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Cyril Bourgenot, Johannes Courtial, Euan Cowie, John Girkin, Gordon Love, David Robertson, Laura Young, "Design, manufacture, and evaluation of prototype telescope windows for use in low-vision aids," Proc. SPIE 10376, Novel Optical Systems Design and Optimization XX, 103760I (24 August 2017); doi: 10.1117/12.2272992

Event: SPIE Optical Engineering + Applications, 2017, San Diego, California, United States

Design, manufacture, and evaluation of prototype telescope windows for use in low-vision aids

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ABSTRACT

Pixellated Optics, a class of optical devices which preserve phase front continuity only over small sub areas of the device, allow for a range of uses that would not otherwise be possible. One potential use is as Low Vision Aids (LVAs), where they are hoped to combine the function and performance of existing devices with the size and comfort of conventional eyewear. For these devices a Generalised Confocal Lenslet Array (GCLA) is designed to magnify object space, creating the effect of traditional refracting telescope within a thin, planar device. By creating a device that is appreciably thinner than existing LVA telescopes it is hoped that the comfort for the wearer will be increased. We have developed a series of prototype GLCA-based devices to examine their real-world performance, focussing on the resolution, magnification and clarity of image attainable through the devices. It is hoped that these will form the basis for a future LVA devices. This development has required novel manufacturing techniques and a phased development approach centred on maximising performance. Presented here will be an overview of the development so far, alongside the performance of the latest devices.

Keywords: Geometric Optics, Imaging Systems, Artificially Engineered Materials

1. INTRODUCTION

Most conventional optical systems, such as telescopes or common spectacles, consist of components which are always designed to preserve continuity of transmitted phase fronts. This allows the system to be broadly free form diffractive effects but it limits the function of them to transmitted ray fields which are curl-free.

In contrast pixellated devices are a class of optical devices in which phase continuity is preserved only over small sub-areas of the device, *pixels*, with phase discontinuities between these areas. Pixellated optics introduce oportunities for optical design that is not possible in conventional optical systems such as generalised refraction in air.[1–3] They are used in light-field imaging or integral imaging[4] and can, in principle, be used to construct metamaterial-free Transformation Optics devices.[5–7] An example of a pixellated optics devices is shown in Fig. 1.

Our first foray into making pixellated optics deviecs were CLAs, Confocal Lenslet Arrays.[1,4] These devices consist on two arrays of microlenses (lenslets) place the sum of their focal length apart, creating a surface of miniature telescopes (telescoplets). These devices have the property of being able to change light rays in ways that are wave-optical forbidden.[8]

This work has lead us to discover a very general law of refraction enacted by a planar surface, and that it can be realised in pixellated form using Generalised Confocal Lenslets Arrays (GCLAs).[6] These devices exapnd upon the CLA devcies by allowing the lenslets arrays to consist of lenses whose optical axes is not perpendicular to the plane of the device. As a result GCLAs have a large nubmer of degrees of freedom and are being considered

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Novel Optical Systems Design and Optimization XX, edited by Arthur J. Davis,
Cornelius F. Hahlweg, Joseph R. Mulley, Proc. of SPIE Vol. 10376, 103760I
© 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2272992

