Panoramic Lens Applications Revisited

Simon Thibault* M.Sc., Ph.D., Eng
Director, Optics Division/Principal Optical Designer
ImmerVision
2020 University, Montreal, Quebec, H3A 2A5 Canada

ABSTRACT

During the last few years, innovative optical design strategies to generate and control image mapping have been successful in producing high-resolution digital imagers and projectors. This new generation of panoramic lenses includes catadioptric panoramic lenses, panoramic annular lenses, visible/IR fisheye lenses, anamorphic wide-angle attachments, and visible/IR panomorph lenses. Given that a wide-angle lens images a large field of view on a limited number of pixels, a systematic pixel-to-angle mapping will help the efficient use of each pixel in the field of view.

In this paper, we present several modern applications of these modern types of hemispheric lenses. Recently, surveillance and security applications have been proposed and published in Security and Defence symposium. However, modern hemispheric lens can be used in many other fields. A panoramic imaging sensor contributes most to the perception of the world. Panoramic lenses are now ready to be deployed in many optical solutions. Covered applications include, but are not limited to medical imaging (endoscope, rigiscope, fiberscope…), remote sensing (pipe inspection, crime scene investigation, archeology…), multimedia (hemispheric projector, panoramic image…). Modern panoramic technologies allow simple and efficient digital image processing and the use of standard image analysis features (motion estimation, segmentation, object tracking, pattern recognition) in the complete 360o hemispheric area.

Keywords: medical imaging, image analysis, immersion, omnidirectional, panoramic, panomorph, multimedia, total situation awareness, remote sensing, wide-angle

1. INTRODUCTION

Photography was invented by Daguerre in 1837, and at that time the main photographic objective was that the lens should cover a wide-angle field of view with a relatively high aperture[1]. However, these requirements were only satisfied after many years of development. Today, panoramic lens designers are facing the same challenge but with a different goal -- to efficiently control the image mapping to produce high performance digital imagers.

The paper is mainly divided in two parts. We will first describe the evolution of the panoramic lens, we will not review everything but it gives a good understanding of this field. The second part will focus on the applications of modern panoramic imagers.

2. DEVELOPMENT OF MODERN PANORAMIC LENS

2.1 The first immersive lens

Adding a large negative meniscus element mounted on the head of a compact positive component will create a system with a long back focal distance and a short focal length, which is namely a reversed telephoto. In the past, these types of lenses were very popular, since any lens used with a 35 mm camera had to have a back focal length of at least 35-40 mm to clear the rocking mirror on the camera. Consequently, any lens with a focal length of less than approximately 40 mm is a reversed telephoto type. Fortunately, this type is favourable for a wide-angle field of view. Wide-angle lenses are generally considered to be lenses with a field of view greater than 60 degrees.

* simon.thibault@immervision.com; phone: +1 418-261-0049; www.immervision.com

Optical and Digital Image Processing, edited by Peter Schelkens, Touradj Ebrahimi, Gabriel Cristóbal, Frédéric Truchetet, Proc. of SPIE Vol. 7000, 70000L, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.781598

However, for angles larger than 100 degrees, the barrel distortion becomes difficult to correct. With an extended field of view, the reversed telephoto lens will cover a hemispherical field -- we will call such lens a fisheye lens. This lens is not really an extension of a wide-angle lens. The fisheye lens has inherent large distortion, but this distortion should not be considered an aberration but rather the result of the projection of a hemispheric field on a circle, which is not possible *without* distortion. Panoramic lenses are generally considered to be lenses with a field of view greater than 130 degrees.

2.2 Fish eye view

The classical example of a fisheye lens "type" of image formation is an actual fish eye under water[2-3]. Robert W. Wood described in his book, *Physical Optics* (1911), a water-filled pinhole camera that was capable of simulating a fish's view of the world (Figure 1A). Bond added a hemispheric lens with a pupil at the centre of the curvature in place of the water (Figure 1B). In 1924, Hill developed his Sky lens by adding a diverging meniscus lens (Figure 1C) before the hemispheric lens to improve the field curvature (thereby reducing the Peztval sum). This lens was a first prototype of the modern fisheye lenses (Figure 1D) which was patented by Schultz (1932) and Merté (1935). Some 40 years later, the now famous afocal wide-angle door viewer was patented[4].

