2.3m × 2.3 m, ΔT= 2 °C, T=27 °C, RH=70 %, V=10 km)	Detection: 4.0 km Recognition: 2.5 km

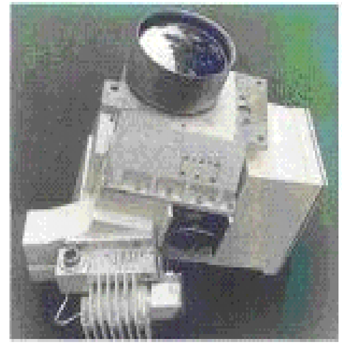

Figure 5. Thermal imager for tank fire control system.

4.2 Target Acquisition System

4.2.1 Ground Version

This thermal imager is based on second-generation 288 x 4 linear FPA MCT detector. The target acquisition system (TAS) for ground version comprises of second-generation thermal imager, CCD camera and a LRF (LH 30) which has been integrated with reconfigured MICA II and has undergone user-assisted trials in KK ranges and Mahajan ranges. The thermal imager has given the desired recognition ranges of 4 km against tank targets. The specifications are given in Table 2 and photograph of TAS is given in Fig. 6(a).

4.2.2 Airborne Version of Thermal Imagers

For airborne platform, IRDE has designed and developed the following sighting packages for navigation, target acquisition, and target engagement.

(i) Gyro-stabilised navigational sighting system (NSS) comprising FLIR and CCD.

(ii) Gyro-stabilised target acquisition system (TAS) comprising TI and LRF.

IRDE has designed and developed Gyro-stabilised navigation system (FLIR and CCD) and target acquisition system (TI and LRF). These sighting systems have undergone EMI/ EMC testing, environmental testing, and are ready for integration.

The photographs of these sighting system are shown in Fig. 6(b) and detailed specifications are given in Tables 3 and 4.

Table 2. Specifications of target acquisition system

Type	Second generation thermal imager	* CCD range: recognition - 8 km
Spectral band	7.7 –10.5 µm	* LRF range: maximum -- 6 km (± 5 m)
Detector	288 × 4 MCT LFPA	minimum -- 80 m
FOV	2.2 ° × 1.6° (N) 8° × 6 ° (W)	
TI range NATO target (ΔT= 2 °C, V=10 km, T=27 °C, RH=85%)	Detection - 8 km Recognition - 4 km	
Weight	25 kg	

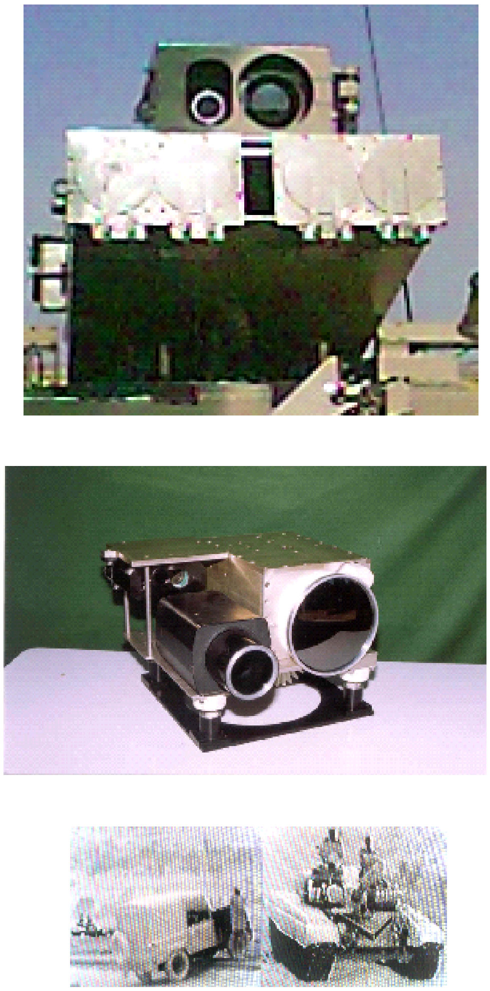

Figure 6(a). Target acquisition system.

Figure 6(b). Navigational sighting system and target acquisition system for airborne platform.

Table 3. Specifications for navigational sighting system

FLIR (second-generation)	
Spectral band	7.7 –10.5 µm
FLIR FOV	8° × 6° (N) 16° × 12° (W)
Detector	288 × 4 MCT LFPA
Range	Detection – 4 km
NATO target (ΔT= 2 °C, V=10 km, T=27 °C, RH = 85%)	
CCD camera	
FOV	3.1° × 2.3° (N) 33.7° × 23.3 ° (W)
Range	Detection - 4 km Recognition - 3 km
Total weight	48.0 kg

Table 4. Specifications for target acquisition system

Thermal sight (second-generation)	
Spectral band	7.7 –10.5 µm
FOV	2.2° × 1.6° (N) 8° × 6° (W)
Detector	288 × 4 MCT LFPA
Range	Detection - 8 km
NATO target (ΔT= 2 °C, V=10 km, T=27 °C, RH = 85 %)	Recognition - 4 km Identification - 2.5 km
LRF	
Range	maximum -- 6 km (± 5 m) minimum -- 80 m
Total weight	62.0 kg

4.3 Electro-optical Fire Control System for Naval Ships

The second-generation thermal imaging sight developed was also used as a part of electro-optical director (EOD) comprising second-generation thermal imaging, CCD camera and LRF and electronics units such as system control computer, turret control unit, and video tracking unit, power supply alongwith operator control console unit.

