IR Panomorph Lens Imager and Applications

Simon Thibault
ImmerVision
2020 University, Montreal, Quebec H3A 2A5 Canada

ABSTRACT

During the last decade, protection of civilian and military operational platforms or vehicles against threats has been an issue of increased importance. *A significant difference exists between warfare as viewed ten years ago and the nature of conflict today. More emphasis is being placed on short range positive ID, wide field of regard situational awareness and quick reaction times* .The standard countermeasure is inadequate when not accompanied by a set of efficient sensor. The sensor packages primarily consisting of an alerting device of four different detection steps: pre-alert, giving the directions of possible attack, detection of an action of attack, identification of the threat and finally the precise localization (3-D). The design of the alerting device is greatly depending on which it will be used, the associated cost and the nature of the threat. Recently the requirements for these sensors have become more and more stringent due to the growing number of scenarios. The attack can practically be from any direction, implying the need for a large Field of Regard, the attack range and the type of threat can vary considerably. Especially the localization at short ranges is a challenging issue which can be addressed by an optimized panoramic imager. The new panoramic IR panomorph lens imager, considered, and evaluated at ImmerVision is presented for integration on various platforms. This innovative panomorph approach provides enhanced performance with better pixel/cost ratio by providing an increased resolution in the zone of interest. The IR panomorph based sensor is as an aberration-corrected hemispheric imager with a custom lens designed to match the resolution the IR camera (MWIR-LWIR) with improved image quality , field coverage and resolution for target detection, classification, and tracking. Various configurations and scenarios including advantages and drawbacks are discussed.

Keywords: Surveillance, security, panoramic, intelligent video, wide-angle lens, IR, pixel optimization, situational awareness, vehicle protection, video data fusion

1. INTRODUCTION

Situation awareness is an important element of security. The capacity to immediately respond to a fast changing environment is the result of surveillance of surrounding areas, and surveillance is based on the observation of various parameters of the environment. The observation is achieved using specific electro-optic sensors, including visible, near-, mid- and far-infrared as well as ultra violet[1-3]. While the visible/near-IR camera is certainly one of the most popular EO sensors for surveillance because it provides the most life-like results, the thermal imagers become essential because it has the ability to gather situation awareness when the vision is typically compromised. The sensing capability of thermal imaging provides clear images in total darkness, through smoke clouds, and through haze and fog. Consequently, the thermal imager is an effective means for performing a covert visual assessment.

However unless many imagers are used in combination, it is difficult to achieve 100% area coverage 100% of the time. Such a solution necessarily means high cost, and difficult installation problems[4]. A different solution was suggested by using a step-stare type concept but it is inherently limited to long revisited times. Scanning system using wide field of view (WFOV) forward looking infrared (FLIR) camera for scanning large field of regard with a narrow FOV (NFOV) FLIR used for high resolution tracking and surveillance can also be considered. Again, such system architecture is still limited to slow scan rates and long revisited times.

For critical infrastructures as well as situation awareness, the next generation of surveillance system will have to cover the following items:

- ✓ Foul weather capability

- ✓ Darkness and night time detection
- ✓ Determine exact location of breach
- ✓ 100% coverage, 100% of the time
- ✓ Limit the false alarms due to machine error and operator error
- ✓ Manage the voluminous amounts of data captured by numerous imagers and sensors

Panoramic imaging is of growing importance in many surveillance programs around the world. While primarily valued for its ability to image a very large field of view (180^o X 360^o, hemispheric), other characteristics such as its ability to reduce the number of sensors and to increase the pixel/cost ratio are also important benefits of panoramic imaging -- particularly if the panoramic imager is designed to increase the number of pixels in the zones of interest, as is the Panomorph[5].

In this paper, we show how a highly effective surveillance and security solution can be developed by integrating state of the art thermal panoramic imager for detection and situation awareness system. The section 2 will focus on the panomorph lens concept, the analysis of resolution and contrast sensitivity. At the end of this section we will present a lens design of an IR panomorph lens. Section 3 present some of the operational benefit of using an IR panoramic camera and how immersive 3D visual assessment benefits from panomorph technology. Finally, the last section describes various surveillance scenario where a thermal panoramic imager can be used.