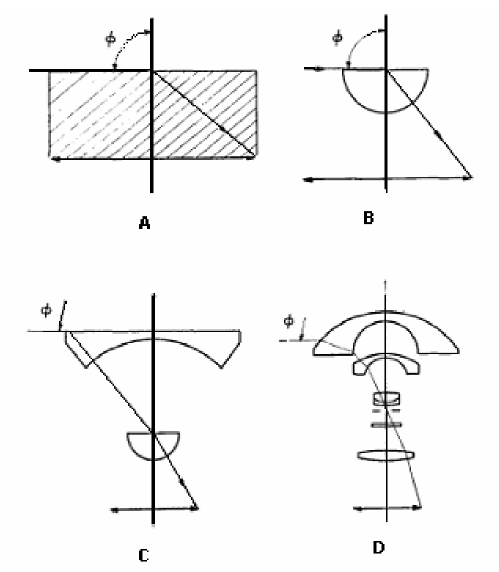


Figure 1 A-D: Development of fisheye lens[2]

At that time a severe drawback was encountered when the fisheye was facing up or down, because in these positions the subject of interest might have appeared at the edge (large angle) of the field where the barrel distortion is very large. We will see later in this paper how the modern high-resolution lens design can now control this distortion, to improve the field coverage of a panoramic lens and solve this historical concern.

2.3 Cylindrical panoramic view

Motivated by the need to record a distortion-free panoramic image, the flat cylinder perspective was born[5]. The panoramic feature is different from the fisheye in that there is no longer imaging of a hemispheric field onto a circle, but instead a 360^{o} cylindrical field of view imaged onto a two-dimensional annular format (Figure 2). The annular image produced by such a geometrical transformation will not produce (theoretically) radial distortion (cylinder height); however, the horizontal (circle circumference) direction will suffer from compression, from the edge to the centre of the image plane.

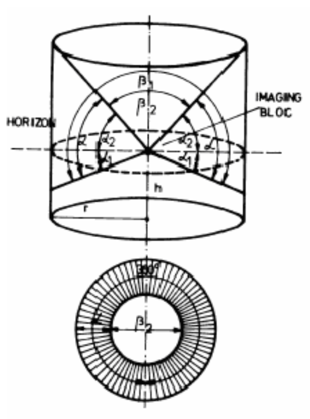


Figure 2: Flat cylinder perspective

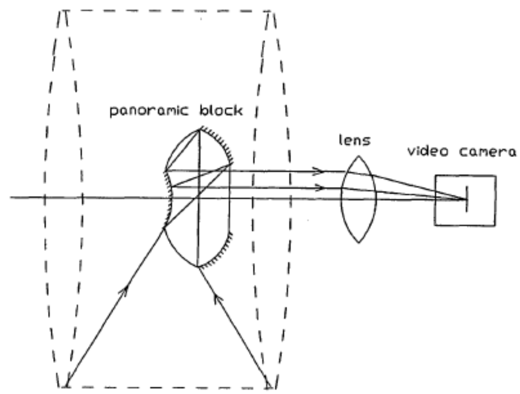


Figure 3: Optical arrangement proposed by Greguss

There are many known panoramic viewing optical arrangements that use this cylinder perspective. In particular, Greguss' patent[6] was one of the most promising approaches. Figure 3, which shows a block arrangement, is a copy of an actual drawing included in the patent. Rather than a fisheye, the panoramic block field-of-view is centred around a plane which is orthogonal to the optical axis at the expense of the on-axial imagery. This configuration allows a limited field-of-view in the radial direction (vertical in the field), where the imagery is relatively good to a first-order approximation.

Another approach to getting a flat cylinder perspective is to rotate a conventional camera around the vertical axis. This technique requires several frames (with proper synchronization) for the camera to complete a full rotation. This method is useful and widely used today in the production of high-quality panoramic photography.

