Enhanced Surveillance System Based on Panomorph Panoramic Lenses

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ABSTRACT

Modern surveillance and security systems demand a technological approach because only technology can provide highly efficient vigilance, a certainty of detection and a fast response 100% of the time. Recent developments, including new wide-angle lenses, advanced cameras, IP networks and video analysis technology, provide significant improvements in system performance and flexibility.

This paper presents a new advanced surveillance system featuring a panoramic Panomorph lens for event detection, recognition and identification over a 360-degree area with 100% coverage. This innovative approach provides enhanced performance with better pixel/cost ratio. Intelligent video technology enables the video camera to be "more" than just a video camera; it allows the panoramic image to follow events (such as moving objects or unauthorized behavior) in real time, which in turn allows the operator to focus his/her activity on a narrow field pan/tilt camera without losing any information in the field.

Adding incremental capabilities such as a Panomorph lens-based imager to an existing surveillance video system can provide improvements in operational efficiency and effectiveness. Foreseen applications are in the fields of border surveillance, high-security environments, aerospace and defense, mass transit, public security and wherever the need for total awareness is a prerequisite.

Keywords: Surveillance, security, panoramic, intelligent video, wide-angle lens.

1. INTRODUCTION

Security is the result of surveillance, and surveillance is based on the observation of various parameters of the environment within the protected area. The observation of these parameters is achieved using specific electro-optic sensors, including visible, near-, mid- and far-infrared as well as ultra violet[1-3]. The visible/near-IR camera is certainly one of the most popular EO sensors for surveillance, because it provides the most life-like results, and is widely available on the market at a relatively low cost. However unless many cameras are used in combination, it is difficult to achieve 100% area coverage 100% of the time at a good cost/benefit ratio. Most of the time a limited number of cameras is used due to budgetary constraints. Consequently the operator is restricted by a limited field of view, making it difficult to evaluate or detect events and their relationship with the surrounding environment. The result is an inefficient surveillance system. To overcome this problem, we proposed adding a panoramic imaging camera featuring a Panomorph lens to both existing and new surveillance systems.

Panoramic imaging is of growing importance in many security programs around the world. While primarily valued for its ability to image a very large field of view (180^o X 360^o), 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 patented ImmerVision's Panomorph lens[4].

These new technologies provide the user community with vast improvements in surveillance system performance and flexibility. The three most significant developments discussed in this paper are:

- the increased performance and sophistication of Panomorph lenses;

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- IP networks;
- and intelligent video technology.

2. SYSTEM DESIGN USING A PANOMORPH LENS

2.1 Key system trade-offs

It is well known that the choice of camera for security applications is based on a methodical approach as well as for security tasking. The major key system trade-offs include (not necessary in this order)[5]:

- Cost: This drives a lot of decisions. Cost includes maintenance and support throughout the life cycle of the system.
- Coverage: The field of view or field of regard defines the total area to be covered by the sensor (ideally as large as possible with the ability to see everywhere).
- Coverage rate: The coverage rate defines how often a part or the entire field of view must be revisited (ideally 100% of the time).
- Target types: The target types will have an impact on the sensor type and on the required resolution.
- Resolution (detection, recognition or identification). The resolution criteria may be defined using Johnson criteria (see section 2.4).
- Size, weight and power.
- Environment (temperature, indoor /outdoor): The environment criteria should also include illuminance levels (see section 2.5).

All security and surveillance systems can be designed with the above trade-offs in mind. However, recent developments in technology developments can now help ensure a better surveillance system. The Panomorph lens is one such development, allowing an increase in overall system performance.

The benefits of a Panomorph lens are based on a custom-designed approach, simply because advanced surveillance systems should be unique and designed to meet real and very specific needs. Each area to be covered by the surveillance system is not facing the same challenges or threats. As a safety function, a security system should be built around suspected threats. The installation of a standard camera may be a cost-effective way to deploy a surveillance system, but it can result in a very inefficient system. To enhance the system, a custom approach must be taken.