2. IR PANOMORPH LENS CONCEPT AND ANALYSIS

2.1 Zone of Interest Concept & Panomorph Lens

The Panomorph lens provide a full hemispheric field of view. In contrast to other types of panoramic imagers that suffer from blind zone (catadioptric cameras), low-image numerical aperture and high distortion, the Panomorph lens is designed to use distortion as a design parameter, in order to provide a high resolution coverage where it is needed, i.e.: in the zone of interest.

In the design of an efficient panoramic IR lens, the coverage area is divided into different zones. A specific resolution requirement as well as a particular field of view is defined for each individual zone. Figure 1 shows a typical surveillance scenario.

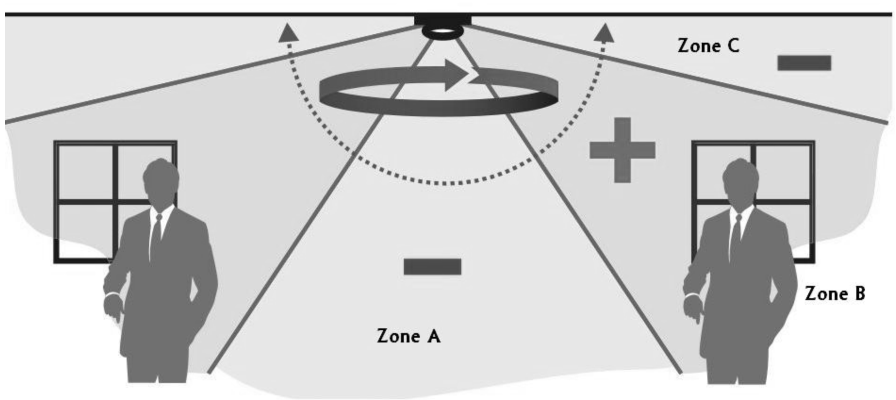


Figure 1: Specific security zones.

For this particular scenario, the panoramic coverage area is divided into five adjacent and continuous zones. Zones B and C are symmetrical with the vertical axis. The five adjacent zones, while still providing full hemispheric coverage, each feature a different resolution requirement The most significant objects are in Zone B. This zone is the most important one because it can enable facial recognition and identification. An object in Zone B is also more distant to the camera than an object in Zone A. This means that the relative angular resolution (pixels/degree) in Zones A and B should also be different.

For example, a human face in Zone B (at 60 degrees from the vertical axis) will subtend an angle, which is half of the angle that the human face will subtend in Zone A (above the camera). To get the same number of pixels per face in both Zones A and B, the pixels/degree in Zone B must be twice the pixels/degree in Zone A. This means that the number of pixels required on the sensor to image Zone B is twice the number of pixels used to image Zone A. It also means that the constant pixel/angle resolution achieved with a fisheye lens is not ideal for this surveillance scenario.

From a system design point of view, you will need a camera in Zone A with a focal length (F-A) that is half of the focal length (F-B) of the camera used to cover Zone B. By deduction, we can conclude that at least one camera per zone with various type of lenses will be needed. This is the reality! However, this will not result in an efficient surveillance system. There will be many cameras to follow, a lot of pixels to transfer and a heavy infrastructure to manage. The common approach is to use a single camera with PTZ functionality…this is the arguably acceptable compromise, with something always missing in the trade-off, as discussed in the introduction.

The panomorph IR lens with a proper FPA will cover each zone with one solution. By controlling the optical distortion, we were able to design and build a completely new type of panoramic IR imager. Figure 2 presents the field of view (angularly) as a function of the position in the FPA The FOV ranges from 0 (vertical) to 90 (horizontal) degrees and the dimension *d* is the half dimension of the sensor (from the centre) The dashed line represents the linear relation (f-theta distortion) between the field of view and the position on the FPA, as seen with a fisheye lens. As discussed earlier, the constant resolution is not ideal. A linear function means a constant slope or a constant pixel/degree ratio. The solid line represents a relationship between the FOV and the pixel that is typical with a Panomorph lens. We can see that:

- for a small angle (Zone A) the slope is high, which corresponds to a lower pixel/degree resolution;
- the slope is lower in Zone B with a peak in the middle, which corresponds to a higher pixel/degree resolution;
- and finally, in Zone C, the slope is high again, which means lower resolution.

Consequently, the Panomorph lens provides the best solution to cover the hemispheric zone, using only a single FPA equipped with a single IR lens and without any mechanical PTZ function. A digital PTZ function is provided and the operator can see an undistorted image with different views; however all the hemispheric information is available 100% of the time.