2.4 Insect vision and Multi-lens camera

Ideally, the goal in panoramic imaging is to be able to capture the entire scene in a single image from a single camera. This ideal imaging system would allow more than one hemisphere to be visible, similar to some insects' vision system[7]. In reality, this can be achieved by using a multi-lens system with individual consecutive fields-of-view, totally covering a hemisphere[8] (Figure 4).

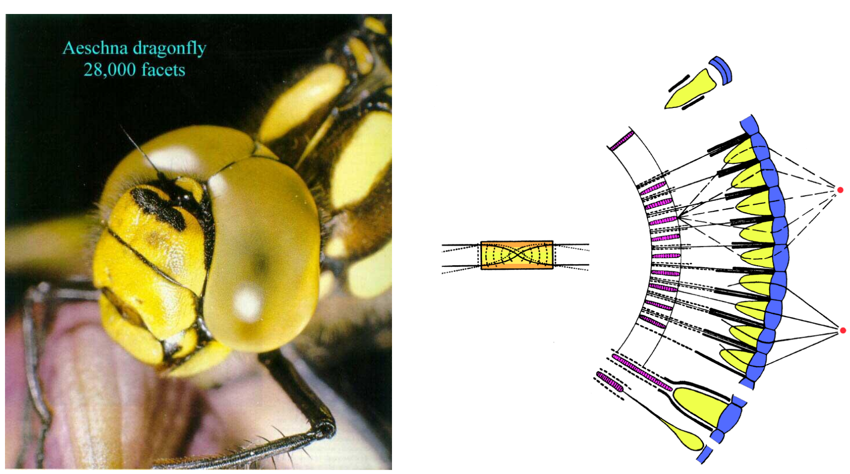


Figure 4: Compound eye allow light to travel through several facts before striking the light sensitive surface.

2.5 Omnidirectional and catadioptric panoramic lens

Reflective optics offer an alternative to panoramic imaging. A standard camera placed below a convex mirror will image a large field-of-view, the properties of which will depend on the shape of the reflective surface[9]. This approach has been used predominantly for producing panoramic TV displays. The projected images are captured by another equivalent optical arrangement (the reversibility property of light). For such an arrangement, the surface shape is not important as long as the projection mirror and the acquisition mirror are equivalent.

Systems with spherical and conical mirrors have been used to capture wide-angle images for robotics and machine vision devices (omnidirectional vision system). The mirror shape design is important and can provide a global image on the sensor, which presents a polar image with elevation and azimuth linearly distributed to radius and angle respectively[9].

Recently Kweon *et al*[10] have developed a wide-angle catadioptric lens with a rectilinear projection scheme. The lens was designed for a miniature camera with a 1/3'' colour CCD sensor (70 lp/mm) video graphics. The wide-angle lens will respect the relation between the pixel (r) and the angle (θ) as $r = f \tan \theta$ as a standard camera lens. However the field-of-view is not a full hemisphere. The field-of-view of Kweon's imager is limited to 151 degrees, and the distortion is less than 1%. The f-number is limited to 4.5, as the authors were not able to lower the f/number. Figure 5 shows a photograph of the catadioptric lens and a sample video image.

Figure 5: Photograph of the lens with the camera on a pole (left sample image).

2.6 Modern Panomorph lens

Modern panoramic lenses are able to add a distortion control which is considered a major enhancement in panoramic vision[11]. Specifically, the panoramic imager can be designed to increase the number of pixels in the zones of interest using a distortion control approach, which is a process patented by ImmerVision. The main benefit of the ImmerVision patent is that it is based on a custom-designed approach, simply because the panoramic lens application should be designed to meet real and very specific needs. By including specific distortion during the optical design stage, ImmerVision can produce a very unique and more efficient panoramic lens.

The Panomorph lens[12] uses this distortion control approach and an anamorphic image mapping to provide a unique full hemispheric field coverage. 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 uses distortion as a design parameter, in order to provide a high-resolution coverage where it is needed. It also features an anamorphic image mapping of the full hemispheric field, which produces an ellipse image footprint rather than a circle (or annular footprint) as do all other types of panoramic imagers. This feature provides an immediate 30% gain in pixels used on the sensor (the ellipse footprint matches the 4:3 ratio of a standard CCD or CMOS imager). The combination of distortion control and anamorphic design provides an important gain in resolution, and an advantage over all other types of panoramic imagers.

