SUPER RESOLUTION METHODS FOR ELECTRO-OPTICAL SYSTEMS

RELATED APPLICATIONS

The present application is related to copending commonly assigned U.S. patent application Ser. No. 08/763,610, filed on Dec. 11, 1996, entitled "Apparatus and Method For Providing Optical Sensors With Super Resolution", incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to optical devices, and more particularly to an optical sensor utilizing background reconstruction image processing techniques in order to provide a much higher level of resolution of a localized object within a background scene.

BACKGROUND OF THE INVENTION

Optical sensors are devices which for decades have been used to detect and record optical images. Various types of optical sensors have been developed which work in the Ultra Violet Bands, Infra Red Bands as well as in the Visible Bands of operation. Examples of such devices include Weather Sensors, Terrain Mapping Sensors, Surveillance Sensors, Medical Probes, Telescopes and Television Cameras.

An optical sensor typically includes an optical system and one or more detectors. The optical system portion is made up of various combinations of lenses, mirrors and filters used to focus light onto a focal plane located at the image plane of the optical system. The detectors which make up the image plane are used to convert the light received from the optical system into electrical signals. Some types of optical sensors use film rather than detectors to record the images. In this case, the grain size of the film is analogous to the detectors described above.

An important performance characteristic of optical sensors is their "spatial resolution" which is the size of the smallest object that can be resolved in the image or, equivalently, the ability to differentiate between closely spaced objects. If the optical system is free from optical aberrations (which means being "well corrected") the spatial resolution is ultimately limited by either diffraction effects or the size of the detector.

Diffraction is a well known characteristic of light which describes how light passes through an aperture of an optical system. Diffraction causes the light passing through an aperture to spread out so that the point light sources of a scene end up as a pattern of light (known as a diffraction pattern) diffused across the image. For a well corrected, unobscured optical system known as a diffraction limited system, the diffraction pattern includes a very bright central spot, surrounded by somewhat fainter bright and dark rings which gradually fade away as the distance from the central spot increases.

An optical sensor that is designed to be diffraction limited usually has a very well corrected optical system and detectors sized so that the central spot of the diffraction pattern just fits within the active area of the detector. With conventional sensors, making the detectors smaller does not improve resolution and considerably increases the cost due to the expense of the extra detectors and the associated electronics.

The size of the aperture used in the optical system determines the amount of resolution lost to diffraction

effects. In applications such as camera lenses and telescope objectives, the aperture size is normally expressed as an f-number which is the ratio of the effective focal length to the size of the clear aperture. In applications such as microscope objectives, the aperture size is normally expressed as a Numerical aperture (NA) which is the index of refraction times the sine of the half angle of the cone of illumination. For a given focal length, a high f-number corresponds to a smaller aperture, while a higher Numerical aperture corresponds to a larger aperture.

A basic limitation of conventional optical sensors is the aperture size required for a given level of resolution. Higher resolution images require larger apertures. In many situations the use of such a system is very costly. This is because using a larger aperture requires a significantly larger optical system. The cost for larger systems which have apertures with diameters greater than one foot is typically proportional to the diameter of the aperture raised to a power of "x". The variable "x" usually ranges from 2.1 to 2.9 depending on a number of other particulars associated with the sensor such as its wave band, field of regard, and field of view.

The size of the optical sensor is particularly relevant for systems that fly on some type of platform, either in space or in the air. Under such conditions the sensor must be light weight, strong, and capable of surviving the rigors of the flight environment. Thus the cost of going to a larger optical system can be in the hundreds of millions of dollars for some of the larger and more sophisticated sensors. Practical considerations, such as the amount of weight the host rocket, plane, balloon, or other vehicle can accommodate, or the amount of space available, may also limit the size of the sensor. These practical considerations can prevent a larger system from being implemented no matter how large the budget.

A number of optical imaging techniques have been developed to increase spatial resolution. One such technique is known as sub-pixel resolution. In sub-pixel resolution the optical system is limited in spatial resolution not by diffraction but by the size of the detectors or pixels. In this case, the diffraction pattern of the aperture is much smaller than the detectors, so the detectors do not record all the resolution inherent in the optical system's image. Sub-pixel resolution attempts to reconstruct an image that includes the higher resolution not recorded by the detectors. This technique does not require hardware or system operation changes in order to work. Examples of sub-pixel resolution techniques are disclosed in an article in ADVANCED SIGNAL PROCESSING ALGORITHMS, ARCHITECTURES AND IMPLEMENTATIONS II, by J. B. Abbiss et al., The International Society For Optical Engineering, Volume 1566, P. 365 (1991).

Another example is the use of "thinned aperture" systems where for example, a widely-spaced pattern of small holes is used as a substitute for the complete aperture. However, even "thinned apertures" are limited in resolution by diffraction theory and by the outer diameter of the widely-spaced pattern of small holes. Note that current electro-optical systems are sometimes designed so that the size of their detector matches the size of the diffraction blur of their optics.

Other examples of optical imaging techniques are disclosed in an article entitled SUPER RESOLUTION ALGORITHMS FOR A MODIFIED HOPFIELD NEURAL NETWORK, by J. B. Abbiss et al., IEEE Transactions On Signal Processing, Vol. 39, No. 7, July 1991 and in a paper entitled FAST REGULARIZED DECONVOLUTION IN