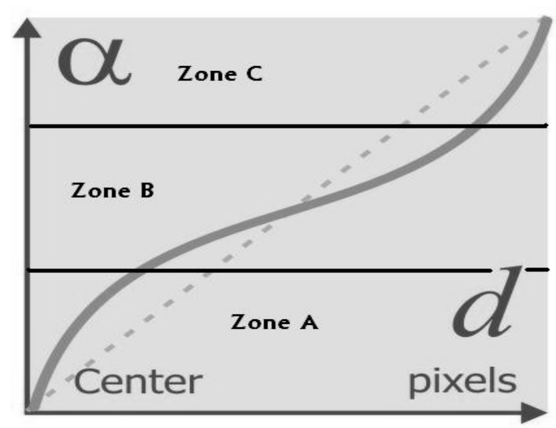


Figure 2: The ideal FOV (α) vs the position (d) on the sensor for the case study presented in Figure 1.

2.2 System Resolution

Panomorph lens use of hemispheric field of views naturally compromises the geometrical resolution of the sensor. However, by designing the lens with an increased resolution in the zone of interest and by considering a combination of new emerging and enabling technologies, we can consider Panomorph technology (optic and software) as a viable solution in future IR surveillance system. Technologies include:

- ✓ New generation of IRFPAs (2nd & 3rd generation up to 640X512 format and more)
- ✓ Integration of accurate strap down INS
- ✓ High quality, low f-number Panomorph lens
- ✓ Resolution enhancement technology (Super resolution technique)[6]
- ✓ High end image processing DSP software
- ✓ Wide FOV HMD visor

It is difficult to evaluate the exact resolution as function of the sensor because it depends of the choice of the resolution in the zone of interest. However, if we define i zones (1 to n) where each zone cover an angle θ_i with a number of pixel N_i we can describe the resolution for each zone as well as the nyquist frequency associated ($Fnyq_i$):

$$Fnyq_i = \frac{N_i}{2 \cdot \theta_i}, \tag{1}$$

with the following limit condition:

$$\sum_{i=1}^{n} N_i = \sum_{i=1}^{n} 2 \cdot Fnyq_i \cdot \theta_i = \#\, pixels\ . \tag{2}$$

However, this mathematical function does not include all effects. As an example, since Panomorph IR lens is a high quality fast optics, the resulting image on the FPA may be under sampled. As a consequence, the formed image contains high frequency data (called latent) which can be reconstructed either by enhancing the raw image using signal processing if required.

2.3 System thermal contrast sensitivity

It is well known that one of the major advantages of staring IR technology compared to thermal scanning sensor is their enhanced contrast sensitivity because FPA support of long term integration times. However, this advantages is not optimally achieved on applications where narrow spectral bandwidth filtering is required. As a IR lens, panomorph IR based imager can used the standard NETD figure of merit quantification to get the thermal sensitivity.

2.4 Lens Design

2.4.1 Reflective vs refractive design

A few IR panoramic imagers have been developed during the last few decades. The Automatic Panoramic Thermal Imaging Sensor (APTIS) is an IR panoramic imager designed to be used with a sensor network[11]. The APTIS design features automatic detection, location and tracking of multiple targets. The system is a catadioptric configuration designed to match the resolution of 640X480 pixels. However, as discussed by Gutin[11], designing a compact IR panoramic catadioptric optics with low aberration and high numerical aperture presents a real challenge. Having a mirror on top of the imaging lens is not ideal from a packaging point of view. The mirror becomes sensitive to alignment error and it is also difficult to have a compact system.

In addition, a design study has been done comparing different types of panoramic IR concepts. In particular, Powel[12-13] designed different types of IR imagers for a 3-5 um band. They concluded that the main advantages of all refractive solutions were the small diameter and the fact that there was no blind zone in the field-of-view.

In a recent application, DRS & ORA[14] have studied the optical design of a refractive panoramic lens imaging system for the full 3-12 um band. They also concluded that a refractive design solution is the most compact and practical means of achieving a panoramic field-of-view in the IR. Nonetheless, a catadioptric design using a highly curved reflective component in front of a refractive design is undesirable from the point of view of fabrication and packaging, and offers no advantage over a more conventional all-refractive solution due to the diameter and the complexity of the refractive components required to correct the mirror aberrations.