3. MODERN APPLICATIONS

In the following section, we will present various applications that can benefit from the Panomorph technology. The main goal is always to view without distortion 360°X180° for total situational awareness. The main features of the Panomorph approach are:

- ✓ Pixel usage optimization in High Resolution and Low Resolution
- ✓ Reduced maintenance compared to mechanical PTZ mounting
- ✓ Low bandwidth compared to other panoramic technologies
- ✓ Fully customizable (optic and software)

3.1 Security & Surveillance

The advantages of panoramic imagers with high-image resolution include increased area coverage with a limited number of cameras, instantaneous detection, and location and tracking of multiple targets simultaneously. Adding incremental capabilities such as a visible, NIR or IR panomorph lens-based imager to an existing surveillance video system can provide improvements in operational efficiency and effectiveness[12].

Panoramic imagers offer a real 360-degree coverage of the surrounding area, valuable for a variety of surveillance, security and defence applications, including force protection, port security, perimeter security, site surveillance, border control, airport security, maritime operations, search and rescue, intrusion detection, and various others. Adding automatic detection, location, and tracking of targets ensures maximum protection, increases the protection system reliability and user confidence, and at the same time reduces the personnel workload.

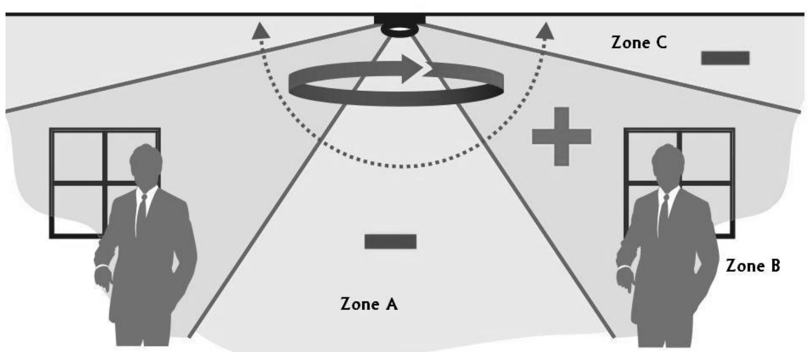
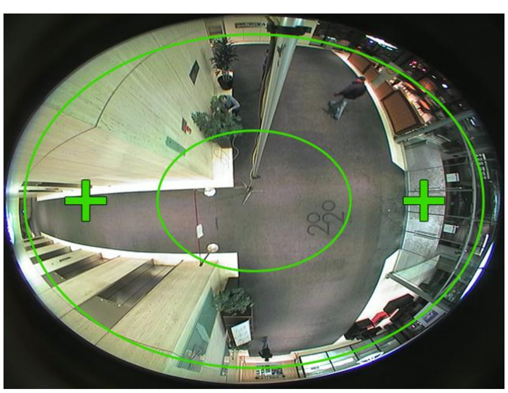


Figure 6: Surveillance scenario.



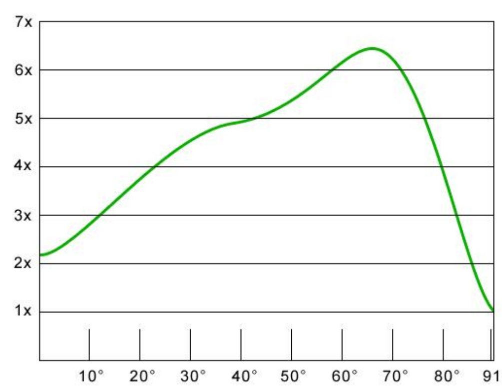


Figure 7 : Image footprint with higher (+) resolution in the zone of interest for video surveillance scenario (right : the resolution distribution)

3.2 Projection & Immersive Systems

Panomorph lens feature can also be used in projection systems. To project in a dome to produce immersive experience, the projected pixel of the DLP or SLM will use only a circular area of the active device making the other pixel obsolete. By using the Panomorph lens concept in particular the anamorphic correction we can display on the active device an elliptical area that pass through the Panomorph lens to project into a dome. Such approach will increase the number of projected pixel and will also provide more light on the screen. This make possible the use of HDTV projector for immersive experience.