A custom approach means that each individual area to be covered by the surveillance system is defined as unique. The first step is to split the areas into smaller zones. The size and number for each zone is not easy to define (at this point it may be important to consult a specialist). The second step is to define within each zone a critical zone that is called a zone of interest. The zone of interest will be the sub-area where the exact requirements of your surveillance system will be defined. An example of a panoramic surveillance system's close-up area is presented in section 2.2. Here we see that not only is the type of threat important, but also its displacement, path, speed, etc. The third step is to define the security trade-offs zone by zone. An advanced surveillance system will also incorporate intra-zone communication protocols as well as zone-to-zone tracking mechanisms. Last but not least, this advanced security system can help the operator manage the system.

2.2 Zone of Interest Concept & Panomorph Lens

The patented ImmerVision's Panomorph lens can 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 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.

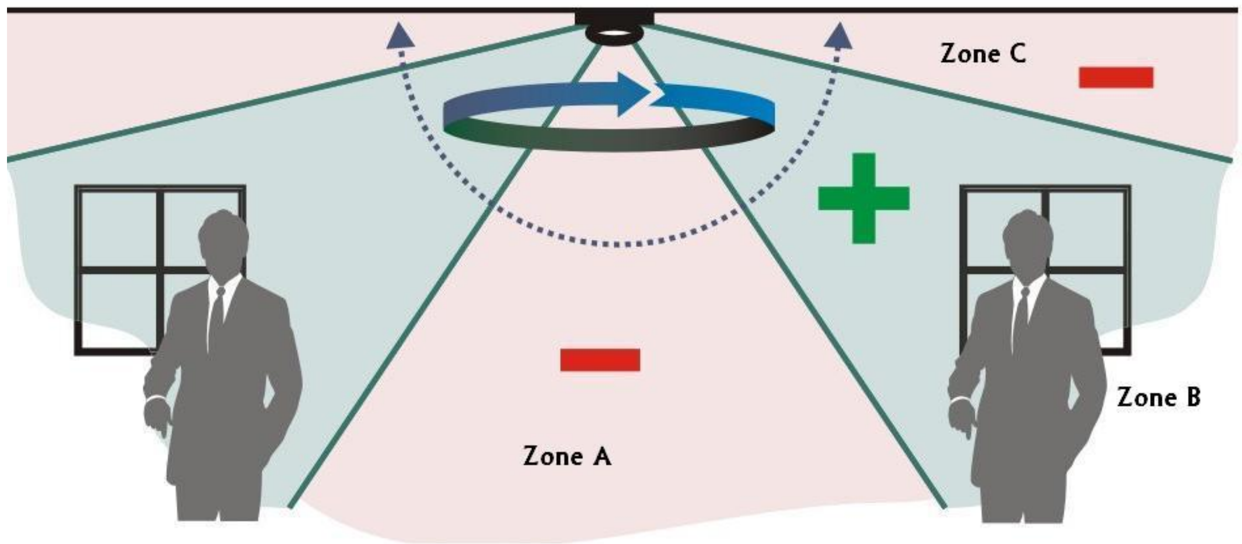

Figure 1: Specific security zones.

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.

We proposed to design a custom system to meet the surveillance requirement of each zone with one solution. The Panomorph lens is a panoramic lens designed to increase the resolution where needed. By controlling the lens optical distortion, we were able to design and build a completely new type of panoramic imager. Figure 2 presents the field of view (angularly) as a function of the position in the CCD (or the EO sensor). 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 CCD, 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 camera equipped with a single 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.

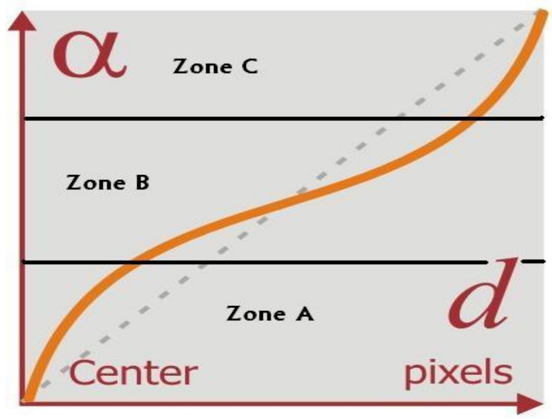

Figure 2: The ideal FOV (α) vs the position (d) on the sensor for the case study presented in Figure 1.

