# RESOLUTION ENHANCEMENT AND ZOOM

## BACKGROUND OF THE INVENTION

Image systems including television cameras, charge coupled device imagers, forward looking infrared sensors, and infrared charge coupled device detectors produce a video image having a resolution limited by the sampling rate of the imager. Designers of such systems typically limit the sampling rate to slightly more than two samples between the first zeros of the diffraction blur in accordance with the Nyquist criteria. The Rayleigh resolution limit (computed from the size of the aperture and the wavelength of the sense energy) describes the limits of what the eye can see. A discussion of the Rayleigh limit is given in Jenkins and White, *Fundamentals of Optics,* McGraw-Hill, 1957, at page 304. Specifically, a minimum angle of resolution between two points, for an imager having a circular aperture of diameter D sensing light wavelength $\lambda$, is $0.244\lambda/D$ radians. Accordingly, scanning imager systems are typically designed so that scan angle subtended between adjacent samples is less than $0.122\lambda$ radians.

## SUMMARY OF THE INVENTION

In this invention, the resolution of an object is enhanced first by effectively decreasing the scan angle subtended between adjacent samples to well below that of the Rayleigh limit to obtain a better estimate of an image blurred by the point spread function (or diffraction pattern) of the aperture. The next step is to process this blurred image at least to partially remove the blur. The unblurring process consists of correlating each small segment of the blurred image with blurred images of preconstructed image primitives and then synthesizing a new silhouette image comprising a mosaic of spatially correlated members of the original (unblurred) primitive set. The blurred images of the primitives are obtained from a complete set of image primitives comprising, ideally, all possible primitive shapes. These primitives are blurred by convolution with the point spread function of the aperture of the imager.

In one embodiment of the invention, the increase in sampling rate, beyond the Rayleigh limit in a conventional imager having its sampling rate limited by the Rayleigh criterion, is achieved by using multiple image registration. This technique allows the present invention to be used on existing imaging systems. In the multiple image registration of this invention, a single multiple-registered video frame, consisting of a plurality of subpixels of reduced area, is constructed from a plurality of normal video frames, each comprising a plurality of standard pixels. The image motion or camera jitter between subsequent normal video frames determines the subpixel displacement in the multiple-registered video frame. Implementation of multiple-image registration in already existing system hardware may be accomplished using a correlation tracker, or image motion compensating servo error or camera platform stabilizing gyro error. The subpixel displacement is determined in this way.

In another embodiment of the invention, the number of samples in a given angle of scan in a conventional imager may be increased by using image interpolation and zoom. Image interpolation and zoom is useful when there is not enough time to process a plurality of video frames to construct a multiple-registered video frame. Another technique is to use smaller sized detectors in order to achieve dense sampling in a single frame.

## DESCRIPTION OF THE FIGURES

The invention may be understood by reference to the accompanying drawings, of which:

FIG. **1***a* illustrates a typical aperture and sensor receiving light from two point sources;

FIG. **1***b* illustrates the diffraction pattern or point spread function corresponding to FIG. **1***a;*

FIG. **2***a* illustrates four multiple-registered video frames;

FIG. **2***b* illustrates a sub-pixel mosaic synthesized from the four multiple-registered video frames of FIG. **2***a;*

FIG. **2***c* illustrates an imaging device suitable for generating multiple-registered video frames;

FIG. **3** illustrates a scheme for fast acquisition of multiple-registered video frames;

FIG. **4** illustrates an image interpolation technique which may be used in this invention in lieu of the multiple-registration technique of FIGS. **2***a,* **2***b* and **2***c;*

FIG. **5** illustrates an exemplary set of image primitives;

FIG. **6***a* illustrates the image primitive matched filter correlation technique for synthesizing an enhanced resolution image;

FIG. **6***b* illustrates the implementation of the technique of FIG. **6***a* for a single image primitive matched filter, as a simplified example; and

FIG. **6***c* illustrates a point spread function of the same function shown in FIG. **6***b.*

## DETAILED DESCRIPTION OF THE INVENTION

FIG. **1***a* is a simplified schematic diagram illustrating two points A, B viewed through a circular aperture **1** (shown in cross-section) of diameter D by a lens **3** of a camera **5** senses the radiation of wavelength $\lambda$ emitted or reflected from the two points A and B. The angle $\theta$, subtended between the two points A and B at the lens **3**, is equal to the Rayleigh limit $0.244\lambda/D$.

FIG. **1***b* is a diagram illustrating the corresponding diffraction patterns produced at the lens **3** by the radiation from point A (solid line) and from point B (dashed line) in which the ordinate corresponds the photon intensity and the abscissa corresponds the position along the X axis of FIG. **1***a.* Such diffraction patterns of point source images are uniquely characteristic of the aperture, and are termed "Point Spread Functions".

The Rayleigh criterion establishes the resolution limit of two points viewed through an aperture. Specifically, the Rayleigh criterion states that the minimum perceptible separation between the two points A and B occurs where the peak P(A) of the diffraction blur of one point corresponds to the first zero Z(B) of the diffraction blur of the other point. This is exactly the condition illustrated in FIG. **1***b.* This criterion is based upon the fact that, below this separation, there is no longer a discernable diffraction valley between the peaks. However, it is a principle of this invention that the Rayleigh criterion relates to the behavior of the human eye and is not a fundamental limit on the resolution of an image viewed through a particular aperture and, in fact, a greater resolution is possible if processing is used. Specifically, the shape of the blurred image of two points, whose separation is precisely at the Rayleigh limit, is different from that of a single point. Furthermore, the blurred