Figure 8: Immersive projection experience

3.3 Biomedical & Inspection

The Panomorph lens can be miniaturized in order to be installed on a cell phone or other very small device. For example, inspection fiberscope or endoscope can use a Panomorph lens to replace a standard limited FOV lens. This makes larger field of view available in very small zone where it is not possible to rotate the fiberscope.

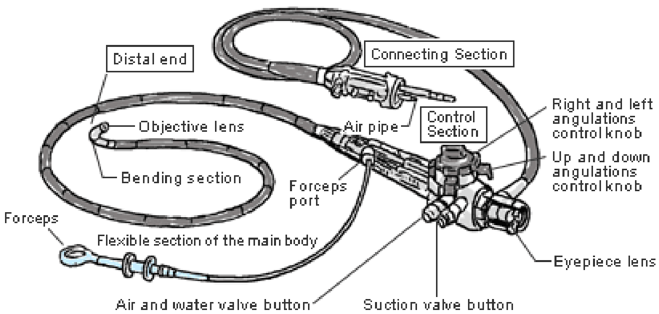


Figure 9: Fiberscope system for inspection

3.4 Automobile

In an automotive application, the benefits of panoramic technology might include "intelligent" airbag deployment, blind spot detection, automated or assisted parking, back-up warning systems, pedestrian detection, and lane departure warnings -- all accomplished with the use of a very limited number of sensors. For example: A single panoramic sensor flush-mounted on the front of a vehicle could provide all the information necessary for adaptive cruise control, pedestrian detection, lane-departure alerts and even lane following. A second panoramic sensor mounted on the back of the vehicle could provide all the information necessary for parking assistance, assisted overtaking of another vehicle (by allowing a view of the other side of the road from a point of view different than the left rear-view mirror), back view, and others.

As another example, an intelligent airbag system might combine seat-specific weight sensors with a stereo 2D overhead camera. Complex software is required to correlate the data from each sensor, and it may take additional devices to discriminate between a 70-lb. box and a 70-lb. child. The alternative is to build a consolidated system around a few or even a single panomorph optical sensor that can recognize and size (range) the object in the vehicle. Combining both ranging and recognition in a single, dedicated, small panomorph sensor will result in a practical imaging system that could potentially reduce the number of sensors required in the car. The same imaging sensor could also be used as a back-seat view camera (for child safety) or even as a anti-theft system that could view/record (pre-determined loop time) the entire inside area of the car. In fact, a rear, interior and forward-view single panomorph camera can handle a large number of applications simultaneously.

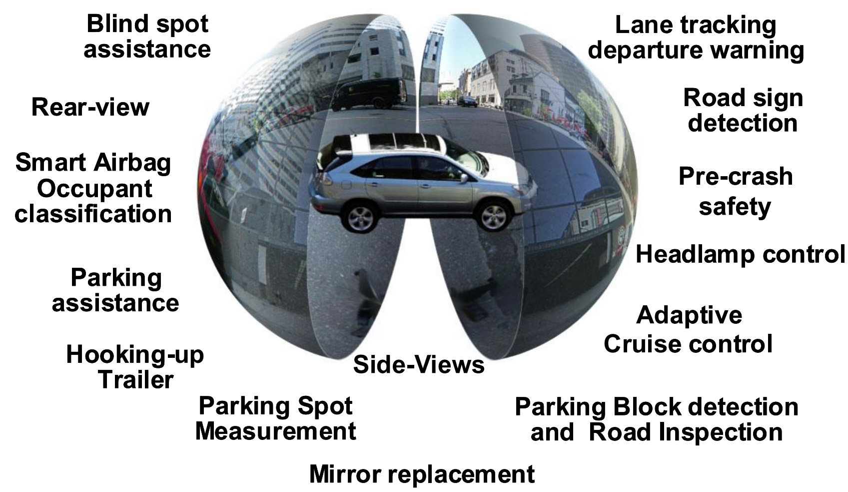


Figure 10: Advance camera applications for automotive

3.5 Unmanned vehicle and Robotic

During the last decades, a lot of work have been done to provide efficient and effective navigation vision system. However, to make navigation decisions based on 360 degrees FOV is still today a subject of interest. However, standard panoramic imager has not provided a good solution. The Panomorph lens provides an efficient alternative.

