Hanwha Vision

White Paper

Thermal Image Camera

March 19th 2024

Contents

1 Introduction

1.1 The Role of Thermal Image Cameras in the Video Surveillance Market

Cameras have progressed to the point that their performance surpasses the capabilities of human sight. Video surveillance camera technology has continuously evolved allowing observation with greater precision and range, aligning with their specialized objectives. Beyond maintaining consistent performance video surveillance across various environments and conditions, recent advancements fuse AI into video analysis, propelling the market toward technologies that offer users more efficient and meaningful information.

Furthermore, thermal image cameras, traditionally utilized for military and specialized applications in environments where surveillance is challenging for optical cameras, have gradually secured their position in the general video security market in recent years. Empowered by advancements in semiconductor and MEMS technologies, thermal imaging has experienced rapid growth since the 2000s as sensor and image processing technology advancements supplement previously insurmountable challenges of thermal image cameras. As the video security market continues to expand and the demand for industrial automation increases, coupled with contemporary circumstances like the COVID-19 pandemic, the demand for thermal image cameras is forecasted to grow.

1.2 Contents that will be covered

This white paper aims to explore the utilization of thermal image cameras in the video surveillance market through thermal imaging inspection and analysis based on an explanation of thermal imaging processing using infrared and infrared sensors. It also intends to delve into more effective methods for utilizing thermal image cameras. The content will be covered broadly divided into three main sections:

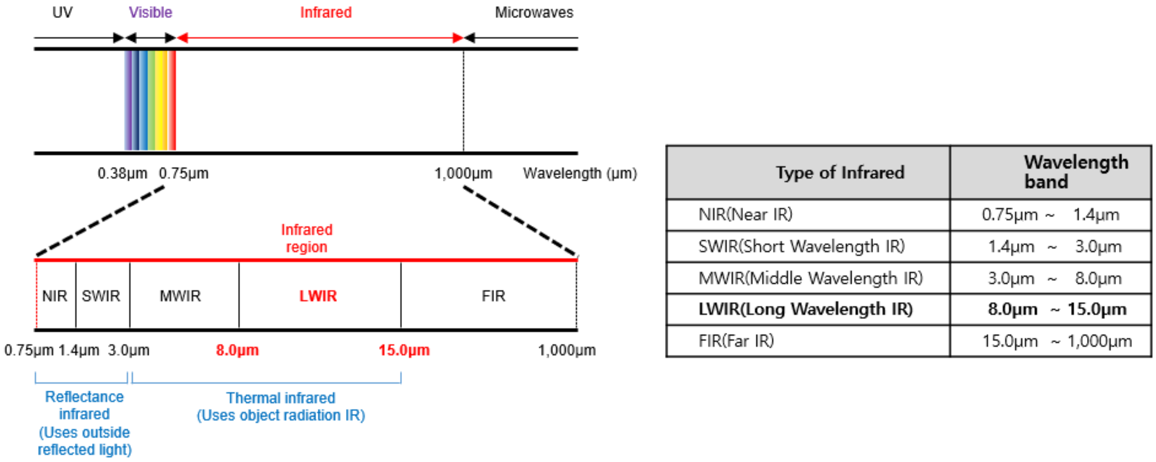
① Understanding Thermal Image Sensors
② Types and Features of Thermal Image Camera Solutions
③ Considerations for Thermal Camera Image Installation and Operation

2 Understanding Thermal Image Sensors

2.1 Infrared Spectrum and Infrared Sensors

The infrared (IR) region, within the electromagnetic spectrum, covers wavelengths ranging from 0.75μm to 1,000μm, as shown in Figure 1. Infrared radiation exhibits distinct characteristics across these wavelength ranges, thus categorized into near-infrared (NIR), short-wavelength infrared (SWIR), middle-wavelength infrared (MWIR), long-wavelength infrared (LWIR), and far-infrared (FIR). Although classification criteria vary among organizations such as the International Organization for Standardization (ISO) and the International Commission on Illumination (CIE), the criteria depicted in Figure 1 are commonly used.

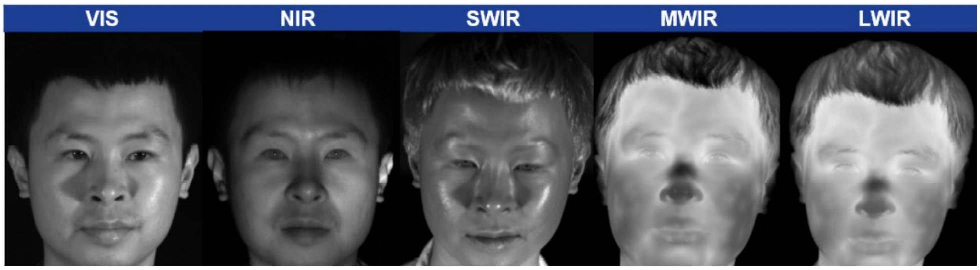
Applications utilizing NIR and SWIR regions mostly leverage light reflected by objects. Therefore, they are termed as reflected infrared (Reflected IR). Applications utilizing MWIR and LWIR regions leverage the infrared radiation emitted from objects. Therefore, MWIR and LWIR are also called thermal infrared (Thermal IR).



Type of Infrared	Wavelength band
NIR(Near IR)	0.75μm ~ 1.4μm
SWIR(Short Wavelength IR)	1.4μm ~ 3.0μm
MWIR(Middle Wavelength IR)	3.0μm ~ 8.0μm
LWIR(Long Wavelength IR)	**8.0μm ~ 15.0μm**
FIR(Far IR)	15.0μm ~ 1,000μm

[Figure 1. Infrared region in electromagnetic wave]

Figure 2 below illustrates the differences in images of an object obtained using visible light and infrared. NIR and SWIR utilize light reflected similarly to visible light, and the images look similar to the visible image. Conversely, MWIR and LWIR, utilizing infrared radiation emitted from the object, which is the skin surface here, showcase noticeable differences with the visible image. (Source: Shuowen Hu et al., 2017)



[Figure 2. A comparison between visible light and infrared imagery of an object]

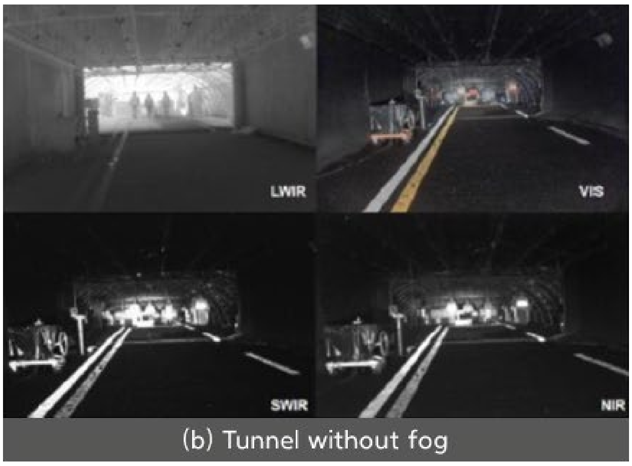
Like visible light imagery, SWIR cameras acquire images through reflected light from objects. Recent production of sensors utilizing uncooled methods with InGaAs semiconductor material suggests an anticipated reduction in sensor costs. However, SWIR cameras remain relatively expensive compared to MWIR and LWIR sensors. SWIR cameras have the advantage of acquiring images during the day and on starlit nights and can penetrate glass and clouds to acquire images. SWIR cameras are used in agricultural produce identification and sorting, electronic board inspection, solar panel examination, and anti-counterfeiting measures.

MWIR cameras, like LWIR cameras, acquire images using the infrared radiation emitted from objects. Compared to SWIR, MWIR is less affected by scattering in the atmosphere, experiencing less impact from smoke, dust, or fog. Besides military purposes, MWIR cameras are used to detect specific gases like methane, propane, ethanol, and sulfur hexafluoride.

LWIR cameras, like MWIR cameras, acquire images using the infrared radiation emitted from objects. LWIR cameras are most commonly used as visual security surveillance systems. This is not only due to the reduced costs in comparison to other infrared sensors, resulting from advancements in manufacturing technologies utilizing thermal materials like vanadium oxide (VOx) or amorphous silicon (α-Si) in MEMS production, alongside the widespread use of uncooled sensor technology. Additionally, LWIR cameras demonstrate superior performance in demanding conditions for visible light cameras, including low-light-level scenarios and environments affected by smoke, fog, dust, rain, and limited visibility.

Figure 3 below compares images acquired using visible light, NIR, SWIR, and LWIR under various conditions. In daylight conditions (Figure a), images from visible light, NIR, and SWIR show excellence compared to LWIR imagery. However, in dark tunnels (Figure b) or situations with a thick fog and a strong headlamp of a vehicle (Figure c), LWIR imagery shows the highest quality. Figure b shows that detecting pedestrians in entirely dark environments is achievable solely through LWIR cameras. Similarly, as shown in Figure c, when vehicle headlamps are on in a thick fog environment, detecting pedestrians without missing is possible through the LWIR camera (Source: N. Pinchon et al. 2018).

