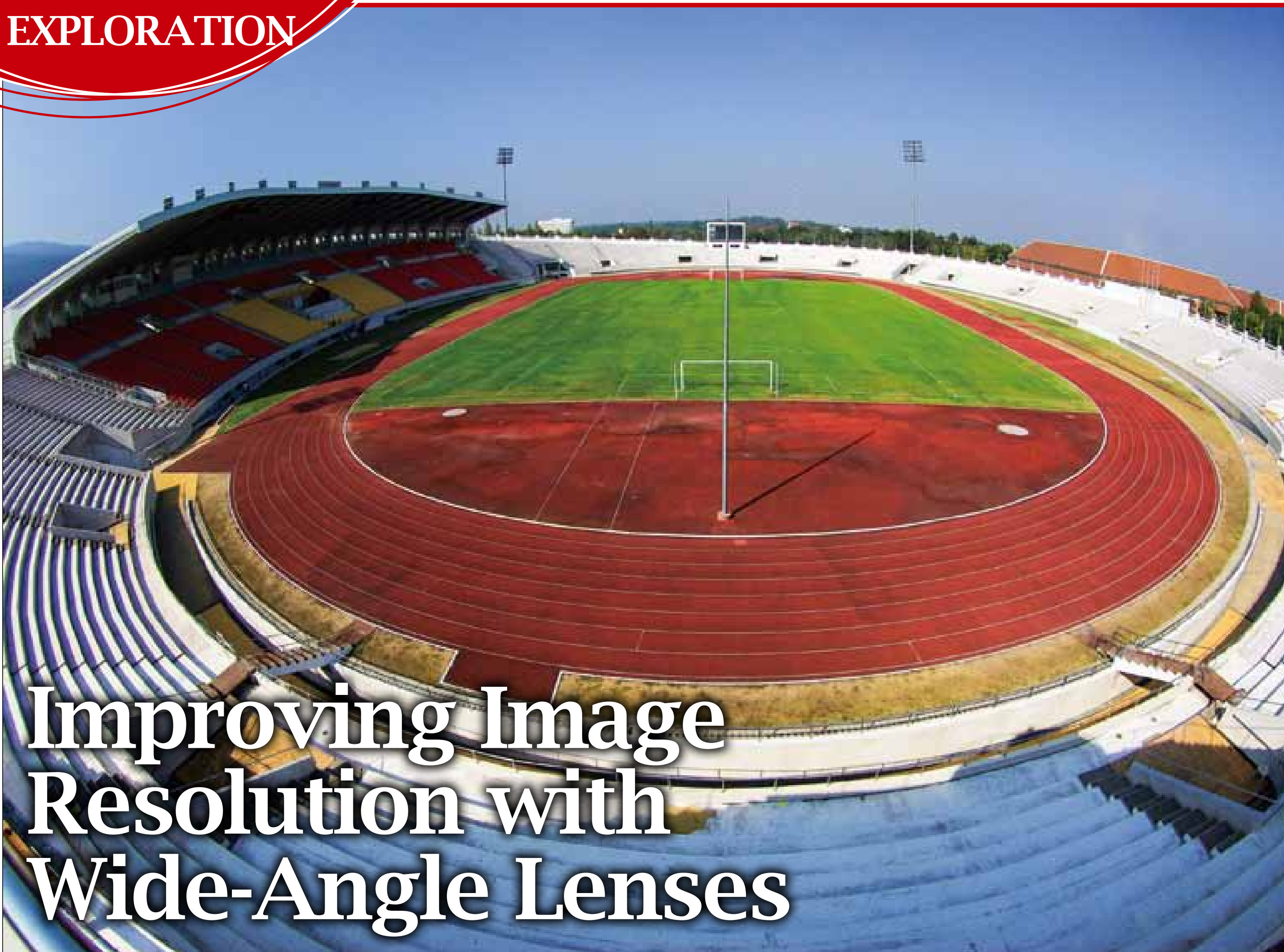
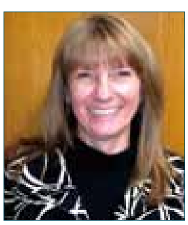


Improving Image Resolution with Wide-Angle Lenses

Theia Technologies provides a detailed explanation on how users can avoid falling for one of the many marketing hypes out there. Also, this article explains in detail the benefits of using a rectinlinear lens and how users can utilize wide-angle lenses to their advantage in suitable environments.