Four other applications can be made with such 220^o x 360^o FoV Panomorph lens configuration and will allow total situation awareness system with a reduced number of sensors:

- Remote and automatic navigation
- 3D vision and 3D reconstruction
- Secondary Targets detection and tracking: Using distortion management algorithms (provided in ImmerVision's SDK), it is possible to generate a virtual unwarped view (Undistorted 2D view) around each detected target in the hemispheric FoV. Each of the view would track/follow each detected target allowing operator to qualify.
- Primary Target detection and tracking: image fusion between high resolution PTZ camera and the panomorph camera would allow an operator to better qualify primary target and still keep/track secondary target in the full hemispheric FoV,

Figure 11: Robot and unmanned vehicle system.

An IR panoramic system can also be used for driving ground vehicles in darkness or conditions of limited visibility, since it provides a field of view similar to that of the human eye and is therefore intuitively more user-friendly. Mounted on top of a vehicle it can be used to see events in darkness and the activity all around the vehicle, including people and other life forms, objects, and activities. It can also be used to see around ships to detect threats or to follow activities in progress.

5. CONCLUSION

We have discussed the current developments in panoramic imager design by providing an historical perspective from the reversed telephoto to the new controlled-distortion lenses such as the panomorph lens. Modern panomorph lenses which provide a distortion control approach and an anamorphic design are considered a major enhancement in panoramic vision. We have presented various current scenarios where a high-resolution panoramic imager will be most advantageous. In a sense, this a new age for Panoramic applications.

Over the last several years, ImmerVision's research team has focused on the imaging process and the development of a new type of panoramic imager that is optimized to provide superior image mapping with respect to specific applications. The recent development in panoramic vision system created a new interest for the research and technology field. We will focus during the next years on the technology development to produce new generation of panoramic imager using most recent digital camera (MPxs), IR FPA and miniature systems. In the mid time, we develop simulation tools that can provide the virtual system performance before fabrication. Such unique tools can be used to determine and orient future development.

REFERENCES

[1] Kingslake R. Development of the photographic objective. *Proc SPIE* Vol. 0531, pp. 60-67, 1985

[2] Miyamoto K. Fish Eye Lens, Letters to the Editor. *JOSA*, Vol. 54, pp. 1060-1061, 1964.

[3] Kumler J, Bauer M. Fisheye lens design and their relative performance. *Proc SPIE* Vol. 4093, pp. 360-369, 2000.

[4] US Patent 4,082,434. Wide-angle optical system for door viewer, issued to T. Hiyashi, September 4, 1978.

[5] Greguss, Pal. Panoramic Security. *SPIE* Vol. 1509, pp. 55-66 (1991).

[6] Greguss P. Panoramic imaging block for three-dimensional space. US Patent 4,566,763 (28 January 1986).

[7] Horridge GA. The compound eye of insects. *Sci Am* Iss. 237, p 108-120, July 1977.

[8] A. N de Jong and P.B.W. Schwering, IR panoramic alerting sensor concepts and applications, *Proc SPIE* **5074**, 658-668 (2003).

[9] Chahl JS and Srinivasan MV. Reflective surfaces for panoramic imaging. *Applied Optics* Vol. 36, No. 31, pp. 8275-8285.

[10] Kweon G, Hwang-bo S, Kim G-h, Yang S-c and Lee Y-h. Wide-angle catadioptric lens with a rectilinear projection scheme. *Applied Optics* Vol. 45, No. 34, pp. 8659-8673.

[11] Thibault S. Distortion Control Offers Optical System Design a New Degree of Freedom. *Photonics Spectra* May 2005, pp. 80-82.

[12] Thibault S. Enhanced Surveillance System Based on Panomorph Panoramic Lenses. *Proc SPIE* Vol. 6540, paper 65400E, 2007.