2.3 Detection range

The performance enhancement that a Panomorph lens can provide to a surveillance system is not limited to the concept above. The Panomorph lens also includes an anamorphic correction to increase the effective number of pixels, which is used to image the hemispheric field of view. The hemispheric field of view is not seen on a circular disk but rather on an elliptical surface (Figure 3). This anamorphic correction is achieved by using anamorphic lenses in the design of the Panomorph lens. The dark rectangular corresponds to the full CCD (typical ratio 4:3). Figure 3 shows a schematic view (with Zones A, B and C indicated). These sketches also include the increased resolution in the zones of interest. The final result is a net increase of the target dimension, as well as an increased detection range.

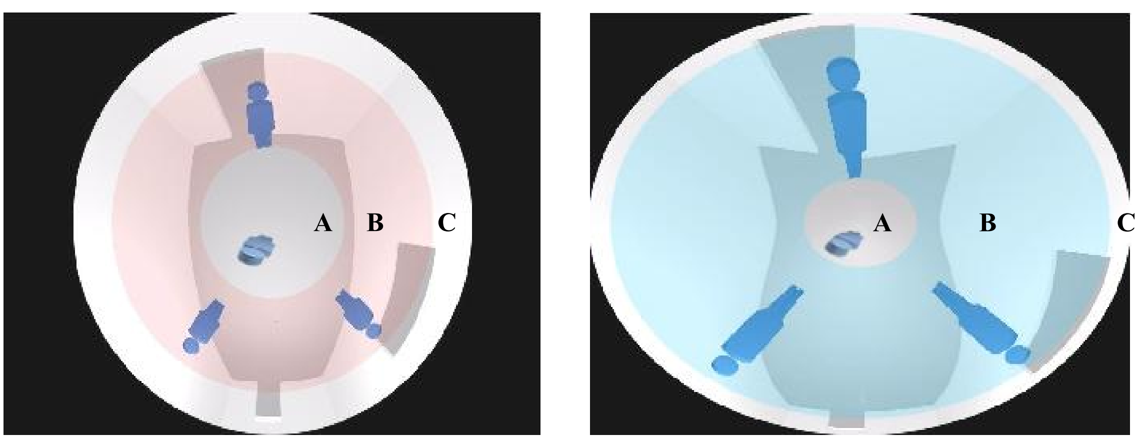

Figure 3: Image footprint on the CCD (left: standard hemispheric image footprint with a constant pixel/angle ratio, right: Panomorph hemispheric image footprint with an increased pixel/angle ratio in the zone of interest)

The detection range is a function of the number of pixels on the target used to recognize, identify or detect. Based on Figure 1, we define the range detection vertically (height of the people). Range detection can also be defined as the number of horizontal pixels on the target (width)[1]. This last definition uses the number of pixels on a circumference at a given angle (a circle in the image footprint) to define, for a given FOV angle, the detection range. Because the number of pixels on the perimeter of an ellipse is larger than on the circumference of a circle, the detection range for horizontal detection is also always larger when using a Panomorph lens.

In order to understand the detection range we will further develop our example. We want to define the distance from which the face of a human body (Figure 1) might have at least 30 pixels per dimension. Using a simple mathematical expression we can calculate this distance for each FOV angle. The distances then define a surface that is illustrated in Figure 3 for a 360 KPx CCD sensor (NTSC).