■ **CONTRIBUTED BY** THEIA TECHNOLOGIES

Despite inflammatory media accounts proclaiming the end of the megapixel race in the security industry, recent conversations with camera OEMs suggest otherwise. In fact, camera companies appear poised to up the ante and are moving forward with plans to increase camera resolution, following the lead of cellphone and digital camera companies before them. Nokia, for example, has come out with their 41-megapixel cellphone camera. While the camera may indeed provide 41 megapixels of native resolution, the image resolution is likely limited by the lens. Without a good megapixel lens, the claims of multi-megapixel resolution are just marketing hype.



> **"Without a good megapixel lens, the claims of multi-megapixel resolution are just marketing hype."**
>
> **Andrea Iñiguez,** VP Business Development, Theia Technologies

WIDE-ANGLE LENSES

Creating a representation of this world on a two-dimensional plane in a camera creates some optical effects, especially when viewed through a wide-angle lens.

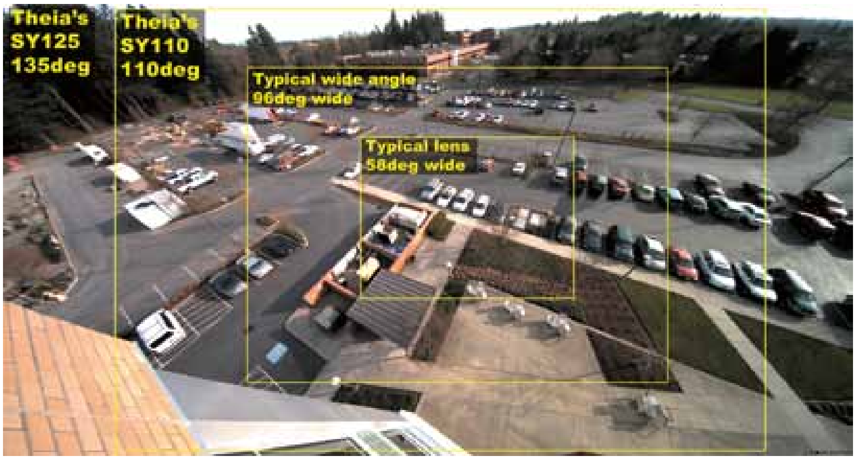


Figure 1 FOV increases with increasing camera resolution (total number of pixels) without any change in image resolution (pixels per foot). The 3- and 5-megapixel images are cropped vertically to eliminate uninteresting sky and ground areas of the image. This cropping reduces the total number of pixels but doesn't affect the pixels-per-foot resolution.

There are two approaches used when designing wide-angle lenses: equal angular slices — each pixel receives an equal angle leading to barrel distortion in the image; equal planar distances — each pixel images an equal distance in a plane, this is a rectilinear lens. The two families of wide-angle lenses create very different views of the world.

HD and megapixel cameras have many advantages as long as you have the right lens for the job. When that includes covering large areas or reducing cost by installing fewer cameras, that lens is a wide-angle lens. Wide-angle lenses are not a panacea, but there are many applications that benefit from their use. For applications requiring large areas of coverage, an ultra wide-angle lens on a megapixel camera is a cost-saving opportunity that should be considered. Wide-angle lenses can reduce the number of cameras required to cover an area, reducing cost of installation, maintenance and monitoring. They can be used in place of a PTZ camera when post-incident digital PTZ is desired and effectively monitor large areas like parking lots, schools, and construction sites. Also, they can be used in close-up applications such as ATMs, card-locked garage entries, and multi-door entryways where both high image detail and wide field of view (FOV) are required.

Until recently, only fisheye lenses had been available for an ultra-wide FOV. Fisheye lenses have the well-known barrel distortion seen in almost all wide-angle lenses with FOV greater than 80 degrees. This distortion causes the image to look curved and resolution to be reduced as the object moves farther from the center of the image. The distortion effect can be eliminated with software (creating a rectilinear lens image), but at the cost of compromised time or processing power. Objects at the edges of the image are compressed and details are lost when information travels through the lens and software is unable to recapture the information.

By contrast, Theia has developed a family of rectilinear lenses giving a different ultra-wide view without the barrel distortion or loss of edge resolution of fisheye lenses. Rectilinear lenses keep straight lines in the real world straight on the image sensor. This creates an effect called 3D stretching, or lean-over, in which objects at the image edge seem to be stretched because they are being "flattened" onto a plane.

