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Improving iris recognition with liquid lens technology

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Abstract

Iris identification and verification systems have become one of the most accurate biometric modalities due to the iris's unique and distinguishable features. Technical advances have significantly reduced the cost and size of these systems, leading to an increase in the value proposition for several industries.

Image resolution and quality of focus are essential in deciphering the complex texture of the iris. Conventional iris recognition devices require bulky and high-cost systems to overcome the optical constraints of mechanical lens-based cameras. This paper describes how the use of a liquid lens device can overcome the optical limitations of traditional systems, leading to a low-cost, smaller, and faster system.

Introduction to liquid lenses

Inspired by the functionality of a human eye, liquid lenses offer manufacturers and OEMs improved speed and reliability over mechanical solutions. The human eye can adjust to the surrounding environment at incredibly fast speeds; similarly, Corning's liquid lenses emulate the eyes' fluid and adaptable characteristics to create a rapid response to variable circumstances. This process is made possible by a technology called electrowetting, which uses an electrical signal to manipulate a liquid solution into a workable lens.

Traditional mechanical solutions are limited in their ability to continuously and reliably deliver sharp images. Corning® Varioptic® Lenses offer innovative solutions to complex optical challenges. Varioptic Lenses enable fast focus and micro-focus without moving parts. Traditional camera systems require moving parts which begin to wear down and fail over the lifetime of the device. In comparison, liquid lenses function without the use of mechanically moving parts, eliminating much of the maintenance typically associated with vision systems.

Biometrics for personal identification systems

Biometrics is the science and technology of measuring and analyzing biological data of the human body such as voice patterns, fingerprints, hand or facial patterns, iris patterns, or DNA. Of these examples, the iris carries very distinctive information due to its complex texture. The annular region of the eye, bounded by the pupil and the sclera, is formed during fetal development and stabilizes during the first two years of life. Each iris is distinct, and in a similar fashion to fingerprints, even the irises of identical twins are different. This unique biological data is extremely difficult to tamper with, which makes it an ideal identification feature for applications such as:

- Commercial uses: ATM and other secured financial transactions, computer login, electronic data security, e-commerce, patient ID in healthcare, device unlock/login, physical access control, and credit card transaction security
- Governmental uses: national ID card, border and passport control, driver's license, and social security
- Forensic uses: criminal investigation and suspect identification.

Following the digitalization of society and the associated growing need for more efficient and reliable authentication, the iris recognition biometric market is expected to witness double digit growth from 2017 to 2024. The global biometrics market is forecast to reach $82.8 billion by 2027, growing at a 19.3 percent CAGR from an estimated $24.1 billion in 2020. Iris recognition is estimated to grow at an 18.8 percent CAGR and reach $10.3 billion by the end of 2027.[1]

Iris biometrics is extremely accurate and easier to perform than similarly precise analysis such as DNA. However, it is not as widely adopted as fingerprint recognition - which is less accurate and easier to tamper with - due to the iris-based recognition system cost. To perform correctly, iris-based recognition systems need to capture high-quality images, which often results in a complex and expensive apparatus. Image resolution and quality of focus are key to deciphering the complex texture of the iris. Use of a liquid lens-based iris recognition device can overcome these optical requirements and decrease the size and cost of the system compared to traditional mechanical solutions.

Figure 1: Eye image in focus – iris recognition functional

Figure 2: Eye image out of focus – iris recognition impossible

Technical requirements of Iris Recognition

Published in 2007, the paper "New methods in Iris Recognition" highlights some of the essential advances in iris recognition that have led to increased integration in identification systems, including:

- Disciplined methods for detecting and faithfully modeling the iris inner and outer boundaries with active contours.
- Fourier based methods for solving problems with iris trigonometry and projective geometry.
- Statistical inference methods for excluding eyelashes.