2.4.2 Optical design

As discussed in the previous section ,refractive design solution is actually the most compact and practical means of achieving a panoramic infrared system operating over the LWIR band. Consequently the all refractive panomorph lens is the best choice in the design of a IR panoramic alerting or vision system.

The Panomorph lens design is a particular design form of a wide angle lens which includes anamorphic and custom pixel to angle image mapping. The design of such lens requires knowledge and specific tasks that are adapted to IR lens design challenges.

The table 1 describes the IR Panomorph lens typical characteristics. This table can be used as guidelines (but not limited to) to define the exact specifications of the required custom IR Panomorph lens. Additionally, the lens material can be any type of IR glass and molded IR glass. Athermalized and achromatized design are also possible as standard IR objective.

Table 1: IR Panomorph lens characteristic

Lens or system orientation	By understanding the application specific needs and knowing the orientation of the lens or the vision system, ImmerVision engineers can define where the enhanced resolution is needed.
Total track	> 2-3 times the sensor dimension (diagonal)
Front element diameter	> 1.5 times the sensor dimension (diagonal)
Total FOV (hemispheric)	180-220 degrees(typical)
Resolution between zone	3-10 times
Maximum slope (resolution variation between two zones)	Factor 2 per 5-10 degrees $(B/A)/(\theta_2 - \theta_1)$ (see figure 3)
Sensor type	Any type
Image Quality	MTF > 65-80% @ Nyquist
Focal Length	Defined by sensor size (standard EFL definition is not relevant)
Focus	Manual or fixed
Anamorphic ratio	Up to 16:9 (typically 4:3)
Aperture (F/#)	IR > 0.8 Fixed iris
Wavebands	MWIR 3-5um, LWIR 8-12um M-LWIR 3-5/8-12um
Transmission	> 60% (typical)
Operation temperature (typical)	-40C to +60C
Storage temperature (typical)	-45C to +70C