WIDE-ANGLE FOV

Another advantage of the higher resolution available from megapixel cameras is the ability to cover a much wider area with the same or better resolution compared to analog cameras. Because the total available pixels spread across the FOV is greater, the FOV can be increased without decreasing image resolution.

Table 1 below compares the FOV of different cameras at a distance of 32 feet from the subject at the same image

Camera	Image width	Resolution	Lens focal length	Field of view	Field of view increase
Analog	Not so wide	18 pix/ft	4.5 mm	58° (36 ft)	
1.3MP	Wide angle	18 pix/ft	2.2 mm*	96° (71 ft)	2x
3MP	Super wide	19 pix/ft	1.7 mm*	120° (110 ft)	3x
5MP	Ultra wide	18 pix/ft	1.3 mm*	132° (144 ft)	4x

Table 1 Image width increases with total number of pixels at constant image resolution
* For the same FOV, rectilinear lenses (see below) and lenses with barrel distortion will have different focal lengths. A 180-degree fisheye lens may have a focal length of 2.2mm because it has a distortion of more than 80 percent, whereas a rectilinear lens can have a focal length of 1.3mm and FOV of only 125 degrees.

resolution. As the camera resolution (total number of pixels) increases, so does the field of view at constant image resolution (pixels per foot). Clearly, the higher the number of pixels in the camera, the wider the FOV at a constant image resolution. This increase in FOV is also shown in Figure 1 below.

RECTILINEAR VS. FISHEYE

The shorter the lens focal length, the wider the FOV. When greater than about 90 degrees, most lenses start to show curved, barrel-distorted images that are compressed at the edges. Rectilinear lenses do not exhibit barrel distortion and thus maintain image resolution out to the edge of the image.

Traditional wide-angle lenses with barrel distortion (also known as fisheye distortion) cause the image to look curved and bulged out in the center. Rectilinear lenses keep lines that appear straight in the real world straight on the image sensor. This has the benefit of increasing the resolution of the image at the edges (i.e. an object will cover more pixels in the image when the object is at the edge of the image), whereas lenses with barrel distortion cause the image to be compressed at the edges and resolution is reduced. With typical distorted wide-angle lenses, potentially valuable information is lost in the lens and no software — dewarping or otherwise — can recapture or reconstruct this lost information in the image. Any dewarping will create an image that looks like that from a rectilinear lens but at lower resolution. With a rectilinear lens, the image is spread over a greater number of pixels at the edges, increasing the probability of detection and identification.

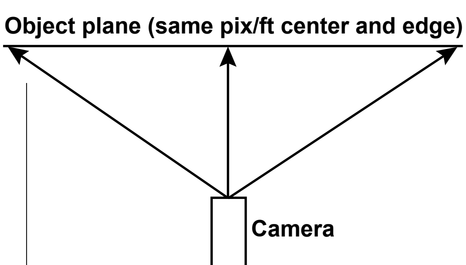


Figure 2 Objects in a plane perpendicular to the camera have the same image resolution at the center and edge of the image.