These advances rely on a high-resolution image acquired by the system. Moreover, according to the ISO/IEC (International Organization for Standardization/International Electrotechnical Commission) standard for iris imaging (ISO/IEC 29794-6:2015 Information technology — Biometric sample quality — Part 6: Iris image data): "Sufficient iris-pupil contrast is needed in many implementations of iris segmentation algorithms. Low or insufficient contrast may result in a failure to process an iris image during feature extraction." Later, this standard states that to decrypt the complex structure of the iris, "defocus should be minimized by placing the subject within the depth of field of the camera" so that the device "shall be able to deliver images that result in a measured Modulation Transfer Function (MTF) with a modulation of more than 50% at 2 lp/mm."[2]

As stated above, successful iris recognition requires both a high-resolution image of the eye's pupil and high focus quality. The high resolution necessitates the use of a relatively long Effective Focal Length (EFL) objective lens to have only the eyes within the field of view and avoid having the person right in front of the camera. The ISO/IEC standard for iris imaging also states that "the iris radius shall be at least 80 pixels for the smallest reported human iris of 5.1 mm radius".[3]

It is therefore possible to estimate the focal length based on the formula:

$$f' = d \times \frac{0{,}08p}{5{,}1 + 0{,}08p}$$

with d, the object's distance, and p, the pixel size in microns

The resulting field of view will decrease when the focal length increases. With the value of the sensor size, we can compute the field of view as:

$$FOV = 2 \times \tan^{-1}\left(\frac{sensor\ size}{2f'}\right)$$

Figure 3: Effect of the field of view on the size of the iris

FOV 25° *FOV 18°* *FOV 12°*

Use case: Let us take a 1/2.3” sensor with a pixel resolution of 2.5 µm and an eye located at a maximum distance of 70 cm. Then the longest focal length that can be used is f^’ = 26 mm. The associated FOV is 17°.

Long EFL lenses are associated with low Depth of Field (DoF) which makes the imaging system sensitive to defocus when the position of the object is not fixed. The depth of field of a system can be computed using the formula:

$$DoF = 2Fc\left(\frac{d}{f}\right)^2$$

With F the aperture number, c the circle of confusion (it often is the pixel size), d the distance of the object, and f the focal length of the system

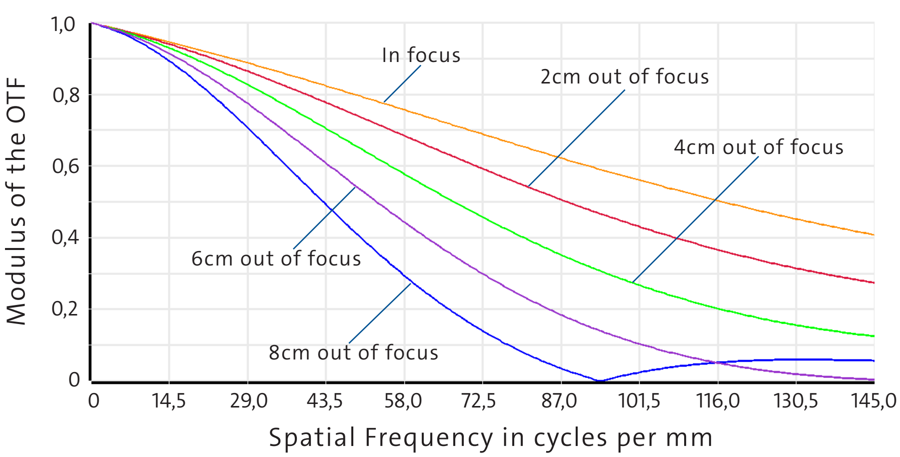
Use-case: With the system previously described, if we assume that the F# is 4, then the depth of field is:

- 14.5 mm @70cm
- 7.4 mm @50cm
- 2.7 mm @30cm

In contrast to fingerprint reading, where the distance from the imaging system to the hand is fixed, it is hardly conceivable to maintain a perfectly constant distance between the imaging system and the eye. Therefore, the primary optical aberration in this use-case is defocus due to the positioning of the eye at different depths in front of the optical stack. The position of the face can vary between tens of centimeters up to a meter. This aberration is not fixed and varies from one case to another, which makes it impossible to compensate for with fixed optical components.

As shown in Figure 4, defocus greatly and rapidly degrades MTF. The loss of MTF is system dependent and may vary from one optical system to another, yet its degradation through focus will systematically occur. The example is given for a 25 mm lens module observing a target located at 90 cm. At 60 lp/mm, the MTF drops from 75% to 57% for a defocus of 4 cm and down to 35% for a defocus of 8 cm.

Figure 4: Impact of defocus on the MTF for a 25 mm EFL lens



One solution is to manually adjust focus. However, this is out of the question for large-scale commercial applications. Some of the automatic solutions for focus compensation include motorized systems, like stepper motors or Voice Coil Motors (VCM). These systems will enable full or partial translation of the optical system and compensate for defocus; however, VCMs are more compatible with small and lightweight lenses and are unable to move heavier lenses such as the telelenses required for iris recognition systems. Additionally, the complex mechanics associated with these solutions result in a bulky system that is often slow, easily breakable, and sensitive to shocks. Finally, moving parts consume high quantities of power and create friction forces which can lead to damage and malfunction after a few hundred or thousand actuations.