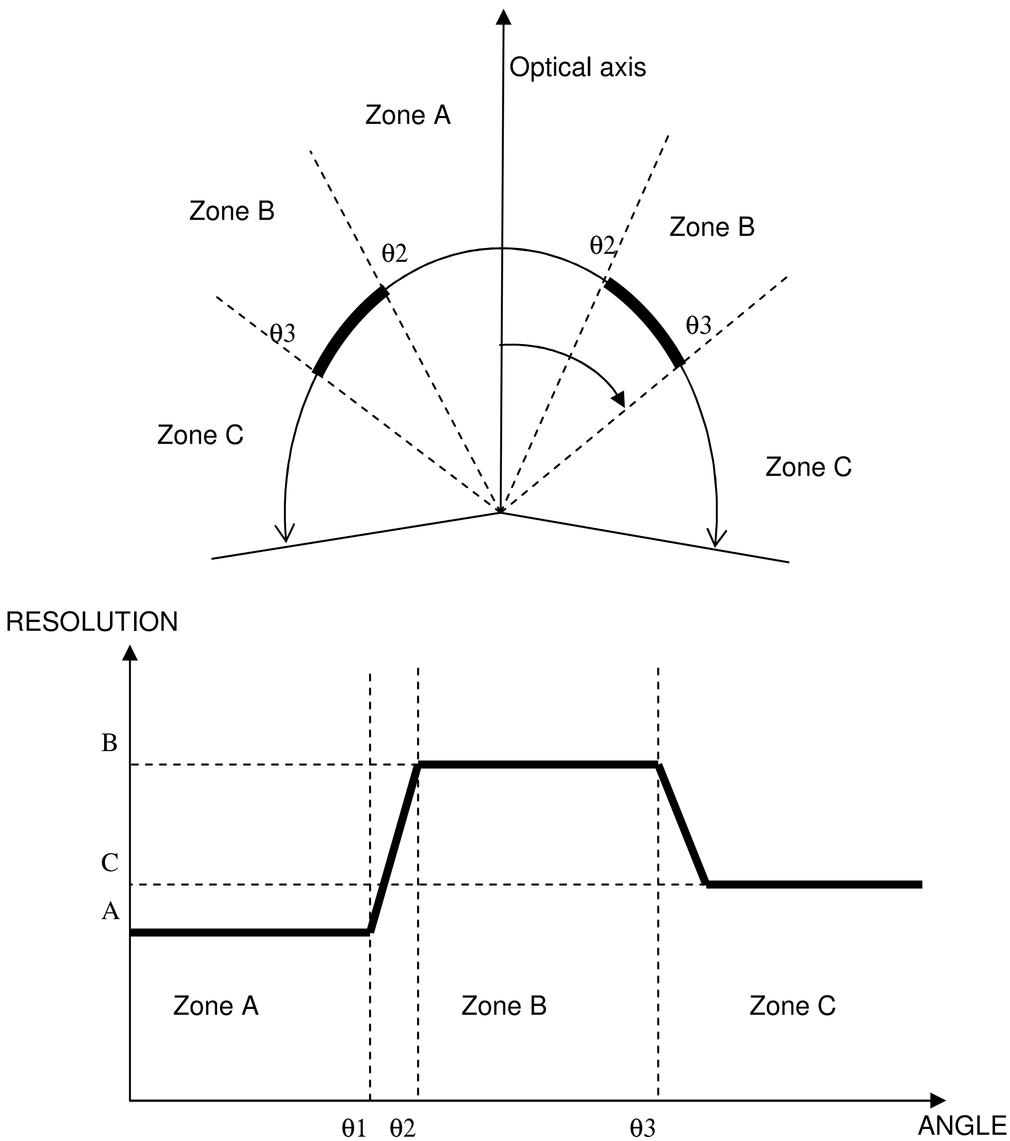


Figure 3: Panomorph lens zone definition (n=3)

The Panomorph lens is designed to match the resolution which is required by a particular application. By using the equation 1 and 2 you can define the ideal panoramic lens for your needs. This capacity is very unique and only available by using a panomorph lens. Today, full panoramic or hemispheric FOV is now accessible with a panomorph refractive lens.

3. IR PANOMORPH LENS OPERATIONAL BENEFIT

3.1 Thermal imaging benefits

The use of thermal imaging cameras is increasing as security officer insist on night time situation awareness. Figure 3 compares scenes taken with a thermal imager with one from a CCTV camera.

Figure 3: Thermal imaging performance (from L-3)[7]

The second main advantages to use IR technology is the capability to see in challenging weather conditions. IR imager will also perform in snow, fog, rain, smoke and haze condition. In such weather conditions, the detection distance will be reduced but this reduction is not as severe as the one from a standard CCTV camera. Figure 4 shows schematically how thermal waves will travel in various condition compared to visible waves. The thermal waves penetrate further that the shorter visible waves through all environmental elements. This characteristic benefits systems which are deployed around coastal areas or water based applications (naval IRST).

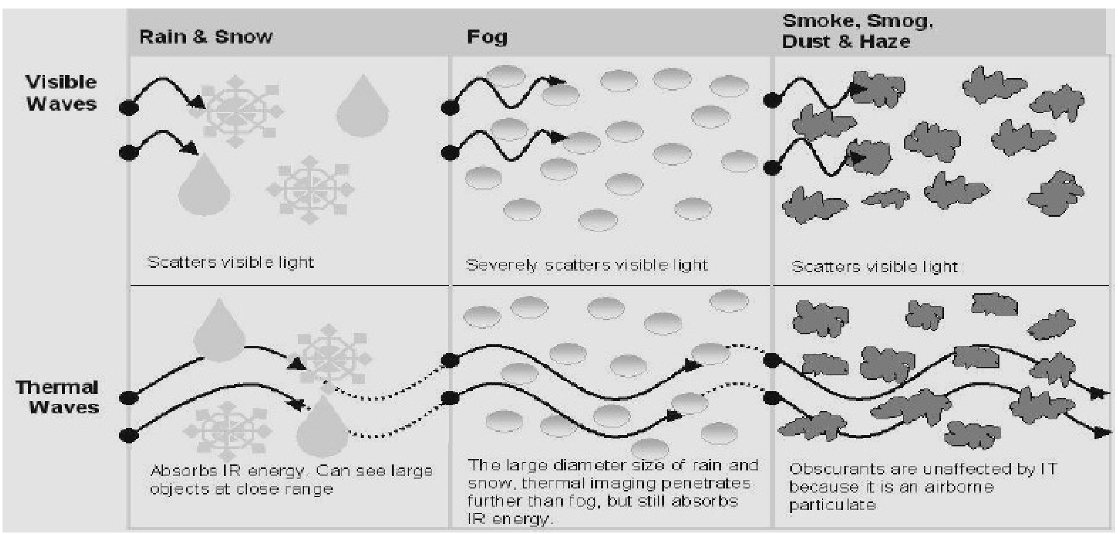


Figure 4: Visible and thermal wave performance under different atmospheric conditions[7]

Finally, thermal imaging system is completely passive. As passive device, the IR camera detects heat emitted by objects but also maintains a covert of presence of the camera in the scene. Active infrared technologies can provides range advantages but it can be detected by other cameras which may compromise the location or position of the surveillance systems.

