Image Processing, vol. 6, no. 12, pp 1646–1658, December, 1997. Using a Steepest Descent algorithm, the following iterative equation may be used.

$$f_{j+1}=f_j+\mu h^T[g-hf_j]$$

where h is the spatial domain point-spread function as defined above, f_{-0}, the initialization vector can be any vector, and where $\mu>0$ is small.

One advantage of the iterative approach is that point-spread function compensation can be combined with two-dimensional resampling. Often, the desired scanned image may have a sample rate that is less than the highest possible optical sampling rate. High resolution color images require a lot of memory, and image analysis or transmission over a communications channel may require a substantial amount of time. Accordingly, an operator may choose a lower sampling rate to reduce memory, processing time, or transmission time. An image may need to be scaled to fit within a frame in a document or display, with a sampling rate that is determined by the resolution of a printer or display device. As a result, the desired sampling rate may be any arbitrary number. Finally, in some scanning configurations, scanning time may be reduced if sampling rate is reduced. Scanning time is often limited by an exposure time per pixel which is required to obtain a particular signal-to-noise ratio. Charges for adjacent CCD elements may be combined to enable a faster, but lower sampling rate, scan.

For any of the above reasons, scanner operators often request some fraction of the highest optical sampling rate. Typically, samples for a single scan line are read by the scanner at the highest optical sampling rate, intermediate interpolated samples are computed, and the desired sampling rate is obtained by resampling the interpolated samples. For example, a scanner may have a 1,200 pixel per inch optical sampling rate, and may interpolate to 4,800 pixels per inch, and then resample the 4,800 pixels per inch samples to provide an image having 938 pixels per inch (where 938 is just an arbitrary example for illustration). For scanners having a moving linear sensor array, interpolation and resampling may provide an arbitrary resolution along the scanline, and resolution in the direction of scanning may be controlled by the translation speed of the sensor array. Alternatively, bilinear interpolation may be used to compute a pixel value using the intensities of the four closest neighboring sensor values. However, as discussed in the article by Elad referenced above, compensation for blurring (by using the point-spread function) and two-dimensional resampling may be combined in the iterative approach.

While there are advantages to the iterative approach as discussed above, many scanners have specialized hardware support for spatial domain kernel operations. Accordingly, in the following discussion, the kernel approach is used for illustration. In general, the point-spread function is only part of the information used to compute the kernel.

Computation of kernels from edge-spread data may be performed within the scanner. Alternatively, for peripheral devices, edge-spread data may be uploaded to a host computer. The host computer may then compute the kernels and download the kernels to the scanner. An image scanner may also need to convolve an image with other kernels, for example, for image sharpening. The various kernels can be convolved together, and the resulting combined kernels can be applied to the scanned image data. Some kernel information may be determined by a host computer. For device independence, the scanner may need to upload internal scanner kernel information to the host computer. The host computer may then convolve scanner specific kernels with kernels determined by the host computer and download the resulting combined kernels to the scanner. See, for example, U.S. patent application Ser. No. 08/775,061. In accordance with the present invention, the scanner may upload edge-spread data to the host computer in addition to other kernel information.

With N patterns, the scan line is divided in N regions, and the point-spread function is assumed to be constant within each region. For each region, a convolution kernel is computed from the corresponding point-spread function and desired modulation transfer function. The kernel size is preferably greater than the extent of any blurring. For example, a kernel of nine-by-nine values may be used if blurring of one pixel does not extend beyond 4 pixels in any direction. For each region, in the spatial domain, a convolution kernel is used to operate on each pixel within the region. Pixels near the document edges may remain unfiltered, or edges may be extended using null data to enable filtering to extend to the edges. If optics compensation kernels are convolved with other kernels, then the optics compensation kernel that is convolved with other kernels will be dependent on the region being scanned.

FIG. **4** is a top view of a scanner illustrating additional calibration patterns alongside a document. FIG. **4** shows patterns **400** on only one side of the document, but they may also be placed on both sides of the document. If temperature change is relatively rapid during a scan, the point-spread functions computed before the scan may become inappropriate. Additional patterns alongside a document enable checking to see if at least one of the point-spread functions is changing during the scan. For purposes of monitoring for change, it may not be necessary to compute an entire point spread function. It may be sufficent, for example, to monitor one edge-spread function at one angle. If the measured function is changing in real time, and if the lens system changes consistently, monitoring patterns as in FIG. **4** may provide sufficient information to permit real time modification of the point-spread functions. Alternatively, the scanner may simply go back to the beginning, and recalibrate and rescan.

Incorporating calibration targets within a scanner also facilitates compensation for operater controlled variables, including resolution and motion blur. If there is continuous relative movement between a sensor array and a document being scanned, some blur results from movement during the exposure time for each pixel. If the amount of motion is known, then motion blur can be incorporated into the compensation kernel. See, for example, the article by Elad referenced above. In many scanners, the optical sampling rate in a direction perpendicular to a scan line is determined by the speed of the relative scanning motion. For example, if an operator asks for a high resolution, the relative scanning motion is relatively slow, and if an operator asks for a low resolution, the relative scanning motion is relatively fast. With calibration patterns internal to the scanner (as in FIGS. **2** and **3**), the patterns should be scanned at the (X,Y) resolution specifed by the operator. Then, image specific resolution and motion blur become inherent to the calibration process.

In summary, providing multiple calibration target patterns within a scanner enables use of a lower cost lens system, where the lens system may have optical characteristics that may vary from lens to lens and may vary with temperature and time. In addition, providing calibration target patterns within a scanner facilitates computation of image specific compensation (for example, specific (X,Y) resolution and motion blur). In addition, no ROM is required to store extensive tables of predetermined point-spread data.