(a) Interstate highway image

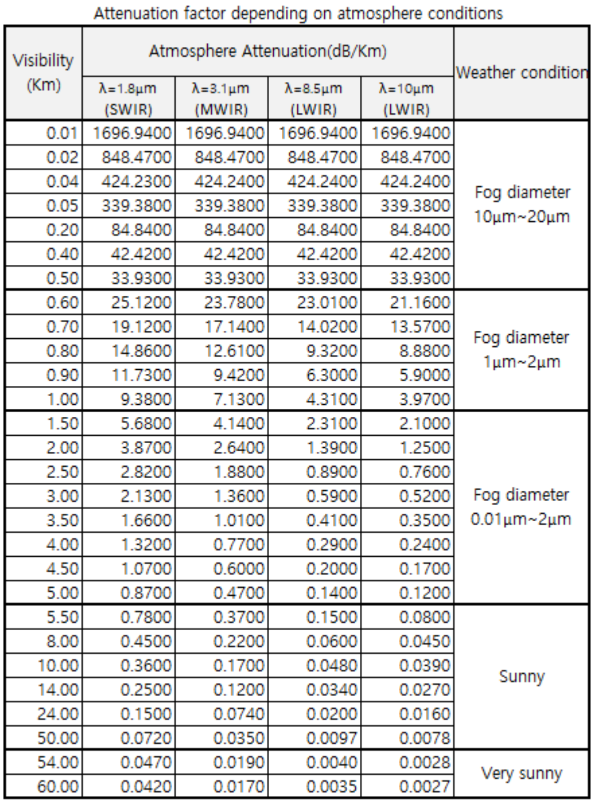


(b) Tunnel without fog

(c) Headlamps on in a tunnel with fog

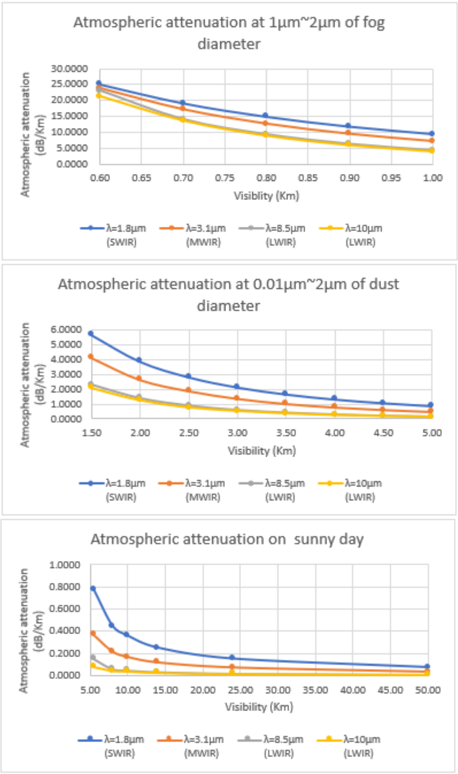
[Figure 3. A comparison of the images in various conditions]

The table shows the superficial characteristics of LWIR cameras compared to other spectral cameras in conditions such as fog/smoke/dust. Table 1 represents the attenuation factor of wavelengths through an empirical formula depending on atmospheric conditions. When fog diameter ranges from 10μm to 20μm, LWIR cameras exhibit attenuation characteristics similar to other cameras, making it challenging to acquire clear images even when using LWIR cameras. However, LWIR cameras are less affected by fog with smaller diameters or particle dust in atmospheric conditions, allowing for clear images compared to other infrared cameras (Yongtaek Jeong, “Latest Technology Trends in Infrared Sensor”, Hongneung Science Publishing, 2014).



Attenuation factor depending on atmosphere conditions

Visibility (Km)	Atmosphere Attenuation(dB/Km)				Weather condition
	λ=1.8µm (SWIR)	λ=3.1µm (MWIR)	λ=8.5µm (LWIR)	λ=10µm (LWIR)	
0.01	1696.9400	1696.9400	1696.9400	1696.9400	Fog diameter 10µm~20µm
0.02	848.4700	848.4700	848.4700	848.4700	
0.04	424.2300	424.2400	424.2400	424.2400	
0.05	339.3800	339.3800	339.3800	339.3800	
0.20	84.8400	84.8400	84.8400	84.8400	
0.40	42.4200	42.4200	42.4200	42.4200	
0.50	33.9300	33.9300	33.9300	33.9300	
0.60	25.1200	23.7800	23.0100	21.1600	Fog diameter 1µm~2µm
0.70	19.1200	17.1400	14.0200	13.5700	
0.80	14.8600	12.6100	9.3200	8.8800	
0.90	11.7300	9.4200	6.3000	5.9000	
1.00	9.3800	7.1300	4.3100	3.9700	
1.50	5.6800	4.1400	2.3100	2.1000	Fog diameter 0.01µm~2µm
2.00	3.8700	2.6400	1.3900	1.2500	
2.50	2.8200	1.8800	0.8900	0.7600	
3.00	2.1300	1.3600	0.5900	0.5200	
3.50	1.6600	1.0100	0.4100	0.3500	
4.00	1.3200	0.7700	0.2900	0.2400	
4.50	1.0700	0.6000	0.2000	0.1700	
5.00	0.8700	0.4700	0.1400	0.1200	
5.50	0.7800	0.3700	0.1500	0.0800	Sunny
8.00	0.4500	0.2200	0.0600	0.0450	
10.00	0.3600	0.1700	0.0480	0.0390	
14.00	0.2500	0.1200	0.0340	0.0270	
24.00	0.1500	0.0740	0.0200	0.0160	
50.00	0.0720	0.0350	0.0097	0.0078	
54.00	0.0470	0.0190	0.0040	0.0028	Very sunny
60.00	0.0420	0.0170	0.0035	0.0027	



[Table 1. Attenuation factor depending on atmospheric conditions]

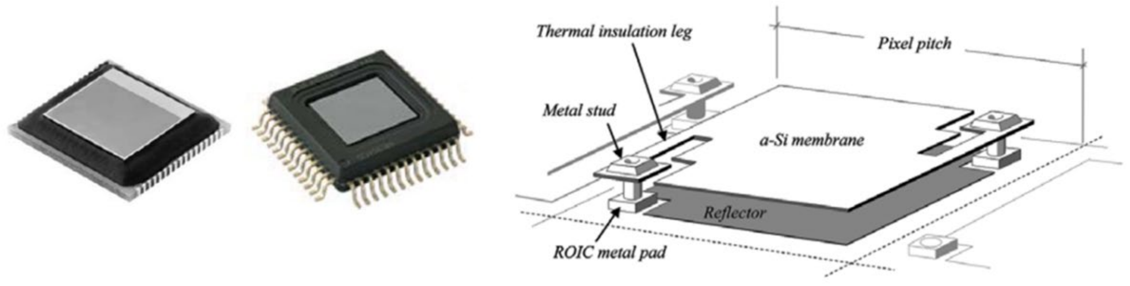
2.2 Image processing using thermal imaging sensor

In our earlier discussion, we examined the characteristics of three types of infrared cameras: SWIR, MWIR, and LWIR. We explained why LWIR wavelengths are commonly used in surveillance cameras for image security. From this point forward, we will refer to the microbolometer thermal sensors detecting infrared signals in the LWIR spectrum as "thermal imaging sensors" and the cameras utilizing these as "thermal imaging cameras".

2.2.1 Thermal Imaging Sensor

Objects with temperatures above absolute temperature 0K (Kelvin) emit energy in the form of infrared radiation. Measuring infrared means gauging an object's radiant energy, something akin to the concept of measuring its temperature. Sensors that enable measuring infrared can be classified into two types: quantum sensors utilizing semiconductor materials and thermal sensors employing non-semiconductor materials. This section focuses on bolometer sensors, a type of thermal sensor mainly used in image security surveillance among various infrared sensors. The term "bolometer" stems from the Greek words "bolo," meaning ray, and "meter," denoting measurement, encapsulating the essence of measuring infrared—bolometers function based on altering internal resistance when infrared intensity or exposure to temperature changes. Hence, the performance of thermal imaging sensors is determined by the efficiency and characteristics of two processes: temperature rise due to incident infrared radiation and electrical changes resulting from temperature variations. As MEM processes have been developed, high-resolution microbolometers have been used in general thermal imaging cameras.

Figure 4 shows the internal-external structure view of the thermal imaging sensor of the general microbolometer type (Source: J.L. Tissot et al. 2013).



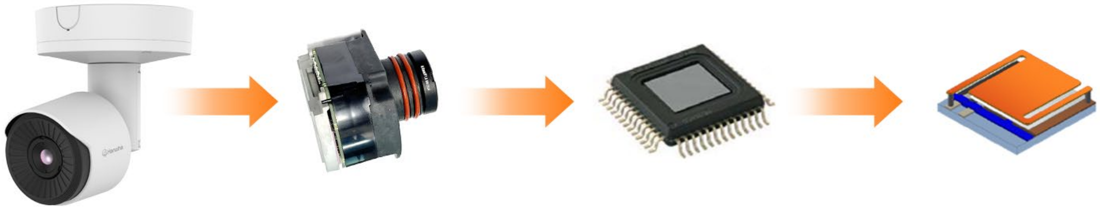
(a) External of a themal imaging sensor (b) Internal structure of α–Si thermal imaging sensor

[Figure 4. External and structure of a thermal imaging sensor]

When infrared radiation strikes the bolometer, it absorbs the radiation, causing a rise in the temperature of the thermally isolated membrane's resistor. The temperature change in the resistor varies depending on the amount of absorbed infrared radiation. The fill factor is the pixel area used to absorb incident infrared radiation, typically having around 80% fill factor per pixel. To enhance the absorption of LWIR infrared radiation, a resonant cavity of λ/4 is utilized between the membrane and the reflector. Thermal isolation legs, made of materials with low thermal conductivity, are designed to minimize the influence of ambient temperature on the bolometer. These legs connect the Focal Plane Array (FPA) to the Readout Integrated Circuit (ROIC) and regulate the gap width between the membrane and the reflector. The ROIC, acting as a multiplexer, connects to the FPA sensor, reads the electrical outputs from individual resistance changes, and amplifies small signals into measurable high-output voltages.