3.2 Immersive visual benefits

Adding one or more IR panomorph lens to the next generation surveillance systems will increase the ability to manage risk and better protect critical infrastructure or military assets. The benefits are based on the use of better immersive video surveillance technology that can merges live views from fixed panomorph lens and high resolution PZT camera with a 3D environment model. This will allows a user to be immerse himself in the scene like playing a video game in order to controlling as wanted (go back and forth in time and space) the views of the situation instead of volleying between multiple single views PTZ cameras. Such approach will be much more simpler by using panoramic imager because the user will see everywhere all the time. The combination of two technologies, panomorph thermal imager and automated software detection and monitoring system will provide a security and surveillance solution with improved situational awareness.

As an example of applied intelligent video technology, consider the common surveillance of a military camp installation during night. The cameras are typically installed in strategic locations where they can monitor the surrounding border of the camp or strategic infrastructure. Virtual security borders (perimeters) are drawn on the image of each camera to define security zones. When the intelligent video system detects an alarm-activating event, such as a person passing from the public zone to a secure zone, then an alarm is issued over the IP security network. The alarm is routed by the management software to the operator or directly to a camera with a higher magnification to further investigate the event. The operator can focus on the alarm and follow the (primary) target with a high resolution PTZ camera. At the same time, the camera using the panomorph lens can continuously provide 100% field coverage and may track multiple secondary targets (from the same camera using the panomorph lens). This helps the operator focus his/her activity on the narrow field pan/tilt camera, without losing any information in the field. In reality, the most sophisticated intelligent video technology needs to be able to manage multiple cameras and alarms and also be 100% efficient 100% of the time.

A panoramic video viewing library is needed to ensure a distortion-free display (i.e. multiple virtual windows) and for controlling the 360° videos from a camera equipped with a Panomorph lens. It has been demonstrated by many ImmerVision NVR/DVR partners that is easy to integrate the ImmerVision's video library into DVRs and monitoring software, allowing the user the ability to see and manipulate distortion-free views. It provides real time viewing mode, virtual PTZ functionalities, simultaneous multi-viewing and 360^{o} panoramic views, and is DVR ready as well as being compatible with Windows, Linux, and Mobile operating systems. Managing videos from a camera equipped with a Panomorph lens is the same as managing standard videos - compression, storage, streaming, algorithms, etc. - and 360° videos can be viewed in real time or deferred time.

Finally, determining sensor placement at a site is also simpler by using panomorph lenses because it provides panoramic coverage. This minimized blind spots as well as reducing the false alarm by providing a constant and full field coverage. It also allows the security management to better locate expensive PZT cameras where is needed.

4. THERMAL PANOMORPH LENS APPLICATIONS

This section will briefly describe basic applications using staring IR sensors which could benefit from panoramic imagery.

4.1 Piloting aid applications

The limited FOV provided by currently deployed night vision piloting and/or navigating system[8] can be enhanced by the used of a full panoramic sensor. The narrow and panoramic views from the two separated sensors can be processed and fused together to provide a embedded dual FOV of the surrounding environment. In figure 5 below, we see an example from video imagery. We see a Panoramic FOV imaging aligned to pilot line of sight with a narrow FOV high resolution camera. Since the rendering is using digital imaging capabilities, video data fusion, bearing information (compass), distance and angle calculation are also possible.