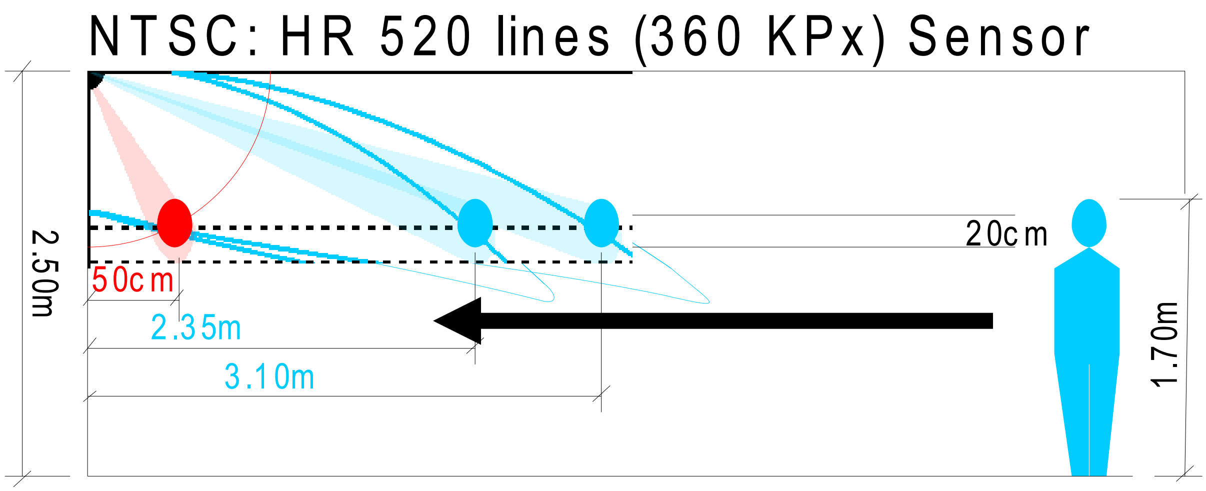

Figure 3: Detection range (30 pixels/face dimension). The red curve (constant) corresponds to the constant pixel to angle ratio. The blue curves correspond to a Panomorph lens axis (two curves for long and short axis).

This example shows how a well designed Panomorph lens can provide a facial recognition range as far as 3 meters away from the camera (3 m calculated on the floor for a 30 pixel/face resolution). This means an extended range for detecting, identifying and recognizing a target. This extended range also provides an extended coverage rate for following the target. The red circle marks the detection area, which has a constant pixel to angle function similar to a fisheye lens.

2.4 Practical resolution considerations

Defining the resolution requirements for surveillance systems is not necessarily a simple task. A rough indication of the practical meaning of resolution can be defined from the following correlation between the resolution criteria and pixels on the sensor (Johnson's criteria[6]).

The criteria usually used are:

Detection	2 pixels per target
Orientation	3 pixels per target
Aim	5 pixels per target
Recognition	8 pixels per target
Identification	12-16 pixels per target
Recognition with 50% accuracy	15 pixels per target
Recognition with 90% accuracy	24 pixels per target

Those criteria are not absolute numbers. The criteria will also depend on the illuminance level of the target, the background, and the S/N ratio of the sensor.

2.5 Illuminance levels produced by several sources

In this section, we introduce some photometric considerations that can be used to design or select a proper EO sensor for a surveillance system. Photometry deals with luminous radiation which the human eye can detect. The basic photometric unit of radiant power is the lumen. The lumen is defined as a luminous flux of monochromatic radiation at 555 nm (green) whose radiant flux is equal to 1/683 watts. In other words, one watt of radiant energy at the wavelength of maximum visual sensitivity (0.555um) is equal to 680 lumens.

To give an idea of the size of the lumen, the following table lists the illuminance levels encountered in a number of common surveillance circumstances[7]. This table illustrates the expected magnitudes of these photometric quantities.

Table 1: Illuminance Levels Produced by Several Sources

Source	Illuminance (lux or lm/m^2)
Sun at Zenith	1.2×10^5
Clear sky	1×10^4
Overcast sky	1×10^3
60-watt incandescent lamp (at 1 m)	1×10^2
Full moon	0.27
Moonless overcast sky	1×10^{-4}

3. THE NETWORK CAMERA SYSTEM

The emerging technology of networked cameras systems is generating many changes in the surveillance and security field. IP videos or cameras use the IP network for camera control and video transmission, which is very different from the traditional CCTV video system. Installation, integration, functionality and life cycle can all benefit from a well-developed camera network. With proper configuration, a network can allow viewers to view the camera video from any location

Cameras equipped with a Panomorph lens will generally not require a networked video control system more sophisticated than those utilized in a typical commercial networked video system. In fact, the camera will drive the network requirements. The Panomorph lens is a passive optical component, used to image a hemispheric field of view.

