Liquid lens technology for adaptive optics: principle, physical limitations and applications

Bruno Berge*,**

*Varioptic, 8B rue Hermann Frenkel 69007 Lyon. **On leave from ENS-Lyon, 46 allée d'Italie 69007 Lyon.
E-mail: bruno.berge@varioptic.com

We will present the state of the art of small size optics using liquid lens technology, enabling to have variable optical lenses without moving parts. After a general presentation of the principle, and of the physical limitations, we will address several potential industrial applications, among which image capture will be the main focus..

1. Introduction

Miniature optical systems are increasingly required in the industry, whereas size, power consumption and robustness count more and more. We present the state of the art of the liquid lens of variable focal length, working on electrowetting [1]. This can be the key element for realizing autofocus camera modules of very high pixel number (2 to 3Mpixels) and very small size (sensor format 1/3" or 1/4"). One of the key advantage of this technology is that it enables an optical function (focus, zoom), without any moving part.

In this paper, we will present the technology, then we will show the performances of the first existing qualified product, Arctic 320 lens, with a discussion of the comparison between the results and the simulation. Finally, we will present several applications of the liquid lenses, like autofocus cameras, zoom systems, or confocal microscopy.

2. Principle,

Figure 1 shows the principle of the liquid lens: two non-miscible liquids are enclosed in a cell having two transparent windows. The interface between the two fluids acts like an optical interface, as the two liquids have different index of refraction. The liquid liquid interface rests on a solid surface which is insulated by a thin film (here a parylene layer). Application of an ac electric voltage across the parylene layer enables to reconfigure the liquid liquid interface at different curvatures, thus changing the focal length of the assembly.

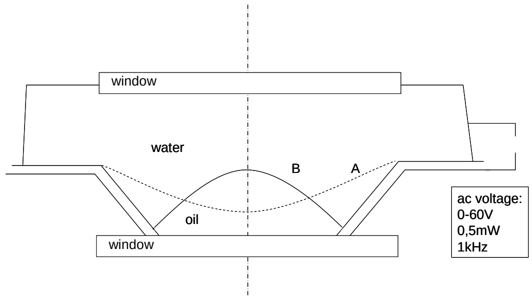

Figure 1: principle of the liquid lens technology

One of the key point is to use two liquids having the same density. Usually one of the liquids is a water solution, the other is an oil. Whereas the terminology for liquids is sometimes vague, this organic liquid can be constituted from either small molecules like solvents, up to small polymers. Among the thousands of potential molecules, there is a great variety of densities, which allow to match the two liquid's densities.

Another important feature of the liquid lens is that it should incorporate a centering mechanism, for insuring that the liquid-liquid meniscus is always centered on the optical axis.

3. Performances

The following measurements were made on the first qualified product from Varioptic; Arctic 320 lens. The figure 2 shows the response curve of the lens, as the optical power of the lens (inverse of the focal length) as a function of the applied voltage.

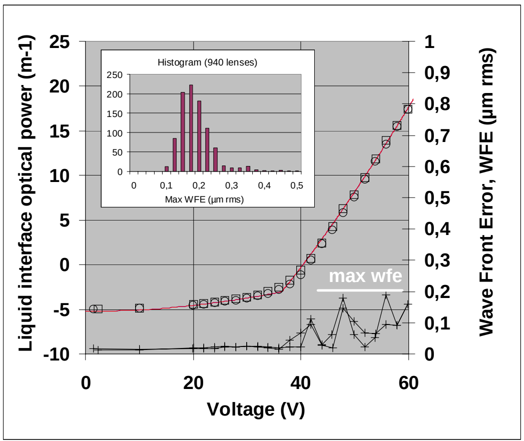

Figure 2: optical response (squares) and residual wave front error (wfe, crosses) as a function of the voltage. The insert shows the statistics of the max wfe for 940 lenses.

The curve shows that the lens is a negative lens (diverging lens) at 0V. That corresponds to the position **A** of the liquid-liquid meniscus of figure 1 whish has radius of curvature towards the liquid which has the highest index of the two. When an ac voltage is applied the curvature of the liquid liquid interface diminishes, as the power of the lens, up to the point that it vanishes, before raising again as a converging lens (positive power), position **B** on figure 1.

The graph of figure 2 shows also a recording of the wave front error introduced by the propagation of the light through the lens. This is expressed as an rms value of the residual error obtained after subtraction of the best fitting spherical wave front. From the curve we extract the maximum value of the wave front error (wfe). The wave front error is thus a measurement of the quality of the lens.

The insert of figure 2 shows the histogram of such wfe over about 1000 lenses of several production batches. this curve show that the liquid lenses have a good optical quality. This might be comparable to a glass lens which is polished on both sides at a level or better than $\lambda/2$. Of course this optical quality can be further increased ad libitum by a control of the mechanical pieces which are constituting the lens.

4 . Reliability,

The lens has been qualified against several environment constraints:

Operational temperature, between -20°C ad +60°C. Storage temperature -40°C to +80°C. Shocks (1,5m fall on a hard metal plate) and vibrations are usually seen as a risk of the technology, but the confinement of the liquids and the fact that they have the same density makes the lens robust against the most severe tests of the industry.

5 . applications, conclusion

A lot of applications have been already mentioned in recent papers [1-2] or publications. Clearly the technology has a lot of specific advantages when lens sizes of about 1-10 mm are considered, and it finds some evident applications in small autofocus and zoom optics for small camera modules in phones. Such optics, enable ultra-compact, high quality digital cameras which fit into the 5 to 7 mm thickness which is typically left in a phone.

Nevertheless, larger diameters are fully applicable, when some constraints are recalled: Usually the aperture size and temperature range cannot be easily both large. Nevertheless future work on liquids with matched thermal expansion coefficients will enlarge the range of possible lens diameters. Even with existing available liquids, a lens used in an indoor environment could be of a much larger diameter (above 10mm).

One potential application of interest in the industry is confocal microscopy: there a liquid lens can be used in both entrance and exit beam, in order to keep the confocality, while addressing the Z scan. An example has been already demonstrated in ref [3] to produce a system for vision inside a turbid medium, where Optical Coherent Tomography (OCT) was used to make an image.

References

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