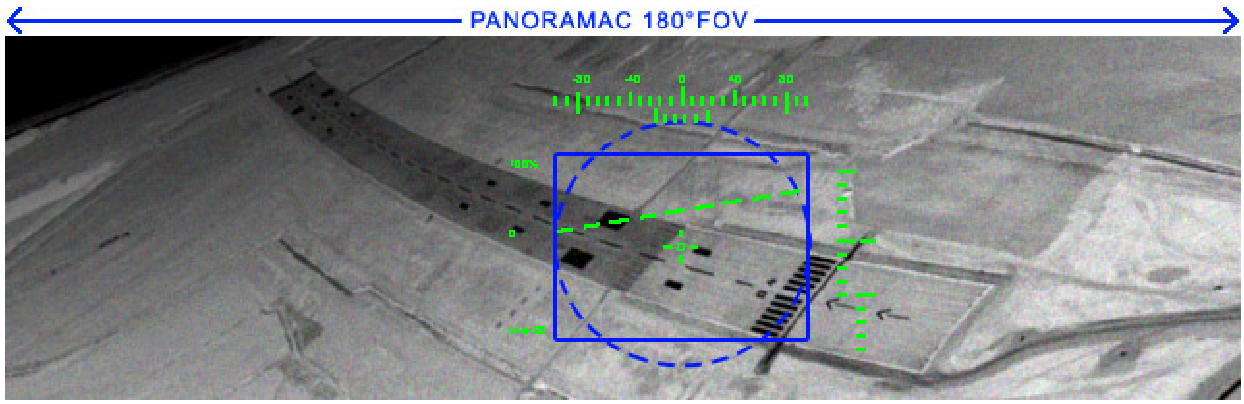


Figure 5: Piloting application example.

With a panoramic full FOV, you can also monitor and analyze objects within the scene to accurately report of any danger in term of collision avoidance or obstacle alert.

4.2 Alerting sensor

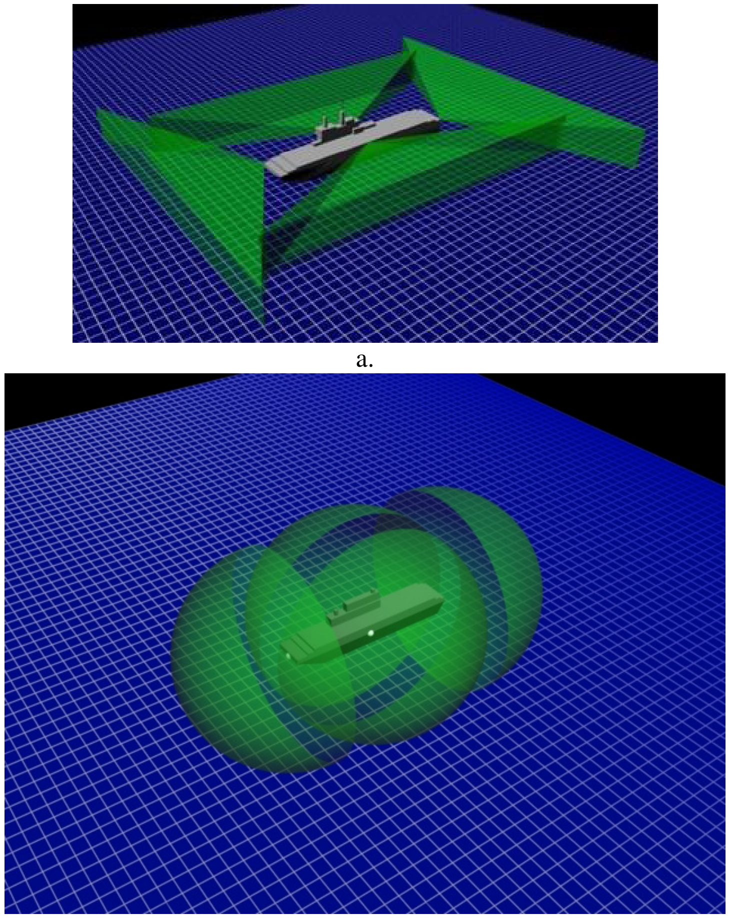
The ability to see and detect on a full hemispheric FOV allows a Panomorph lens thermal imager an immersive visual assessment for situation awareness to manage potential alerts. In such process of alert, the hemispheric thermal imager is able to pre-alert, giving the directions of possible attack (gun shot, blasts, movements or other threats). The pre-alarm is routed by the management software to the platform operator or directly to a FLIR with a higher magnification to further investigate the event. The operator can focus on the pre-alarm and follow the target with a high resolution IR camera to identify the threat and finally determine the precise localization. At the same time, the thermal panoramic imager using the panomorph lens can continuously provide 100% field coverage. This helps the operator focus his/her activity on the narrow field IR view, without losing any information in the field.

