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Scheimpflug with Computational Imaging to Extend the Depth of
Field of Iris Recognition Systems

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Despite the enormous success of iris recognition in close-range and regulated spaces for biometric authentication, it has hitherto failed to gain wide-scale adoption in large, unrestricted environments. The problem arises from a fundamental limitation of optical imaging called the depth of field—the limited range of distances within which subjects appear sharp in the image. The loss of details in the iris image outside a finite volume—the capture volume—dramatically deteriorates the performance of iris recognition beyond a small range of distances. Existing techniques are usually expensive, computationally complex, or exhibit low signal-to-noise ratio. Is there a way to combine the classical Scheimpflug principle, which allows the plane of sharp focus to be expediently oriented, with modern computational imaging to find a reliable method that significantly extends the axial capture volume of iris recognition? Unexpectedly, the technique we found in this thesis is simple, yet it provides several key advantages over existing approaches.

We developed a pair of geometric models to describe imaging in systems in which the lens and the sensor are free to rotate about independent pivots. Apart from being very general, the main advantage of our models over existing ones is that we incorporated the pupil parameters, which

allowed us to predict the geometric properties of the image in such systems more efficiently. Furthermore, analysis of these properties led to the discovery of the set of conditions required for synthesizing an extended depth of field image from a sequence of images captured while continually rotating the lens. We call this new computational technique *angular focus stacking* (AFS). Constrained only by magnification and sensor resolution, AFS can provide significant improvement in the axial capture volume. We have demonstrated an order of improvement of axial capture volume using AFS over conventional image capture. Furthermore, we found that rotation of the lens about the center of the entrance pupil allows us to register the images in the stack analytically, instead of relying on computationally intensive algorithms.

AFS is tailor-made for significantly extending the capture volume of iris acquisition systems, yet it is simple, easily scalable, cost-effective and computationally efficient for real-time performance. Moreover, we obtain huge gains in depth of field without sacrificing optical resolution and signal-to-noise ratio. Additionally, we have demonstrated that we can capture images for AFS faster than the time required by conventional imaging for the same depth of field and exposure level. Therefore, the constraint on subject movement within the large capture volume can be significantly relaxed using the proposed method.

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To Vibha.