In an alternative embodiment, a two-dimensional known random pattern is provided for a target. Cross-correlation of a portion of the known random pattern with the scanned image of the same portion of known random pattern provides an estimate of the point-spread function for the portion of the scan line corresponding to the portion of the known random pattern.

Each individual optical transfer function is then used to compensate for optical aberrations. In one embodiment, the optical transfer function is used to compute a convolution kernel for the corresponding segment of the scan line. The scanned image pixels within each segment of the scan line are convolved with a kernel appropriate for the segment. In an alternative embodiment, an iterative solution is used to compute a compensated image.

Providing a series of targets, or a continuous random target over the width of the scan line, within the scanner, enables determination of the optical transfer function, as a function of position for an assembled lens, at the humidity and temperature appropriate for the scan. Additional targets alongside a document enable ongoing verification during a scan. As a result, a smaller, lower cost lens can be used and some image degradation can be removed from the final scanned image.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-section side view of an example image scanner with a calibration target in accordance with the invention.

FIG. **2** is a plan view of an example calibration target.

FIG. **3** is a plan view of an alternative calibration target.

FIG. **4** is a top view of the scanner of FIG. **1** illustrating additional targets alongside a document.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

FIG. **1** illustrates part of an example image scanner **100**. The scanner **100** includes a transparent platen **102**. A document **104** to be imaged is placed face down on the transparent platen. A light ray **106** originates from a lamp **108**, is reflected off the face of the document, and then is reflected off mirrors **110**, **112** and **114**, passes through a lens system **116** and finally onto a photosensor array **118**. Other configurations are common. In general, lens system **116** may comprise multiple elements. In a scanner in accordance with the invention, the optical performance of the lens system **116** is characterized within the scanner, and the scanner partially compensates for lens aberrations using digital image processing. Of particular interest is a lens calibration target **120**. Target **120** is preferably placed so that calibration patterns on the target are at the same focal plane as the face of the document, and target **120** is preferably placed so that it does not interfere with imaging the document **104**.

FIG. **2** is an example embodiment of target **120**. Target **120** is preferably at least as wide as the widest document that can be scanned by scanner **100**. In the example embodiment of FIG. **2**, there are six identical patterns **200**, each of which is a semicircular array of alternating black and white radial wedges. The choice of the number six is for convenience of illustration only, and an actual target may have fewer than six patterns, or more than six patterns, depending on the requirements of the lens system.

For each pattern on target **120**, because of aliasing, each black to white (and white to black) transition in intensity should not be a true step function, but instead should be rapid, with a known rate of change, and ideally the modulation transfer function of the target should be known. Each intensity transition edge can be averaged along its radial extent to reduce noise. An edge-spread function can be computed for each edge. The resulting edge-spread function can be differentiated to produce a one-dimensional component of the point-spread function at one particular angle. See, for example, Kenneth R. Castleman, *Digital Image Processing*, Prentice Hall, 1996, chapter 16. If the point-spread function is circularly symmetrical then a one-dimensional point-spread function computed from a single edge can be rotated to produce the two-dimensional point-spread function. However, in general, edges at many orientations may be needed to accurately determine the two-dimensional point-spread function.

FIG. **3** illustrates an alternative target pattern. In FIG. **3**, the targets are concentric rings. Concentric rings enable measurement of an edge-spread function at any arbitrary angle, with multiple transitions to enable averaging to reduce noise.

Instead of a series of discrete calibration patterns as illustrated in FIGS. **2** and **3**, an alternative calibration target can have a continuous random two dimensional pattern. For example, a suitable pattern in the spatial domain may be obtained by taking the two-dimensional inverse Fourier transform of a two-dimensional spectrum having constant amplitude and random phase. The cross-correlation of the known random pattern and the scanned image of the pattern is the point-spread function of the system. The random pattern can be logically divided into variable sized sections as needed to determine the point-spread function over various segments of the scan line.

When using the point-spread function for compensation, the lens system is assumed to be a linear system. Given an original image f(x,y) and the spatial domain point-spread function of the lens system h(x,y), the resulting scanned image g(x,y) is:

$$g(x,y)=h(x,y)*f(x,y)$$

where "*" indicates two-dimensional convolution. The discrete form is as follows:

$$g(x,\ y)=\sum_m\sum_n h(x-m,\ y-n)f(m,\ n)$$

Given the scanned image g(x,y), and given h(x,y), then the original image is restored (blurring is reduced) by deconvolution:

$$f(x,y)=s(x,y)*g(x,y)$$

where s(x,y) is a spatial domain kernel (deconvolution matrix, or inverse filter) computed from h(x,y), and perhaps modified to also incorporate a desired point-spread function. Given the system point-spread function h(u,v) in the frequency domain, s(x,y) may be computed by computing the inverse Fourier transform of 1/(h(u,v)). Alternatively, given the spatial domain point-spread function h(x,y), then s(x,y) may be computed by solving a series of simultaneous equations;

Alternatively, instead of expressly computing s(x,y), f(x, y) may be computed directly by iteration. See, for example, Michael Elad and Arie Feuer, "Restoration of a Single Superresolution Image from Several Blurred, Noisy, and Undersampled Measured Images," *IEEE Transactions on*