2.2.2 Thermal imaging camera using thermal imaging sensor

The structure of the general thermal imaging camera using a thermal imaging sensor is shown in Figure 5. Thermal imaging cameras can be divided into the detector and HW modules.



[Figure 5. Structure of a thermal imaging camera]

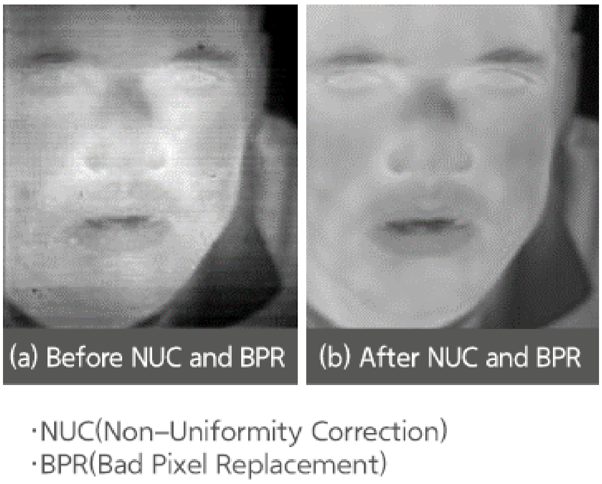
The detector comprises an optical lens and a sensor that detects intense infrared radiation, producing corresponding electrical signals. The lenses typically employ germanium (Ge) in thermal imaging cameras to facilitate efficient infrared transmission. The HW module segment comprises components capable of processing electrical signals input from the detector, such as an image processing unit (utilizing FPGA or DSP), an image output unit, and power circuits. Various image processing techniques are implemented within the image processing unit to render thermal images with greater clarity.

Unlike CMOS sensors, one essential image processing step in thermal imaging sensors is Non-Uniformity Correction (NUC). The FPA structure of thermal imaging sensors encounters non-uniformity issues due to the following three factors:

① Nonlinear characteristics of each pixel regarding the intensity of infrared radiation
② Non-uniform characteristics of pixel-to-pixel gain and offset values
③ Nonlinear variations in offset values over time and installation space

Addressing these issues involves performing the NUC process.

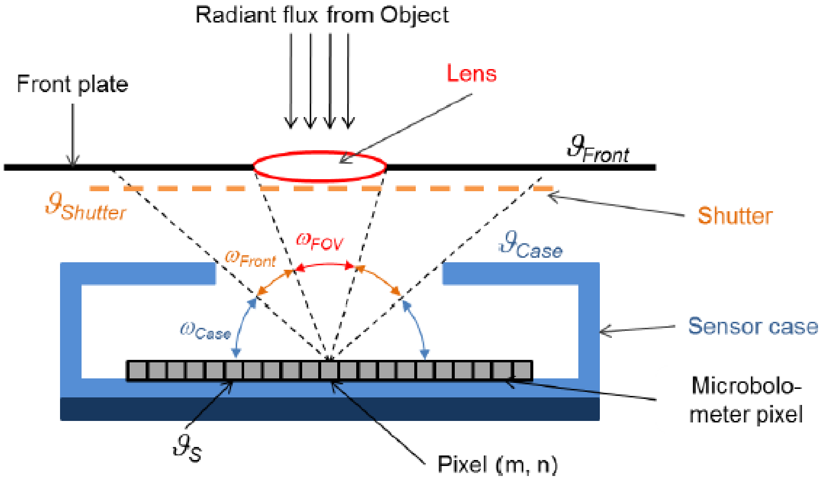
Figure 6 demonstrates the necessity of the NUC process by comparing images before and after NUC. If the disparities between each pixel are not corrected through the NUC process, as depicted in (a), Fixed Pattern Noise (FPN) becomes visible, resulting in unclear images. However, high-quality images can be obtained following the NUC process, as shown in (b) (Source: Vladimir I. Ovod et al. 2005).


(a) Before NUC and BPR
(b) After NUC and BPR

·NUC(Non-Uniformity Correction)
·BPR(Bad Pixel Replacement)

[Figure 6. Comparison image before and after NUC]

Understanding the detector of the thermal imaging camera is required to understand NUC processes. Figure 7 shows the brief structure of the detector.

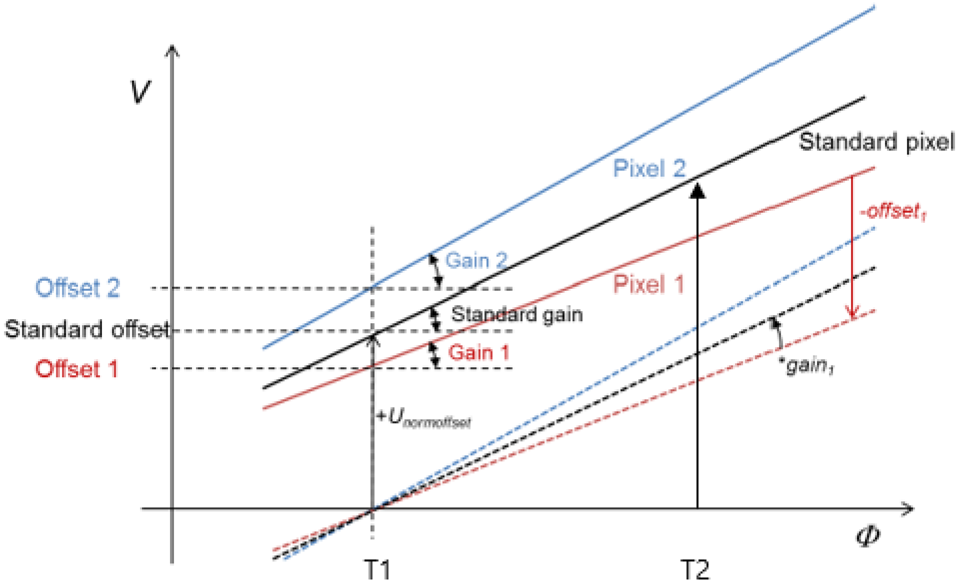


[Figure 7. The structure of the detector of the thermal imaging camera]

As shown in the figure above, the sensor's pixels receive infrared radiation from various sources: emitted from the object, the front housing, the shutter, the casing enveloping the sensor, and the sensor itself. The following method can be employed to measure the infrared quantity emitted by the object exclusively.

The sensor's output responds to the incident infrared radiation and shifts in its temperature. Therefore, when the sensor maintains a consistent temperature (thermal equilibrium), any changes in its output solely reflect variations in the incident infrared radiation. Achieving this involves initially stabilizing the sensor's temperature. Then, by sequentially adjusting the temperatures of two objects, T1 and T2 (where T1 < T2), capturing images, and recording the sensor's output values, we can isolate the infrared quantity emitted by the object alone. Subtracting the output value at T1 from that at T2 removes the influence of other infrared sources, revealing the specific infrared quantity emitted by the object. This process enables the determination of the 2-point NUC gain and offset, which is crucial for rectifying differences among pixels within the thermal imaging sensor's FPA structure.

Figure 8 illustrates the process of determining the gain and offset for two pixels, 1 and 2, to exhibit the characteristics of a standard curve. After setting the temperature of the blackbody to T1 and T2, the average value for all pixels is calculated, establishing it as the standard curve. Subsequently, through computation, the gain and offset for each pixel are adjusted to align their values with the characteristics of this standard curve. This procedure allows pixels that initially display distinct differences to demonstrate a consistent output resembling the standard curve (Source: H. Budzier and G. Gerlach, 2015).



[Figure 8. Schematic for obtaining 2-point NUC Gain and Offset]

2.3 Specifications terminology for understanding thermal imaging sensors

- Pixel Pitch: It represents the size of each pixel composing the Focal Plane Array (FPA) of the thermal imaging sensor. In thermal imaging cameras, the pixel pitch commonly used in thermal sensors is typically 17μm or 12μm.

- Spectral Response: It indicates the range of wavelengths of electromagnetic waves to which the thermal imaging sensor responds. For thermal imaging sensors mainly used in thermal imaging cameras, the wavelength range is usually between 8μm to 14μm.

- Resolution: Resolution indicates how finely an image converted through a thermal imaging sensor can be divided into smaller units known as pixels. The typical resolutions for thermal imaging cameras used for image security are commonly QVGA (320x240) or VGA (640x480). Recently, there has been a growing trend in the market for thermal imaging cameras with resolutions of XGA (1024x768) and SXGA (1280x1024).

- NETD (Noise Equivalent Temperature Difference): This indicates the temperature resolution of a thermal imaging sensor. Considering the noise, it signifies the minimum temperature difference the camera can distinguish. A smaller value indicates better temperature resolution, while a more significant value signifies poorer temperature resolution.

- NEDT(Noise Equivalent Differential Temperature): The same terminology applies to NETD

- NUC (Non-Uniformity Correction): Correction is the process of eliminating output variations between pixels within an FPA-type thermal imaging sensor to achieve consistent output characteristics. Typically, linear correction methods are employed using either a single reference point or two reference points. This correction ensures that each pixel is adjusted to have identical gain and offset, resulting in high-quality images.

- 2-Point NUC: 2-Point NUC is a method to correct discrepancies between pixels using two reference temperatures. During the manufacturing phase of thermal imaging cameras, this correction is performed using two blackbody references. The correction values obtained during this process are stored in memory and applied during camera operation.