A liquid lens solution

Corning Varioptic Lenses are liquid lenses that enable autofocus with a single add-in element. With no mechanical moving parts, a liquid lens can endure hundreds of millions of cycles with low power consumption and at a speed unmatched by conventional actuators. Its robustness and accuracy in autofocus performance makes it well suited for any application requiring large scale autofocus such as iris recognition devices.

Example Use Case

This example considers a security control system at the entrance of a building that performs iris recognition to assess the identity of users entering the premises. The height of each user varies, and their faces could be between 30cm to 75cm away from the recognition device.

At 30 cm, both eyes should be imaged on the sensor. If the device is using a 1/2.3" sensor with a pixel resolution of 1.55 µm, the corresponding EFL is around 15 mm. Let us assume that the F# of the system is 3.7. Based on the system's parameters and the formula for depth of field computation presented previously we estimate the system's DOF to be 0.05 D.

The standard ISO/IEC 29794-6:2015 states that the iris recognition device should be able to resolve 2 lp/mm at 50% MTF in the object space. Based on this value, the system tolerates an MTF drop which extends the DOF (refer to Corning Varioptic Application Note "Best practice for depth of field computation", contact varioptic@corning.com for further information):

$$DOF_{ext} = MTF \times DOF\left(1 + \frac{30(1-\alpha)}{r}\right)$$

With α the contrast required, r the contrast resolution in lp/mm, and
MTF the actual modulation transfer function value without degradation.

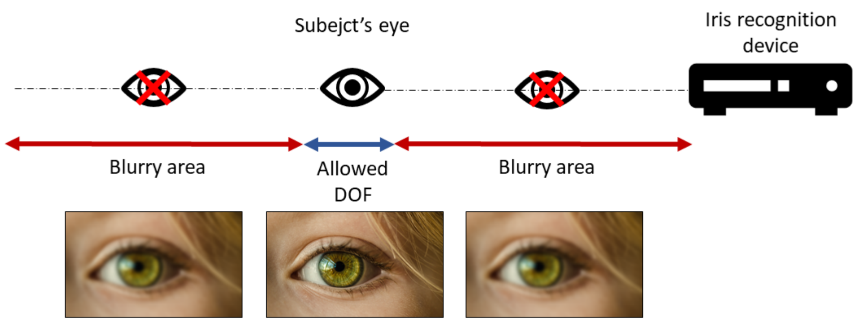
This gives an extended DOF of 0.36 D.

The corresponding areas in focus at different depth are the following:

- @30 cm, the depth of field is 3.3 cm
- @50 cm, the depth of field is 9.2 cm
- @75 cm, the depth of field is 21.4 cm

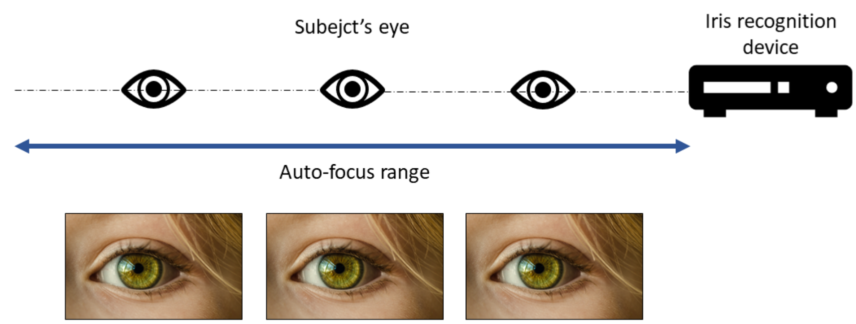
Outside the depth of field, the iris will appear blurry and the identification won't work correctly, as shown in Figure 5 below. Without a proper refocusing solution, it is impossible to be in-focus over the entire range of depth due to the shallow DOF.

Figure 5: Iris recognition without liquid lens autofocus



The integration of a liquid lens within the optical system will not directly increase the depth of field, but it will instead allow the device to automatically adjust focus and maximize the sharpness in the region of interest, the user's eyes, as shown in Figure 6.