The photogragh of the electro-optical director is shown in Fig. 7 and specification are given in Table 5.

Figure 7. Electro-optical director for naval ship and image frame.

Table 5. Specifications for thermal imager sight (second-generation)

Spectral band	7.7 –10.5 µm
FOV	2.2° × 1.6° (N) 8° × 6° (W)
Detector	288 × 4 MCT LFPA
Range (Ship) (ΔT= 6 °C, V=10 km, T=27 °C, RH = 70 %)	Detection - >20 km Recognition - >12 km

4.4 Development of Stand-alone first generation Thermal Imager

IRDE imported all first- and second-generation detectors from foreign vendors, when these were commercially available. In 2000, Solid State Physical Laboratory (SSPL) developed first-generation 60-element MCT linear detector, so to make fully indigenous thermal imager giving a recognition range of 1.5 km against vehicle, IRDE realised thermal imager using 60-element MCT detector developed by SSPL. The specifications are given in Table 6 and photograph is shown in Fig. 8.

Table 6. Specifications for stand-alone thermal sight

Spectral range	8 – 12 µm
Optics diameter	110 mm/ f 2.24
Detector	60 element linear MCT
FOV NFOV	 1.4° (El) × 3.6° (Az)
Range (against vehicle) (ΔT=:2 °C, V=10 km, T = 27 °C, RH = 85 %)	 Detection - 2.5 km Recognition - 1.5 km

Figure 8. Stand-alone thermal imager.

4.5 Third-generation Thermal Imaging System

Presently, IRDE is developing third-generation thermal imagers for a variety of applications[5]. The thermal imagers developed are:

(a) Hand-held thermal imager (HHTI) (3-5 µm),

(b) Medium-range thermal imager (3-5 µm),

(c) Uncooled helmet-mounted thermal imging camera for fire fighting applications, and

(d) Long-range thermal imager (LRTI)(3-5µm).

4.5.1 Hand-held Thermal Imager

The HHTI is the most complex system due to the lightweight and compact requirements. So IRDE focused its attention first to develop 3-5 µm HHTI.

Third-generation staring[4] *InSb* FPAs in the format of 320 × 240 were used to develop the sight. IRDE has developed its indigenous electronics for third-generation thermal imagers with the image processing features. The specifications are given in Table 7 and photographs are shown in Fig. 9.

Table 7. Specifications for hand-held thermal imager

Spectral range	3-5 µm
FOV	
Narrow	$3.2^\circ \times 2.4^\circ$
Wide	$9.6^\circ \times 7.2^\circ$
E –Zoom	× 2
Detector	InSb FPA 320 x 240
Cooler	Integrated stirling cooler
Video O/P	CCIR 625 lines, 50 Hz
Power supply	12 V dc, 18 W Li-ion rechargeable battery
Weight	3.0 kg (without battery)
Reliability	MTBF > 2000 h
Range (ΔT=: 2 °C, V=10 km, T=27 °C, RH = 85%)	Detection : 8.0 km (against vehicle) Recognition: 2.5 km (group of person)

4.5.2 Medium-range Thermal Imager

Medium-range thermal imager (MRTI) is also based on third-generation staring 320 × 240 *InSb* FPAs. IRDE has designed and developed the sight. This MRTI has been interfaced with battlefield surveillance radar (BFSR) unit which is mast-mounted on a vehicle with all remote controls and display placed inside the vehicle. Specifications are given in Table 7 and photographs are shown in Fig. 10.

Figure 10. Medium-range thermal imager and image frame.

Hand-held thermal imager.

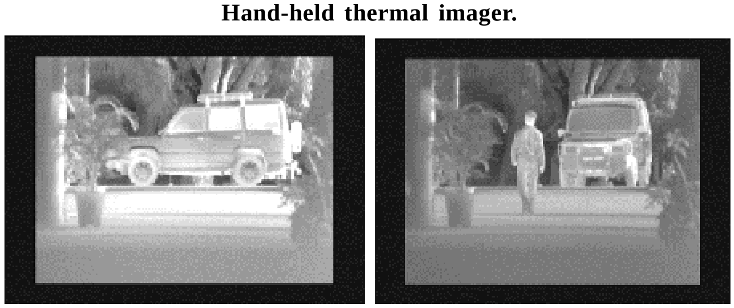

Figure 9. Image frames through HHTI.