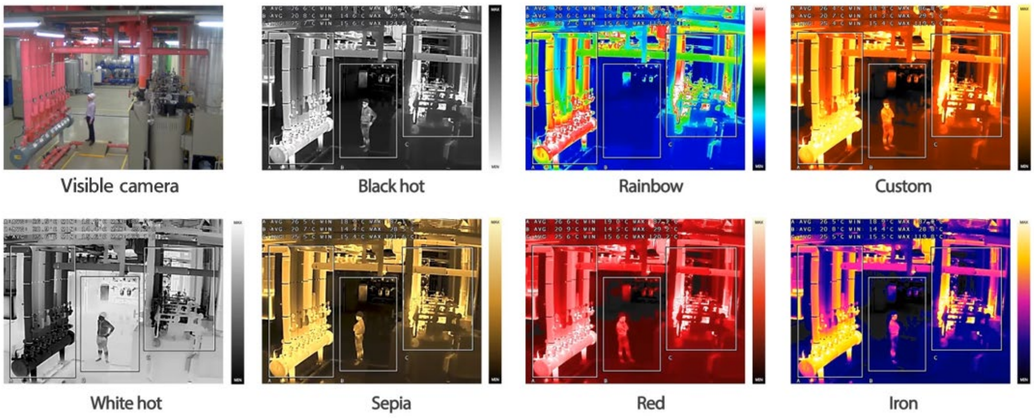
- 1-Point NUC: The NUC method uses one reference temperature to correct differences between pixels. The shutter installed in front of the lens is the reference temperature. To perform 1-Point NUC, the shutter is shut, and the offset adjustment for each pixel relies on the temperature detected on the surface of the shutter. During the shutter closure, the image acquired corresponds to the moment just before the shutter closes, resulting in the drawback of interrupted continuous image output. However, for obtaining high-quality images reflecting real-time temperature changes at the location of the thermal imaging camera, 1-Point NUC is necessary.

- NUC cycle: 2-Point NUC is performed during manufacturing processes, and its resulting values (gain and offset) are stored in memory, requiring execution only once. On the other hand, 1-Point NUC is conducted regularly to appropriately account for temperature fluctuations near the installed thermal imaging camera. In environments with minimal temperature variation around the operational thermal imaging camera, the frequency of 1-Point NUC execution can be extended. Within the thermal camera's settings menu, there is an option to adjust the frequency of 1-Point NUC according to specific requirements.

- Dead Pixel: Also known as a "Bad Pixel," a dead pixel refers to a pixel within the Focal Plane Array (FPA) that responds differently than the average output characteristics of the other pixels. The criteria for identifying dead pixels may vary among manufacturers. Given the inevitable presence of dead pixels in FPA-structured thermal imaging sensors during production, thermal sensor manufacturers provide specifications that include the coordinates of dead pixels upon delivery of the thermal sensor. These known dead pixels, identified during the manufacturing phase of thermal camera production, are rectified through image processing techniques to ensure normal thermal imaging output. Post-delivery, any dead pixels that occur during usage are monitored in real-time during the 1-Point NUC process and corrected to ensure they do not affect the thermal images.

- Color Palettes: The infrared radiation received by the thermal imaging sensor from the object can be represented in various colors according to the internal image processing, allowing for customized visualization. Depending on the environment, the system supports the selection of desired color palettes to facilitate optimal image surveillance. However, please note that the colors and types of the color palette are subject to modification or addition without prior notice.

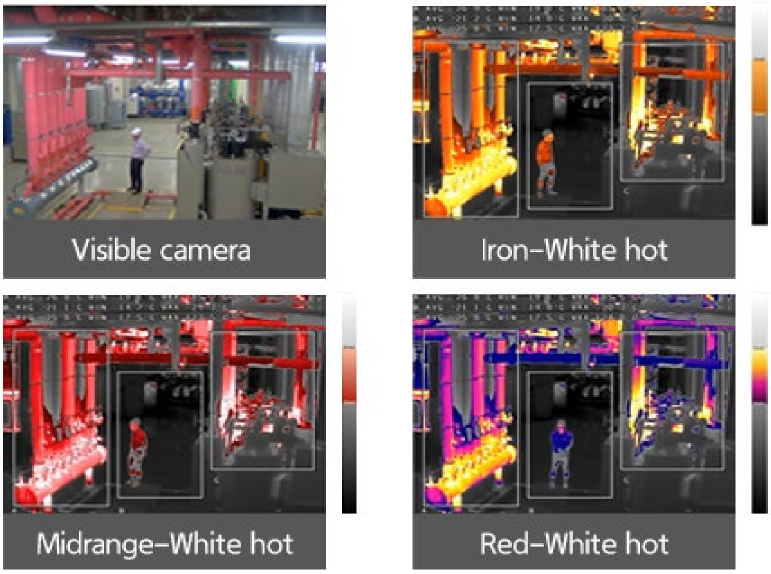
Figure 9 shows all kinds of default palette modes.


Visible camera Black hot Rainbow Custom

White hot Sepia Red Iron

[Figure 9. Default color palette modes]

Figure 10 illustrates an example of the hybrid palette configuration. The hybrid palette is a useful feature for efficient monitoring, emphasizing objects within specific temperature ranges by assigning colors only to objects within the desired temperature range of interest. Figure 10 shows that objects falling within the specified temperature range are displayed according to the selected type of hybrid palette configuration.



Visible camera

Iron–White hot

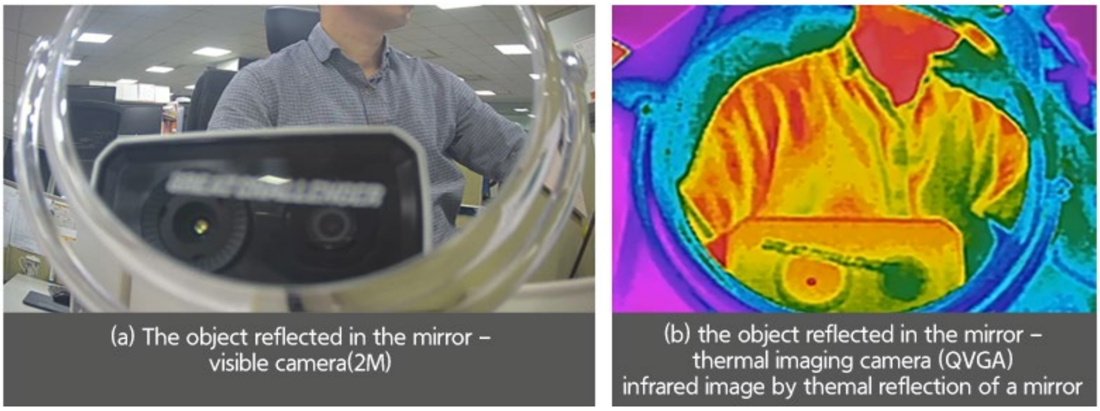
Midrange–White hot

Red–White hot

[Figure 10. The hybrid palette modes]

- The reflection of infrared radiation occurs readily on glass, metal, or smooth surfaces due to ambient heat sources. This thermal reflection is a factor that requires attention in the interpretation of thermal infrared imaging.

Figure 11 illustrates how thermal infrared imaging appears due to thermal reflection. The images below show the actual image (a) and the thermal image (b) of a subject reflected in a mirror, obtained after adjusting the angle of view similarly. In (b), it's evident that the mirror reflects the infrared radiation emitted by the subject.



(a) The object reflected in the mirror – visible camera(2M)

(b) the object reflected in the mirror – thermal imaging camera (QVGA) infrared image by themal reflection of a mirror

[Figure 11. Infrared thermal images by thermal reflection]

In real thermal image analysis, it's crucial not to interpret as there are actual heat sources by thermal reflections.

- Time to Stabilization: The thermal imaging sensor's output is influenced by both the incoming infrared intensity and its internal temperature.

Consequently, thermal imaging cameras need time to stabilize after powering up, allowing the sensor to reach thermal equilibrium. During this stabilization period, the 1-Point NUC using the shutter is executed more frequently to calibrate the sensor correctly. Consequently, temperature measurements or detection operations may lack accuracy until the thermal sensor attains stability. The duration needed for stabilization fluctuates depending on the ambient temperature conditions of the thermal camera, generally averaging around 30 minutes.

- IFoV: The abbreviation for "Instantaneous Field of View" IFoV indicates the spatial resolution of a thermal imaging camera. While the FoV represents the overall image area detected based on the optical system's field of view in a thermal imaging camera, the IFoV denotes the degree to which a single pixel of the thermal imaging sensor geometrically resolves or observes a target within the field of view (FoV) and can detect temperature. In simple terms, IFoV is the smallest target size a thermal imaging camera can identify under the given lens, sensor size, and distance conditions. It's expressed in milliradians, and as the view angle narrows and the camera's resolution increases, the IFoV value decreases. IFoV is typically calculated using the following two equations.