Figure 6: Iris recognition with liquid lens autofocus

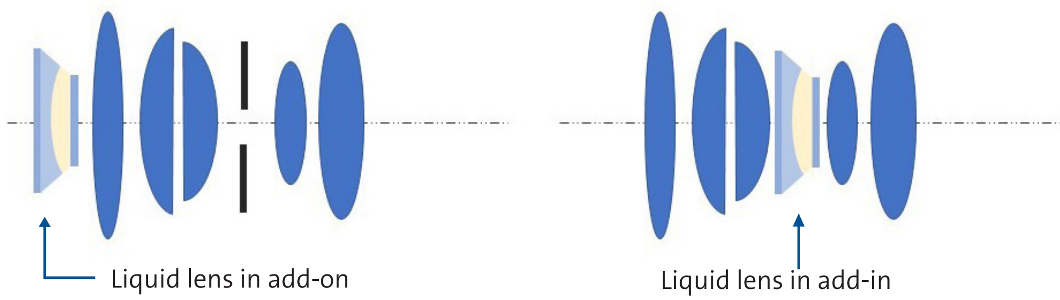


Integration of Liquid Lenses

Liquid lenses are small and can easily be integrated into an existing optical system whether as an add-on or as an add-in component.

- Add-on: The liquid lens is placed either at the front or at the rear of the optical system, whichever minimizes the loss of light. This solution is easy to implement and facilitates the mechanical integration of the liquid lens. However, this method may produce an undesired vignette if the numerical aperture of the system is large. In this case, add-in integration is preferred.
- Add-in: The liquid lens is integrated within the optical stack, ideally close to the aperture stop. This solution is more complex and might require a readjustment of the optical design, but it minimizes the degradation of image quality.

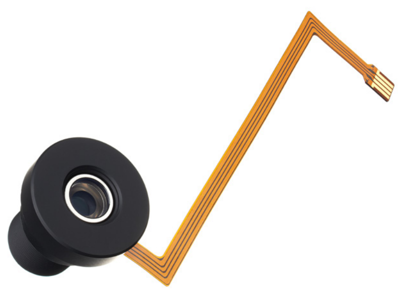
Figure 7: Liquid lens integraton options



For more information on how to integrate the liquid lens in an optical system please refer to Corning Varioptic Application Note: MAAN - 200207 - Design Rules for Liquid Lens Auto Focus Camera Modules." Contact varioptic@corning.com for further information.

Example using Corning Varioptic Lenses

Varioptic Lenses offers a variety of lens modules, either as C-mount or S-mount, with different focal lengths. For instance, the Corning® Varioptic® C-S-39N0-158 lens module is an S-mount lens module with a 15.8 mm focal length. Its field of view is 22° when used with a 1/3" sensor.



The 2 lp/mm resolution criteria in the object space issued from the ISO/IEC standard converts to 97 lp/mm at the sensor plane for an object located at 75 cm (worst case). Corning's lens module has an MTF value of 50% at 100 lp/mm which makes it well suited for the use case previously described. This auto-focus objective lens is using a Corning® Varioptic® A-39N0 A-Series liquid lens in an "add-on" design that features a 3.9 mm clear aperture and 20 diopter dynamic range allowing focus adjustment from 5 cm to infinity, easily covering the 30 cm to 75 cm range described in the example use case.

Conclusion

Iris recognition is proven to be one of the top choices for biometric identification; yet, technical constraints have limited broad adoption in commercial and government applications. The technology relies on high-resolution images produced by the system to perform an accurate assessment; however, conventional iris recognition devices have difficulty capturing a clear image due to a shallow depth of field inherent in their optical characteristics. In addition, applications requiring a fast response time for large-scale continuous identification cannot rely on a complex device without autofocus capabilities. Overcoming these constraints often increases the bulk and cost of the system.

Optical systems using liquid lenses can optimize focus and thus maximize the sharpness of an image. This compact, low-cost, and low-power solution can extend the reading distance from a few millimeters to several meters. Additionally, liquid lenses possess a fast response time, as low as 10 ms, and can perform autofocus in both an open and closed loop system. Liquid lenses can easily be integrated into an existing device or be part of a new product, fully automatic and suited for large scale applications.

The iris recognition biometric market is expected to witness double digit growth from 2017 to 2024. This growth is expected to accelerate due to growing demand for touchless biometric solutions brought about by the COVID-19 pandemic. In addition, the pandemic has led to increased demand for identification solutions for contact tracing. Corning® Varioptic® Lenses provide a low-cost, high-quality solution for imaging applications used in biometric identification.

References

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