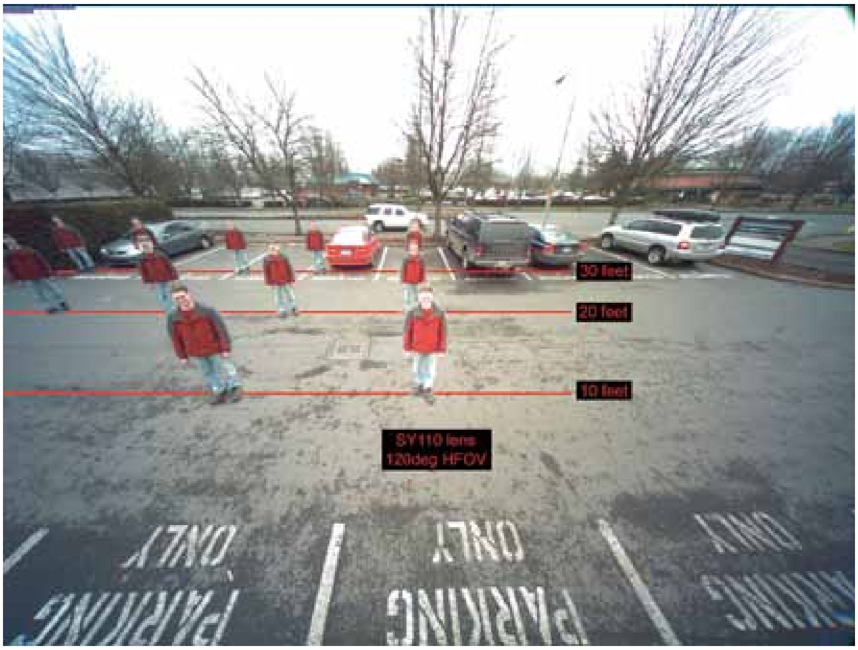


Figure 3 These targets are in a 10 x 10 feet grid. At 20 feet from the camera using Theia's lens with 120-degree field of view, the horizontal field of view (HFOV) is 60 feet. Targets at the edge of the image are twice as far from the camera but can be seen as clearly as those in the center of the image along the same plane.

Objects in a Plane

With a rectilinear lens, objects in a common plane perpendicular to the camera have the same image resolution at the center and edge, even though the objects at the edges are much farther away from the camera. This is shown in Figures 2 and 3.

For rectilinear lenses, the wider the FOV, the more this effect is noticeable. Rectilinear lenses possess an additional benefit in providing increased resolution at the edges of the image because of 3D stretching. This effect is not what most people are used to seeing but it has the advantage of increased resolution (pixels per foot) for objects at the edge of the image compared to lenses with barrel distortion. For lenses with barrel distortion, the objects at the edge of the image will be smaller than those in the center and they will curve towards the center. Because the effect is only present when objects have length parallel to the camera in the third (depth) dimension, such as the length of the cars, it is called 3D stretching.

Objects in an Arc

With a rectilinear lens, the calculation of resolution of objects in an arc with the camera at the center is a little more complicated. As an object moves from the center of the image towards the edge in an arc without changing the distance to the camera, the object will increase in resolution significantly. This is shown in Figures 4 and 5.

Figure 5 As subjects move in a circle with the camera at the center, they increase in size due to 3D stretching, making them more recognizable towards the edges of the image. This 135-degree field of view was captured using Theia's lens.

This case, shown in Figure 5, clearly shows the resolution increase as objects move around the arc at constant distance from the camera. The image of the person standing 11.5 feet from the camera will increase in width due to 3D stretching as they move to the edge of the image. At the image edge, they may be more clearly identified compared to the center and compared to a lens with barrel distortion. Lenses with barrel distortion will not show an increase in object width.

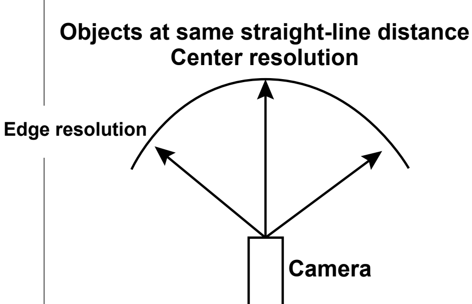


Figure 4 Objects in a circle, equidistant from the camera, will increase in resolution as they move from the image center to edge.

RESOLUTION PERFORMANCE OF LENSES BASED ON LINEAR OPTICAL TECHNOLOGY

Image resolution and half field of view are functions of camera distance for Theia's rectilinear lenses. For example, if 20 pixels per foot are required for a general surveillance application with a 5-megapixel camera and Theia's lens, the camera would need to be 37 feet away from an object in the center of the image. As the object moves perpendicular to the camera (as described in Figure 1), the image resolution will remain 20 pixels per foot even though the object is getting farther from the camera. The resolution of wide-angle, non-rectilinear lenses will decrease as the object moves along this line.

In summary, there are many definitions of resolution. The two most commonly used in the security industry are total number of pixels in a camera and the pixels per foot in an image. As the total number of pixels increases, the detail in the image or the field of view, or both, can be increased. For wide-angle lenses, rectilinear lenses increase the image resolution at the edges of the image, improving the possibility of detection and identification. High-definition and megapixel cameras need high-performance, wide-angle lenses that can display high-resolution images of large areas. Fisheye lenses create barrel-distorted, curved images requiring software image correction whereas rectilinear lenses correct distortion optically in the lens — an elegant and efficient solution. a&s