① IFoV(mRad) = [pixel pitch(mm)] / lens focal length(mm) x 1000

② IFoV(mRad) = FOV(degrees) / Pixel x (π/180) x 1000

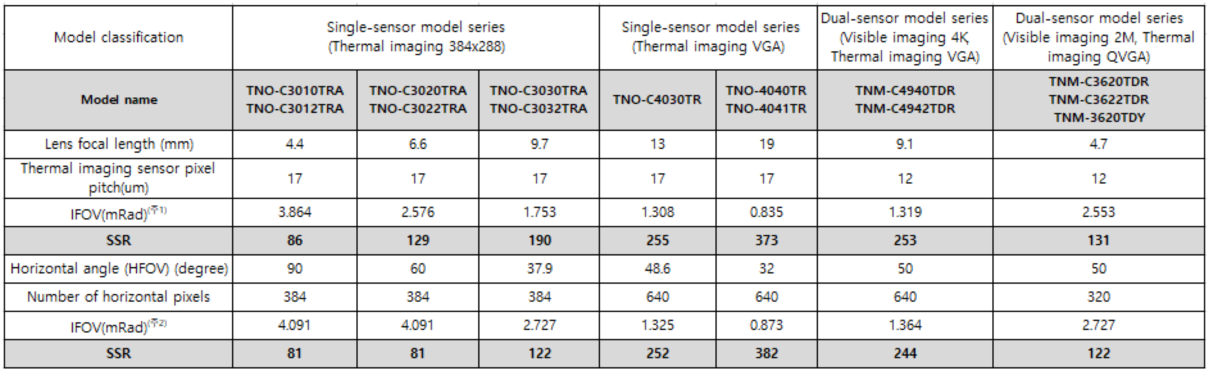
For instance, in the case of a thermal imaging camera with a pixel pitch of 17 μm and a focal length of 4.4 mm, the IFoV is 3.9 mRad. This means that at a distance of 1 meter, the smallest object size capable of being measured for temperature by a single pixel is a square with sides measuring 3.9 mm. At a distance of 10 meters, the minimum size becomes a square with sides measuring 39 mm.

However, this represents the theoretical minimum value. When using a thermal imaging camera to measure temperature, it's advisable to consider practical factors like dead pixels on the sensor and thermal reflections near the target. Therefore, it is recommended to consider a minimum of 3x3 pixels in practical scenarios, considering the target size and the detection distance when selecting an appropriate camera.

- SSR(Spot Size Ratio): To measure the temperature of an object using a thermal imaging camera, consideration of the target's size and detection distance is necessary. Theoretically, temperature measurement becomes feasible if the object is mapped to a single pixel of the thermal imaging sensor. However, relying solely on a single pixel value to measure the object's temperature can lead to misinterpretation. Therefore, temperature measurement is conducted in practice because the object matches 3x3 pixels.

SSR = Detection distance(m) / (IFOV x 3)

The relationship between the distance at which an object of 1 meter in size is mapped to 3x3 pixels of the thermal imaging sensor is illustrated in Table 2 as follows.



Model classification	Single-sensor model series (Thermal imaging 384x288)			Single-sensor model series (Thermal imaging VGA)		Dual-sensor model series (Visible imaging 4K, Thermal imaging VGA)	Dual-sensor model series (Visible imaging 2M, Thermal imaging QVGA)
Model name	**TNO-C3010TRA TNO-C3012TRA**	**TNO-C3020TRA TNO-C3022TRA**	**TNO-C3030TRA TNO-C3032TRA**	**TNO-C4030TR**	**TNO-4040TR TNO-4041TR**	**TNM-C4940TDR TNM-C4942TDR**	**TNM-C3620TDR TNM-C3622TDR TNM-3620TDY**
Lens focal length (mm)	4.4	6.6	9.7	13	19	9.1	4.7
Thermal imaging sensor pixel pitch(um)	17	17	17	17	17	12	12
IFOV(mRad)(주1)	3.864	2.576	1.753	1.308	0.835	1.319	2.553
SSR	**86**	**129**	**190**	**255**	**373**	**253**	**131**
Horizontal angle (HFOV) (degree)	90	60	37.9	48.6	32	50	50
Number of horizontal pixels	384	384	384	640	640	640	320
IFOV(mRad)(주2)	4.091	4.091	2.727	1.325	0.873	1.364	2.727
SSR	**81**	**81**	**122**	**252**	**382**	**244**	**122**

[Table 2. SSR calculated value of thermal imaging cameras]

For example, using the TNO-C3030TRA, if a 1-meter object's temperature needs to be measured, it should be within 190 meters for the object's temperature measurement. Utilizing this relationship, to measure the temperature of a 2-meter object, it needs to be within 380 meters for the object's temperature to be measurable.

However, using a thermal imaging camera, SSR represents the theoretically calculated maximum distance for temperature measurement. It is crucial to consider environmental factors (ambient temperature, temperature, relative humidity, etc.), object emissivity, camera installation angles, etc., as these can affect the measurement distance.

3 Characteristics and types of thermal imaging camera solutions

Hanwha Vision has developed a diverse lineup of multiple thermal imaging camera models with various resolutions and form factors to provide customers with thermal imaging cameras tailored to their needs. Figure 12 shows images of some of the currently released models of Hanwha Vision's thermal imaging cameras.

(Note 1) IFoV(mRad) = [pixel pitch(mm)] / Lens focal length(mm) x 1000, when using relation rules

(Note 2) IFoV(mRad) = FOV(degrees) / Number of pixel x (π/180) x 1000, when using relation rules

[Figure 12. Thermal imaging camera model of Hanwha Vision]

3.1 Thermal Imaging Camera Classification

3.1.1 Temperature Detection and Display Models

Thermal imaging cameras are generally divided into two main types: temperature detection models and temperature display models known as radiometric camera models. Both perform an internal process that involves measuring absorbed infrared radiation and converting it into temperature data. However, temperature detection models don't directly show the measured temperature to the user; instead, they indicate changes within the specified area of interest. Users can set up alarm triggers based on the area's maximum, minimum, or average temperatures. In contrast, temperature display models perform temperature detection and present the converted temperature values directly to the user for observation.

3.1.2 Single Sensor and Dual Sensor Models

Thermal imaging cameras are designed to overcome the limitations of visible cameras in challenging conditions like fog, smoke, dust, rain, snow, or low light, where visible cameras fail to perform properly. Despite considerable improvements in thermal imaging camera resolution over time, they might not match the image clarity of visible cameras in general situations. Consequently, there's a rising interest in the surveillance market for camera models integrating two sensors within a single unit to harness the advantages of both camera types.

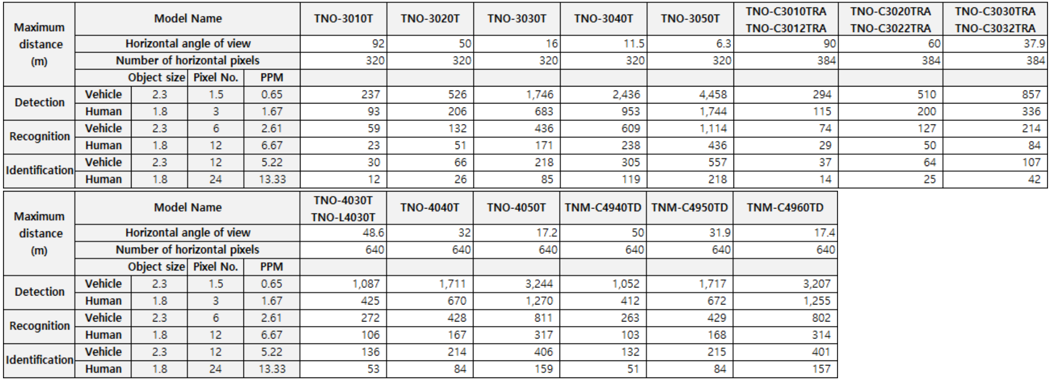
3.2 Main characteristics of thermal imaging cameras

3.2.1 Detection-Recognition-Identification Distance of Thermal Imaging Cameras

Thermal imaging cameras employ the detection, recognition, and identification (DRI) method to measure the distance at which targets can be identified. The DRI (Detection, Recognition, Identification) standard, coined by the US Army in the 1950s, is defined as follows:

- Detection: Ability to distinguish the object from the background
- Recognition: Capability to classify the object type (animal, human, vehicle, boat, etc.)
- Identification: Ability to discern specific details of the object (a man wearing a hat, a dog, a jeep, etc.)

Table 3 presents the calculated value of the thermal imaging camera DRI distance depending on models using the calculation formula.



Maximum distance (m)	Model Name				TNO-3010T	TNO-3020T	TNO-3030T	TNO-3040T	TNO-3050T	TNO-C3010TRA TNO-C3012TRA	TNO-C3020TRA TNO-C3022TRA	TNO-C3030TRA TNO-C3032TRA
	Horizontal angle of view				92	50	16	11.5	6.3	90	60	37.9
	Number of horizontal pixels				320	320	320	320	320	384	384	384
		Object size	Pixel No.	PPM								
Detection	Vehicle	2.3	1.5	0.65	237	526	1,746	2,436	4,458	294	510	857
	Human	1.8	3	1.67	93	206	683	953	1,744	115	200	336
Recognition	Vehicle	2.3	6	2.61	59	132	436	609	1,114	74	127	214
	Human	1.8	12	6.67	23	51	171	238	436	29	50	84
Identification	Vehicle	2.3	12	5.22	30	66	218	305	557	37	64	107
	Human	1.8	24	13.33	12	26	85	119	218	14	25	42

Maximum distance (m)	Model Name				TNO-4030T TNO-L4030T	TNO-4040T	TNO-4050T	TNM-C4940TD	TNM-C4950TD	TNM-C4960TD
	Horizontal angle of view				48.6	32	17.2	50	31.9	17.4
	Number of horizontal pixels				640	640	640	640	640	640
		Object size	Pixel No.	PPM						
Detection	Vehicle	2.3	1.5	0.65	1,087	1,711	3,244	1,052	1,717	3,207
	Human	1.8	3	1.67	425	670	1,270	412	672	1,255
Recognition	Vehicle	2.3	6	2.61	272	428	811	263	429	802
	Human	1.8	12	6.67	106	167	317	103	168	314
Identification	Vehicle	2.3	12	5.22	136	214	406	132	215	401
	Human	1.8	24	13.33	53	84	159	51	84	157

[Table 3. DRI distance calculated table depending on thermal imaging cameras]

The DRI calculation formula is as follows:

DRI range: distance= (Lens focal length) x (object size) / {(Number of Pixel) x (Pixel Pitch)}

However, when using a thermal imaging camera, it's essential to consider the camera's DRI and the detection range when using Video Analytics. The detection range of a thermal imaging camera can be influenced by the temperature of the target object and environmental factors such as humidity, potentially shortening the actual detection distance. Therefore, validating this through Proof of Concept (PoC) in the installation environment is recommended.