4.3 Man portable situation awareness system

Recently, IRST and threat warning system used in vehicle have been move to the portable applications[9]. Such optical detection system is capable to detect transient even detection by an operator in motion. The test done to date incorporate relatively modest FOV (about 40 degrees HFOV), but a full hemispheric FOV will provide not only event detection but it can also provide surrounding situation data that can be analyzed by video analytic systems and remotely provide support to officer and land warrior.

4.4 Ship self protection system

Naval IRST system offers crucial benefits to situational awareness and ship self-defence capability. Advanced system provides a fully passive infrared surveillance system capable of automatic detecting and tracking both air and surface targets simultaneously around the ship. Figure 6a shows Artemis IRST from Thales which is a new and original design of naval IRST[10].



a.

b

Figure 6: a : Artemis IRST sensors[10] ; b : Enhanced with panomorph lenses

As we see on the figure 6a, the surrounding areas is not perfectly covered by such advanced IRST system. This is not the goal of the IRST system to provide a very close situation awareness system. Adding four low cost IR panomorph imagers (figure 6b) on each side of the ship will provide a complete coverage 100% of the time. Any smaller threat (small boat) or close areas deplacement (in a port) can use these proximity situation awareness which make the ship self protection system more efficient.

5. CONCLUSION

Panomorph lens development has led to a new type of thermal panoramic imager that can be customized to enhance any surveillance, detection and situation awareness system. The IR Panomorph lens is a refractive lens with high throughput, very low f# (0.8 possible), compact and robust package which can be adapted to virtually any type of platform. The design features full field of view coverage, increased resolution in the zone of interest, and 100% coverage rate. Its simple integration and intelligent video process benefits have been designed, implemented and demonstrated in the commercial video-surveillance market. IR panomorph lens can be used as transient event detection (gun shot and detection of blasts) or part of staring IRST with increased coverage particularly in shadow zone (close region around vehicle or ship). Full hemispheric coverage make panomorph lens an efficient choice for vehicle situation awareness in urban scenario where gun fire can come from high level building close to the street.

REFERENCES

1. Mikhail A Gutin, Eddy K Tsui, Olga N Gutin, Automatic Panoramic Thermal Integrated Sensor, Proc. of SPIE, vol. 5778, 792-799 (2005).
2. Arie N.De Jong, Piet B.W. Schwering, IR panoramic alerting sensor concepts and applications, Proc. of SPIE vol. 6185, 769-779 (2006).
3. Greguss, Pal. Panoramic Security, Proc. of SPIE Vol. 1509, 55-66 (1991).
4. James R. Buss, Staring infrared panoramic sensor (SIRPS), Proc. of SPIE, vol. 3436, 743-762 (1998).
5. Simon Thibault, Distortion Control Offers Optical System Design a New Degree of Freedom, Photonics Spectra, May 2005, 80-82(2005).
6. R.G Driggers et al., Superresolution performance for undersampled imagers, Opt. Eng., 44 (1), Jan2005.
7. G. Francisco, J. Tillman, K, Hanna, J. Heubusch, R. Ayers, Integrated homeland security system with passive thermal imaging and advanced video analytics, Proc of SPIE vol. 6542, 65423E(2007).
8. S. Nadav, SAPIR – Operational Benefits of IR MWS as Panoramic Vision and Piloting System, proc SPIE vol. 6206, p62061V(2006).
9. G. Tidhar, R, Manor, TED – A novel man portable infrared detection and situation awareness system, Proc SPIE vol. 6542, paper 65423A(2007).
10. C. Grollet, Y. Klein,V. Magaides, ARTEMIS: Staring IRST for the FREMM frigate, Proc SPIE Vol. 6542, paper 654233(2007).
11. Gutin MA, Tsui EK, Gutin ON. Automatic Panoramic Thermal Integrated Sensor. *Proc SPIE,* Vol. 5778, 792-799 (2005).
12. Powel I. Design study of an infrared panoramic optical system. *Applied Optics* Vol. 35, No. 31, 6190-6194, (1996)
13. Powel I. Panoramic lens. *Applied Optics* Vol. 33, No. 31, 7356-7361(1994).
14. Spencer HM, Rodgers JM, Hoffman JM. Optical design of a panoramic, wide spectral band infrared fisheye lens. *Proc SPIE* Vol. 6342, paper 63421P(2006).

Author contact:

Simon Thibault, M.Sc., Ph.D., P.Eng.
Principal Optical Designer
ImmerVision
simon.thibault@immervision.com