Table 8. Specifications for medium-range thermal imager

Spectral range	3-5 μm
Field of view	
Narrow	2.3° × 1.7°
Wide	4.6° × 3.4°
E–Zoom	× 2
Detector	*InSb* FPA 320 × 240
Video O/P	CCIR 625 lines, 50 Hz
Power supply	24 V dc
Weight	2.6 kg (Thermal imager) 840 gm (Remote unit)
Reliability	MTBF > 2000 h
Range (ΔT=2 °C, V=10 km, T=27 °C, RH = 85 %)	Vehicle Detection : 9 km Recognition : 3 km

4.5.3 Uncooled Thermal Camera for Fire Fighting Applications

The uncooled thermal imagers are lightweight, cost effective and consume very less power compared to cooled thermal imagers as these can be operated at room temperature. It is a cost-effective solution for application like helmet-mounted thermal imager (HMTI), driver sights for AFVs, etc. The system is based on third-generation amorphous silicon μ-bolometer FPA in the format of 320 × 240. Specifications of HMTI developed in IRDE are given in Table 9. Configuration of HMTI, display and battery is shown in Fig. 11.

4.5.4 Weapon-mounted Thermal Sight (Uncooled)

It is an uncooled cost effective solution and may be used with rifle or any other weapon. The system is based on third-generation amorphous

Table 9. Specification for uncooled helmet-mounted thermal imager

Detector type	Uncooled microbolometer (320 × 240)
Spectral Response	8-14 μm
FOV	45° × 34°
Power	6 W typical
Battery operation time	90 min
Range	50 mts. For human target
Display	OLED display, CCIR-B-compatible
Weight	≤ 1.2 kg (with battery)

Silicon μ-bolometer FPA in the format of 320 × 240. Specifications of weapon-mounted thermal sight (WMTS) developed in IRDE are given in Table 10. ConFiguration of WMTS, display and battery is shown in Fig. 12.

Table 10. Specification for uncooled weapon-mounted thermal sight

Detector type	Uncooled microbolometer (320 × 240)
Spectral response	8–14 μm
FOV	13.8° × 10.3°
Power	7 W typical
Battery operation time	90 min
Range	300 m. For group of persons
Display	OLED display, CCIR-B-compatible
Weight	≤ 1.4 kg (with battery)

4.5.5 Long-range Thermal Imager

Long-range thermal imager (LRTI) is also based on third-generation staring 320 × 240 *InSb* FPAs. This sight can be used for naval applications where

Figure 11. Helmet-mounted thermal imager and the image.

Figure 12. Weapon-mounted thermal sight and the image frames.

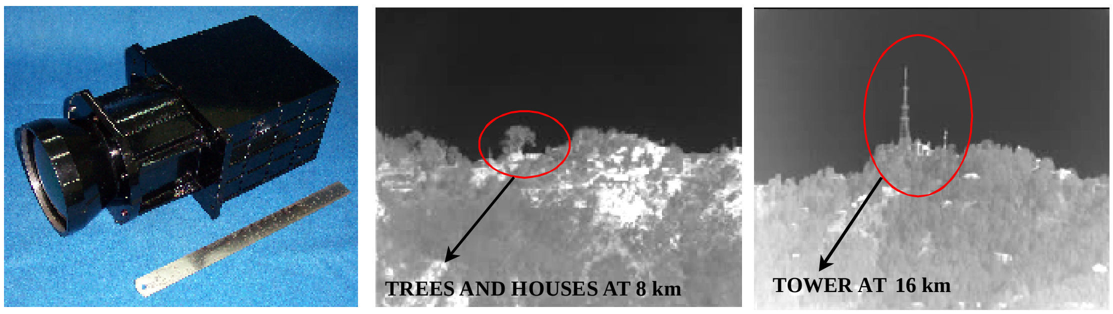

Figure 13. Long-range thermal imager and image frames

longer detection and recognition ranges are required. Specifications of LRTI are given in Table 11 and photograph and images of LRTI developed at IRDE is shown in Fig. 13.

Table 11. Specifications for long-range thermal imager

Spectral range	3-5 µm
FOV	
Narrow	$1.5^\circ \times 1.1^\circ$
Wide	$8.0^\circ \times 6.0^\circ$
E–Zoom	×2
Detector	*InSb* FPA 320 × 240
Cooler	Integrated stirling rotary microcooler
Video O/P	CCIR 625 lines, 50 Hz
Power supply	24 V dc
Reliability	MTBF > 2000 h
Range (Target: 60 m × 10 m) (ΔT=6 °C, V=10 km, T=27 °C, RH=85 %)	Detection: > 20 km Recognition: >15 km

5. CONCLUSION

With the developments enumerated, IRDE, Dehradun, has developed expertise in the design and development, performance modelling, and evaluation of different generations of thermal imaging systems for various imaging and non-imaging applications.

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