Table 4 represents the detection range of video analytics for single-sensor thermal imaging camera models. This represents the theoretical maximum under limited conditions; however, it's crucial to consider that the actual detection range may vary due to the influence of target objects and the surrounding environment during practical use.

Motion Detection Range		TNO-4030T	TNO-4040T	TNO-4050T	TNO-3010T	TNO-3020T	TNO-3030T	TNO-3040T	TNO-3050T
Vehicle	2.3m	160m	234m	430m	86m	150m	438m	607m	1,118m
Human	1.8m	125m	183m	337m	41m	71m	206m	285m	525m

[Table 4. Video Analytics detection range of thermal imaging cameras]

Table 5 represents the measured values of the AI video analytics detection range using the dual-sensor camera model TNM-C49x0TD (x=4,5,6). These measurements were taken under limited conditions; it's essential always to consider that the detected range may vary depending on the environment where the camera is installed and the condition of the target object.

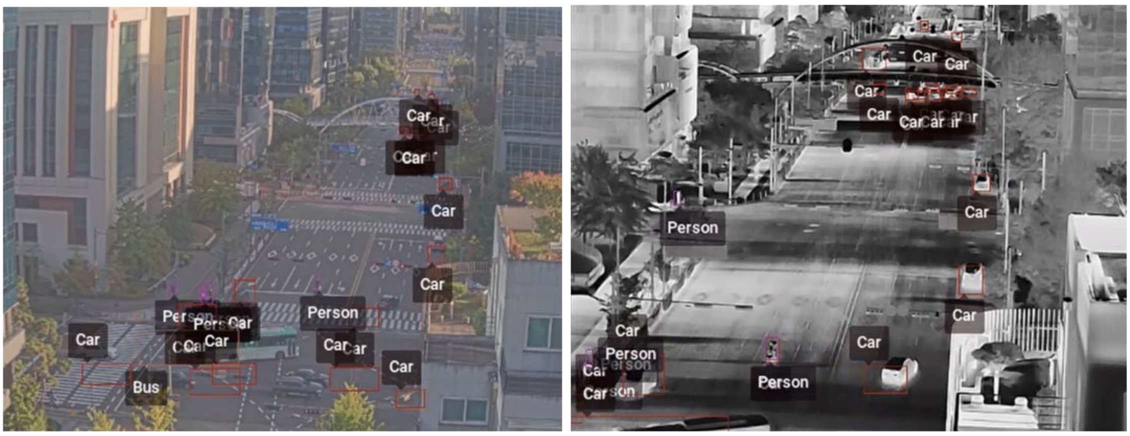
AI based Object Detection Range		TNM-C4940TD	TNM-C4950TD	TNM-C4960TD	TNO-C3010TRA/ C3012TRA	TNO-C3020TRA/ C3022TRA	TNO-C3030TRA/ C3032TRA
Vehicle	2.3m	224m	280m	498m	66m	79m	95m
Human	1.8m	116m	142m	215m	23m	26m	31m

[Table 5. The example of the actual measured AI-based object detection range for TNM C49x0TD(x=4,5,6)]

3.2.2 AI-Based Object Detection/Classification and IVA Functions in Thermal Imaging Monitoring

[Figure 13. Object detection from visible and thermal images]

Figure 14 shows the AI-based object detection screen observed using the dual-sensor camera TNM-C4960TD installed on a building rooftop. It showcases the proper functioning of the Object Detection (OD) feature based on AI in visible and thermal imaging. In this case, the detection range refers to the measurement values provided in Table 5.



[Figure 14. An example of VI detection function using TNM-C4960TD]

3.2.3 Providing Thermal Imaging Monitoring Supplement Services through Handover Support

In the event of detection, it supports handover to a PTZ camera to facilitate clearer identification of the detected object. Additionally, it enables immediate alarms regarding intruders through handover functionality with IP speakers.

3.2.4 Providing Effective and Continuous Monitoring through Bi-spectrum Camera

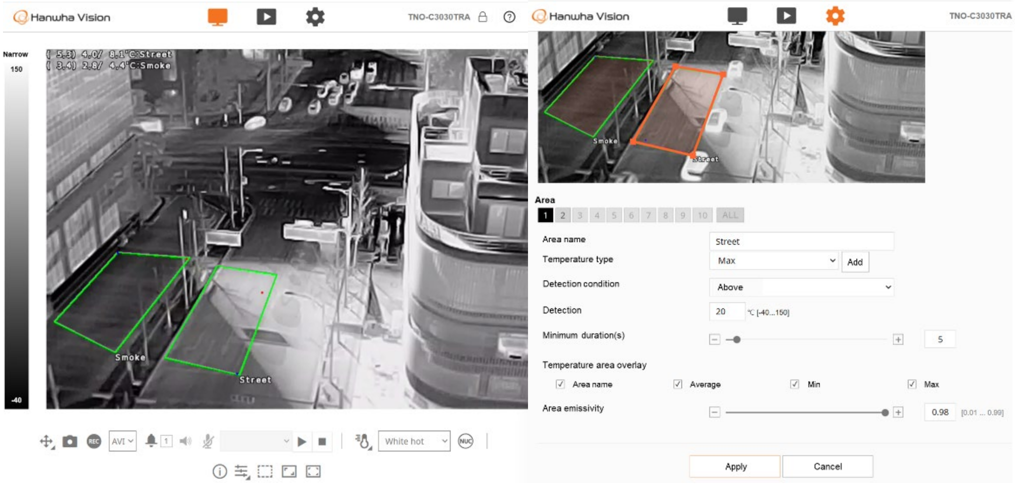
Even with AI-supported thermal imaging cameras, it isn't easy to discern the characteristics of detected objects, similar to visible light cameras. While displaying excellent image quality in low-light environments, visible light cameras are restricted by environmental factors like nighttime, fog, or smoke. Bi-spectrum cameras are dual-sensor cameras that combine thermal and visible light sensors to compensate for the limitations inherent in thermal and visible light cameras. This allows for effective and continuous video surveillance monitoring in all environments.

By sharing metadata between the visible light and thermal channels, it supplements the limitations of both types of cameras, enabling swift detection and understanding of on-site situations. For instance, Figure 15 offers a more accurate grasp of situations even in challenging weather conditions such as nighttime, rain, fog, fire, or smoke, where visibility is limited.

[Figure 15. Visibility difference between visible camera (left) and thermal imaging camera (right) in a night environment]

3.2.5 Providing ROI/Spot Temperature Monitoring Function for Efficient Facility/Equipment Management

Providing polygonal regions of interest (ROI) setting function for temperature monitoring may enhance the efficient setup of areas required for temperature surveillance. The TNO-C30xyTDR models (x=1,2,3, y=0,2) offer the flexibility of configuring up to 10 ROIs, while other models support up to 6 ROIs. Individual alerts can also be received based on the temperature thresholds set for each ROI. Referencing Figure 16 below showcases an instance of defining ROIs tailored to distinct usage scenarios. Users can delineate precise temperature detection ranges and relay corresponding coordinates using customizable fire or object surveillance settings.



(5,3) 4.0/ 8.1°C:Street
(3,4) 2.8/ 4.4°C:Smoke

Area name: Street
Temperature type: Max
Detection condition: Above
Detection: 20 ℃ [-40...150]
Minimum duration(s): 5
Temperature area overlay: ☑ Area name ☑ Average ☑ Min ☑ Max
Area emissivity: 0.98 [0.01 ... 0.99]

[Figure 16. An example of ROI setting]

Support is provided for immediate response by displaying real-time average, maximum, and minimum temperatures for specific areas designated by ROI, as shown in Figure 17, and by notifying users promptly through alerts.

[Figure 17. An example of average, maximum and minimum temperatures depending on areas of ROI]

When temperature monitoring is required for specific locations outside the set ROI, it can be done by clicking with the mouse on the desired location to use the Spot Pointer to check the temperature of that specific spot. Figure 18 below demonstrates an example of using the Spot Pointer in the live monitoring to check the temperature of a specific location.

[Figure 18. Temperature monitoring using Spot Pointer]

When using handheld thermometers for temperature monitoring in unmanned facilities or distributed equipment, the process requires a significant investment in manpower, associated costs, and time, as these devices are limited to measuring at a single point or in a restricted area. However, temperature monitoring using thermal imaging cameras with FPA (Focal Plane Array) sensors allows for monitoring over a broader area since each sensor pixel functions as an individual thermometer. Consequently, it becomes possible to effectively reduce manpower, associated costs, and time by employing thermal imaging cameras for temperature monitoring.