The 'panomorph' video viewing library is needed to ensure a distortion-free display and for controlling the 360° videos from a camera equipped with a Panomorph lens. It is easy to integrate the 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° panoramic views, and is DVR ready as well as being compatible with Windows, Linus, 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.

Key advantages of the Panomorph lens-viewing library:

- Simple integration
- Flexibility
- Scalable/extensible
- Real-time

To be effective, the panoramic video viewing library corrects image distortion from cameras equipped with a panomorph lens, to display and allow control of one or more standard views, like a PTZ (figure 4) in real time. The viewing library allow to simultaneously display as many views as desired from one or more cameras (figure 5).

Figure 4: Real-time distortion-free display (left: the original image produce by the panomorph lens).

Figure 5: Four PTZ views (left), two strips to display a 360° total camera surround in one single view (right).

4. INTELLIGENT VIDEO TECHNOLOGY

Advanced video technology enables each camera to be an active event-detection system, not just a simple camera. An intelligent video processes in real-time, to extract moving objects or to follow events as they happen. It can also incorporate dimensional information, estimate range, and ignore noise from light changes, or background motion from wind

An intelligent video system includes several software tools that allow the user to define the rules for rapid identification, either to generate an alarm or to define regions of interest. Operators can use the output from the intelligent video system of a Panomorph system to identify where they should focus their activity on a narrow field pan/tilt standard camera to access very high-resolution images. During this time, the Panomorph lens recording system will not lose any other information in the field for later access.

Panomorph lens-based intelligent video processes also address operator fatigue. It is generally recognized that an individual monitoring multiple pan-tilt cameras and multiple displays will exhibit decreased effectiveness in a matter of minutes. Using a Panomorph system, the full field of view is recorded and can be displayed in playback as required.

As an example of applied intelligent video technology, consider the common surveillance of a mass transit installation. The cameras are typically installed in strategic locations where they can monitor the surrounding docks (metro station) and stairways. 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 target with a high resolution PTZ camera. At the same time, the camera using the panomorph lens can continuously provide 100% field coverage. 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.

5. CONCLUSION

Panomorph lens development has led to a new type of panoramic imager that can be customized to enhance any surveillance and security system. The Panomorph lens is designed as the node of an intelligent sensor network. 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 addition to the applications mentioned in the report above, Panomorph-based systems have been developed for use in panoramic endoscopy, panoramic projection and NDT metrology.

REFERENCES

1. Mikhail A Gutin, Eddy K Tsui, Olga N Gutin, Automatic Panoramic Thermal Integrated Sensor, Proceeding of SPIE, vol. 5778, pp. 792-799 (2005).
2. Arie N.De Jong, Piet B.W. Schwering, IR panoramic alerting sensor concepts and applications, SPIE vol. 6185, pp. 769-779 (2006).
3. Greguss, Pal. Panoramic Security, SPIE Vol. 1509, pp. 55-66 (1991).
4. Simon Thibault, Distortion Control Offers Optical System Design a New Degree of Freedom, Photonics Spectra, May 2005, pp. 80-82.
5. R. McDaniel, R. Hughes and E. Seibel, EO/IR Sensors for Border Security Applications, SPIE vol. 6203, paper 620304 (2006)
6. J. Johnson, Analysis of image forming systems, in Proc. Image Intensifier Symp., pp. 249– 273, Warfare Vision Branch, Electrical Engineering Department, U.S. Army Engineering Branch and Development Laboratories, Ft. Belvoir, VA, 1958.
7. Robert W. Boyd, Radiometry and the Detection of Optical Radiation, Ed. John Wiley & Sons, ISBN 0-471-86188-X, 1983, chap. 6.

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