In addition, if you use a Hanwha Vision thermal camera model that supports the MQTT (Message Queuing Telemetry Transport) protocol, you can also configure a temperature monitoring system by subscribing to the temperature information published by the camera using MQTT. MQTT is a lightweight and flexible protocol that is easy to implement, and it is attracting attention for its excellent interoperability with other IoT platforms or applications. MQTT provides the maximum, minimum, and average temperature and coordinates of each ROI area and information on temperature detection event occurrences. The following is an example of temperature and event occurrence information published through MQTT in accordance with the ONVIF event standard.

< Temperature Reading >

Topic: C3020TRA/onvif-ej/VideoAnalytics/Radiometry/BoxTemperatureReading/&VideoSourceToken-0/ VideoAnalyticsConfigToken-0/TemparetureDetectionModule-01

```
{
  "UtcTime": "2024-01-17T06:29:13.480Z",
  "Source": {
    "VideoSourceToken": "VideoSourceToken-0",
    "VideoAnalyticsConfigurationToken": "VideoAnalyticsConfigToken-0",
    "AnalyticsModuleName": "TemparetureDetectionModule-01"
  },
  "Data": {
    "Reading": {
      "BoxTemperatureReading": {
        "@ItemID": "Z",
        "@MaxTemperature": "324.4",
        "@MaxTemperatureCoordinatesX": "28",
        "@MaxTemperatureCoordinatesY": "208",
        "@MinTemperature": "307.8",
        "@MinTemperatureCoordinatesX": "227",
        "@MinTemperatureCoordinatesY": "228",
```

```
        "@AverageTemperature": "307.9"
      }
    },
    "TimeStamp": "2024-01-17T06:29:13.480Z"
  }
}
```

< Temperature Detection >

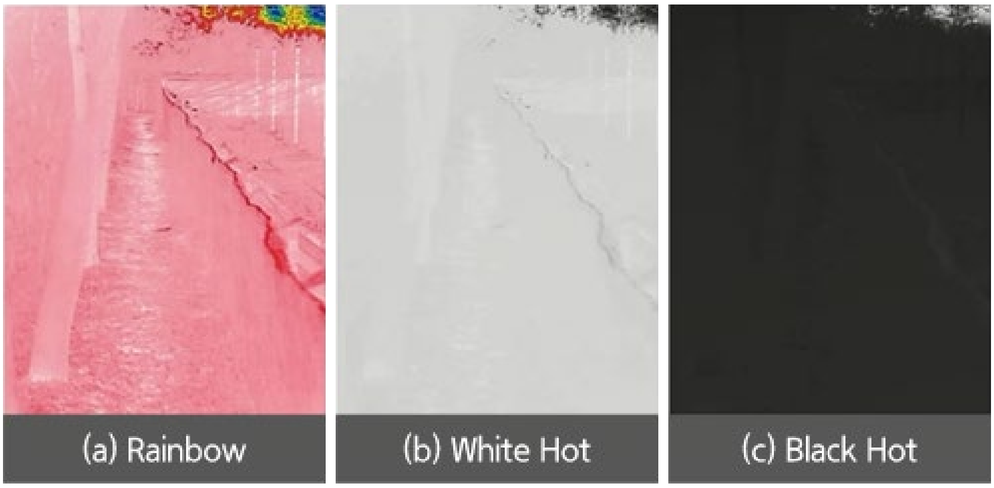
Topic: C3020TRA/onvif-ej/RuleEngine/Radiometry/TemperatureAlarm/&VideoSourceToken-0/VideoAnalyticsConfigToken-0/AAAA/TemperatureDetection-A

```
{
  "UtcTime": "2024-01-17T06:38:47.958Z",
  "Source": {
    "VideoSource": "VideoSourceToken-0",
    "VideoAnalyticsConfigurationToken": "VideoAnalyticsConfigToken-0",
    "Areaname": "AAAA",
    "RuleName": "TemperatureDetection-A"
  },
  "Data": {
    "AlarmActive": "true",
    "TimeStamp": "2024-01-17T06:38:47.958Z"
  }
}
```

4. Considerations when installing and operating thermal imaging camera

4.1 General considerations for the installation environment

The thermal images acquired by a thermal imaging camera appear clear when there is a significant temperature difference between the object of interest and its surrounding environment. It becomes challenging to obtain clear thermal images when the temperature contrast between the object of interest and its surrounding background is not substantial. This is similar to the situation that makes it difficult to obtain clear images with a visible camera in low-light conditions. Figure 19 demonstrates the examples.



[Figure 19. Images that when the temperature difference between the object and its surrounding environment is not significant]

As a device measuring thermal energy, a thermal imaging camera provides thermal images and temperature information. However, the camera's images or temperature data can be distorted due to atmospheric conditions such as heat sources, convection, moisture, rain, snow, the thermal stabilization of the sensor, and the ambient temperature around the camera and the observed subject.

When installing a thermal imaging camera, one must consider its distinct imaging characteristics that differ from those of regular visible cameras. For instance, while visible cameras can acquire images through glass windows, thermal imaging cameras cannot acquire thermal images through glass due to thermal reflection. When monitoring objects of the same material type, particularly with metals, significant differences in thermal images can occur based on the surface condition of the object, including factors like smoothness and corrosion levels.

Therefore, it's always crucial to consider stable installation locations that minimize environmental influence, ensure an adequate field of view for potential temperature variations between the subject and its surroundings, and account for the surface conditions of the observed objects.

4.2 Region of Interest setting

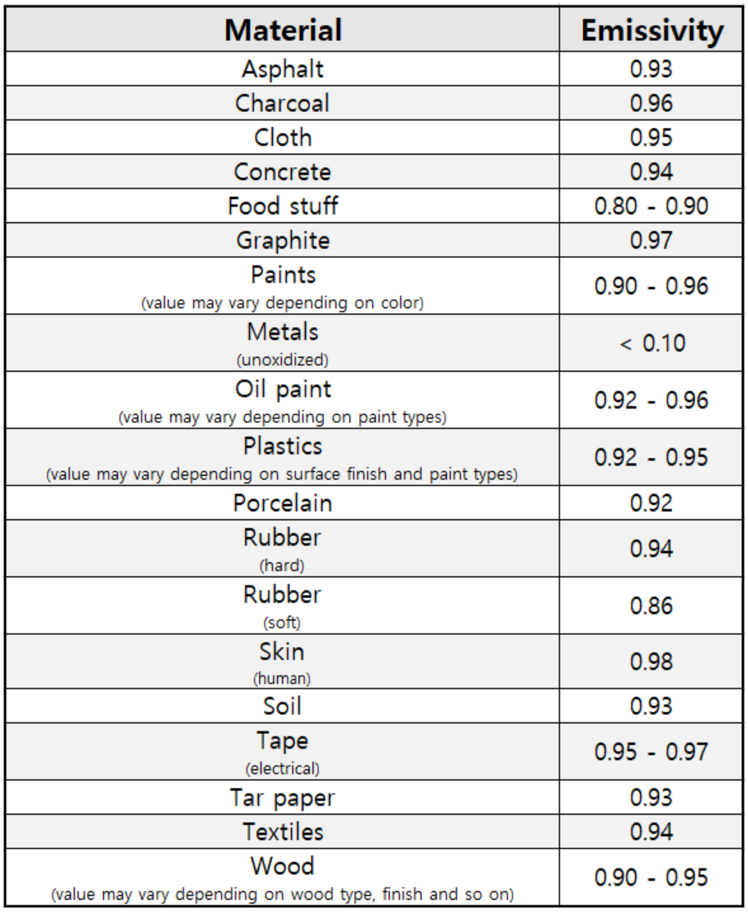
When defining the region of interest, a key concern is to prevent the unintended inclusion of surrounding backgrounds or unrelated objects. Figure 20 below presents an example of an improperly configured region of interest. Examining the defined region in the image, it's uncertain which part is intended for observation through this setting. Furthermore, incorporating the sky within the designated area of interest could result in unexpected temperature measure values.

[Figure 20. An example of when a region of interest was incorrectly set]

- Size of Region of Interest: A clearer thermal image is acquired when there is a significant temperature difference between the object of interest and its surrounding environment in thermal imaging cameras. However, setting the region of interest too small or too large may result in an image that doesn't suit the intended purpose. Setting the region of interest at a minimum size of 50x50 or larger is recommended to ensure that other objects do not obscure it.

4.3 Emissivity

Emissivity refers to the ratio of the radiation emitted by a material's surface to that emitted by a blackbody at the same temperature. A blackbody is an ideal object that absorbs all electromagnetic radiation incidents, as well as vibration frequency and incidence angle. The emissivity of commercially produced blackbodies typically ranges between 0.95 and 0.99 and is essential equipment used for calibrating infrared sensors. The emissivity of an object is less than 1. Table 6 below shows the emissivity values of the main materials.



Material	Emissivity
Asphalt	0.93
Charcoal	0.96
Cloth	0.95
Concrete	0.94
Food stuff	0.80 - 0.90
Graphite	0.97
Paints (value may vary depending on color)	0.90 - 0.96
Metals (unoxidized)	< 0.10
Oil paint (value may vary depending on paint types)	0.92 - 0.96
Plastics (value may vary depending on surface finish and paint types)	0.92 - 0.95
Porcelain	0.92
Rubber (hard)	0.94
Rubber (soft)	0.86
Skin (human)	0.98
Soil	0.93
Tape (electrical)	0.95 - 0.97
Tar paper	0.93
Textiles	0.94
Wood (value may vary depending on wood type, finish and so on)	0.90 - 0.95

[Table 6. Emissivity depending on materials]

The following are variables that influence emissivity, and understanding these is crucial for the proper use, comprehension, and analysis of thermal imaging cameras and thermal images (Source: Michael Vollmer et al. 2010).

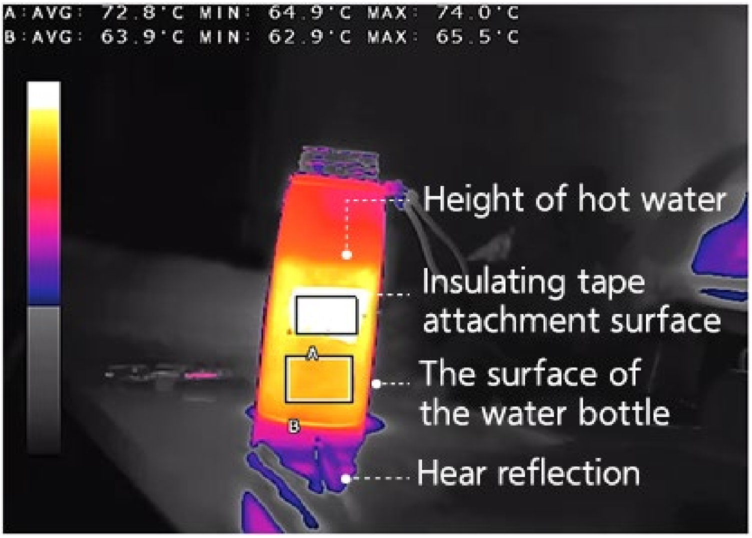
4.3.1 Type of material

It's essential to simplify and categorize materials as metals and non-metals. Surfaces of cast or polished metals are challenging to measure accurately due to their low emissivity. Polished metals typically have emissivity values of 0.2 or less, making it meaningless to measure their temperature using a thermal imaging camera.

4.3.2 Surface structure

In the case of polished metals, as mentioned earlier, they have an emissivity of 0.2 or lower. However, when the metal surface undergoes oxidation or corrosion, it can exhibit an emissivity of 0.8 or higher. The Leslie Cube is commonly used as an example to illustrate the difference in emissivity based on surface structure. This cube is a hollow copper cube with each face treated differently. Each face shows different infrared quantities when filled with hot water and observed using a thermal imaging camera. Since thermal imaging cameras convert infrared quantities into temperature, it's crucial to consider emissivity; otherwise, temperature measurements may be inaccurate.

Figure 21 illustrates the thermal difference when insulating tape is placed in the middle of a regular water bottle and filled with hot water. The section with insulating tape shows a temperature approximately 9℃ higher than the section without.



[Figure 21. A difference in thermal imagery according to emissivity when filling up hot water in the water bottle]

4.3.3 Visibility Range

When the angle between the object and the thermal imaging camera varies from 0˚to 85˚ , measuring the emissivity difference reveals that there's almost no change in emissivity within the range of 0˚ to 45˚. In other words, the emissivity remains relatively constant within this range. However, beyond this angle, as the thermal imaging camera views the object from greater angles, the emissivity value decreases, making accurate measurement challenging. Therefore, when installing a thermal imaging camera, it's advisable to position the field of view and the area of interest within an angle of 45˚or less.

4.3.4 Others

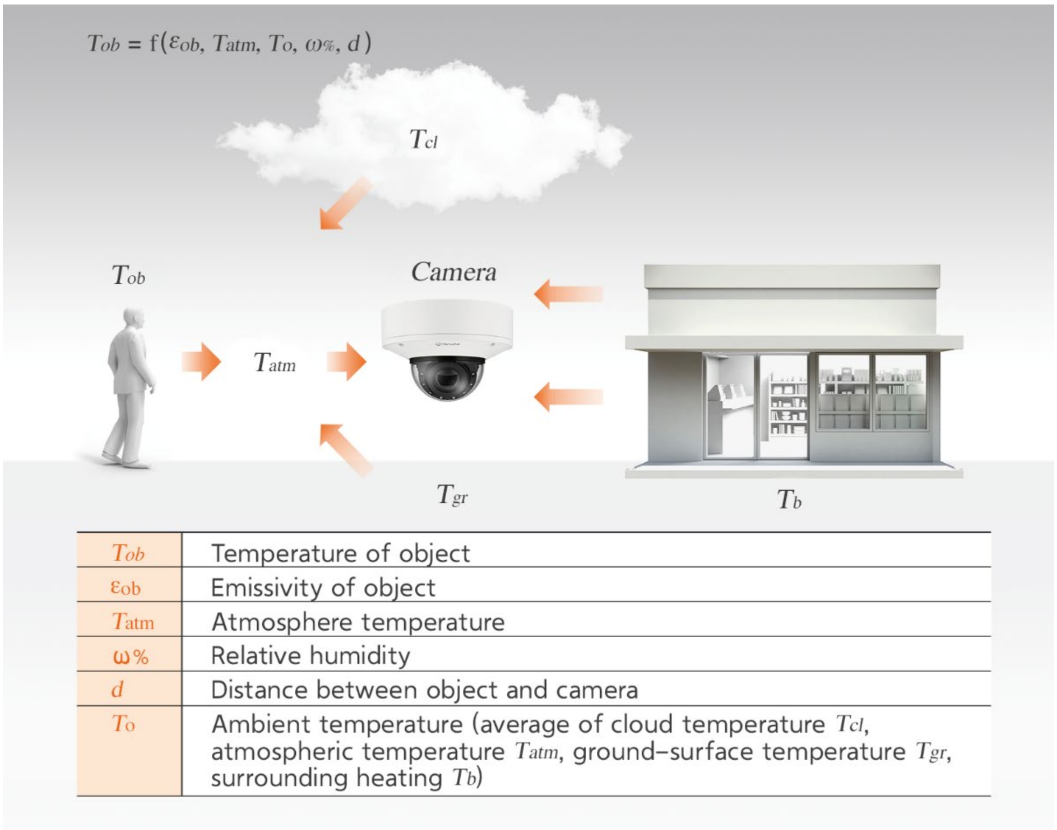
Other factors influencing this comprise the material's temperature range, wavelength range (LW, MW, SW), and geometric shape. Nevertheless, these factors usually hold less significance in standard usage conditions.

4.4 Viewing angle

Thermal imaging cameras provide different measurements based on the angle from which the object is observed. Therefore, during installation, consideration regarding the imaging angle of the thermal imaging camera concerning the object in the region of interest is essential. Typically, it should be installed within a 45-degree angle, and the rationale for this is explained in section 4.3.3 on the visibility range.

4.5 Factors Affecting Temperature Accuracy

When attempting to measure the temperature of an object using a thermal imaging camera, various factors affect the accuracy of the temperature measurement, as illustrated in Figure 22. These factors include the object's emissivity, ambient temperature, surrounding temperature, relative humidity, and the distance between the object and the camera, all expressed as a function (Source: W. Minkina and D. Klecha, 2015).



T_{ob}	Temperature of object
ε_{ob}	Emissivity of object
T_{atm}	Atmosphere temperature
$\omega\%$	Relative humidity
d	Distance between object and camera
T_o	Ambient temperature (average of cloud temperature T_{cl}, atmospheric temperature T_{atm}, ground–surface temperature T_{gr}, surrounding heating T_b)

[Figure 22. Factors Affecting Temperature Measurements]

The infrared emitted by an object undergoes absorption and scattering as it passes through the atmosphere, with water vapor (H_2O) and carbon dioxide (CO_2) in the atmosphere having the most significant influence.

Therefore, temperature measurement accuracy using a thermal imaging camera can vary depending on the environmental conditions in which the camera operates. For a thermal imaging camera to deliver accurate performance, it must account for more than just the mentioned environmental factors. Factors like the camera's installation angle, alterations in the observed object's material, and the impact of thermal reflection also significantly influence accuracy.

5. References

- N. Pinchon, M. Ibn-Khedher, O. Cassignol, A. Nicolas, F. Bernardin, P. Leduc, J-P. Tarel, R. Brémond, E. Bercier, G. Julien, “All-weather vision for automotive safety: which spectral band?”, AMAA(Advanced Microsystems for Automotive Applications), 2018

- Young Taek Jung, “Latest Technology Trends in Infrared Sensors”, pp18-23, Hongneung Science Publishing House, 2014

- J.L. Tissot, P. Robert, A. Durand, S. Tinnes, E. Bercier, and A. Crastes, “Status of Uncooled Infrared Detector Technology at ULIS, France”, Defence Science Journal, Vol. 63. No. 6, 2013

- Vladimir I. Ovod, Christopher R. Baxter, Mark A. Massie, “Advanced Image Processing Package for FPGA-Based Re-Programmable Miniature Electronics”, SPIE, 2005

- H. Budzier and G. Gerlach, “Calibration of uncooled thermal infrared cameras”, JSSS, 2015

- Michael Vollmer, Klaus-Peter Moellman, “Infrared Thermal Imaging Fundamentals, Research and Applicatins, WILEY, 2010)

- W. Minkina and D. Klecha, “Atmospheric transmission coefficient modelling in the infrared for thermovision measurements”, JSSS, 2015

Hanwha Vision Co., Ltd.
13488 Hanwha Vision R&D Center,
6 Pangyo-ro 319-gil, Bundang-gu, Seongnam-si, Gyeonggi-do
TEL 070.7147.8771-8
FAX 031.8018.3715
www.HanwhaVision.com