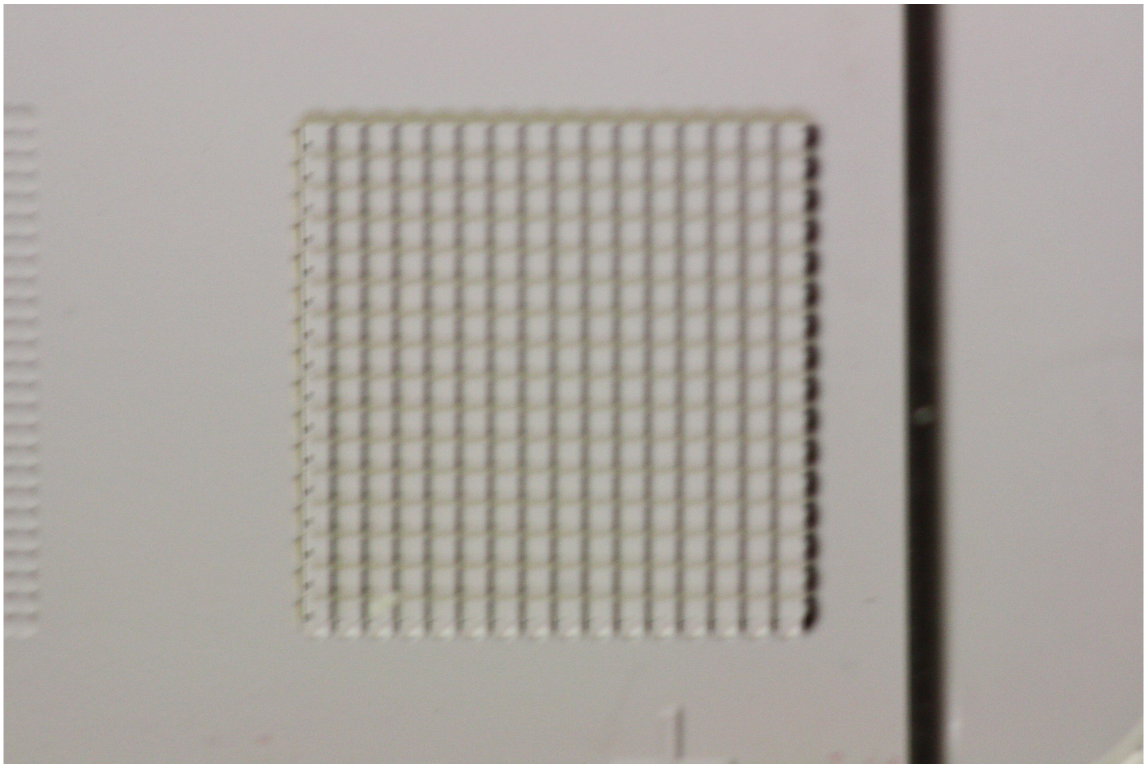

Figure 1. An example of a pixellated optics device; a close up of 0.6 mm aperture from our phase 1 devices. Clearly seen are the individual pixels, arranged in a square packed formation. A fiducial mark, used for alignment, can be seen at the bottom of the image.

for a range of applications, from Low Vision Aids (LVAs), to architectural applications[6] and the pixellated transformation optical devices.[5]

The advantage of pixellated transformation optics is that these devices can be cosntructed out of normal optical materials, such as PMMA, allowing them to function throught the visual spectrum. This contrasts other transforamtion optics consisting of metameterials,[9] which are often narrowband. Additionally if a device were to be designed successfully with GCLAs it utilises methods of manufacture which can be readily scaled, such as injection moulding, which will be outlined in this paper.

The primary focus of this paper, however, is on the potential of GCLAs for use as LVAs. Conventional LVAs cover a range of products and designs, from wearable devices to more technological solutions. They can be useful for a range of conditions from glaucoma to natural deterioration of sight with age. One variety of LVAs that are typically cumbersome are spectacle mounted telescopes, either for distance viewing - for example watching television - or for near sight - such as reading the newspaper. These devices vary in subtleties but have at their core the same principle, to have the user wear a telescope in-front of the eye as with common eyeglasses. Examples of current telescope based devices are shown in Fig 2.

There are many issues with these devices compared to ideal vision: optically they have smaller fields of view and fainter images as result. Moreover the devices often have a number of ergonomic and economic concerns, often being expensive and uncomfortable and requiring training to utlising properly.[10] Whilst GCLAs probably cannot improve upon these optical concerns[11,12], it may be possible for them to improve upon the ergonomic and economic difficulties. A GCLA device is typically only a few mm thick, close to a conventional eyeglass lens, and can be manufactured easily and repeatedly using modern manufacturing methods. Additionally we hope to design LVAs which eliminate some of the difficulty-of-use concerns of current devices. The focus of this paper will be on our ongoing development work of a prototype LVA device based on GCLAs, outlining the manufacturing processes, performance and lessons learned from each stage of development so far and an overview of our future plans to realise this.

Figure 2. A selection of currently available telescope Low Vision Aids, showing devices cfor a range of distances. Reprodcued from ref[10]

2. PHASE 1

The construction of microlens arrays is not new, nor on it's own is it particularly arduous. The primary difficulty we faced in starting our development was not, therefore, if we could make lenslet arrays but how to make two, aligned precisely and placed confocally. To this end we adopted a phased approach to development for our GCLA work, both for practical applications and our more academic work. For phase 1 we designed many variations of a core concept of a Galilean telescope, where f_1 is positive and f_2 is negative, constructed from a hybrid process of injection moulding and direct machining. 12 arrays, each measuring 1 cm by 1 cm, were spread over 2 injection moulded PMMA paddles with different thicknesses, allowing for different focal lengths and different curvature. The moulds were designed with the f_1 lenslet already inset and the f_2 lenslet was then machined into the rear face of the paddle. The 2 paddles were of different thickness, allowing for long and short focal length designs, and the arrays had differing aperture widths, to allow for the study of diffraction and pixellation effects. An example of a paddle is shown in Fig 3.

These first phase devices suffered from a number of performance related issues. Initial calculations of the correct aperture size underestimated the impact of the magnification of each telescoplet and so even the largest aperture arrays were smaller than ideal. Whilst this limits the available performance in the phase 1 devices it is a straight forward and well understood problem to solve, take account of the magnification and increase the aperture size. More pressing from the perspective of the human viewers through the device is the issue of what we term crosstalk. As the device is made from a solid block of PMMA light can freely enter through the front

Figure 3. The phase one device, referred to as a "paddle". Visible are the 6 different sub-arrays we designed for phase 1. Only 3 of the 6 had the rear lenslet machined as it was already apparent from the larger lenslets that the aperture widths were too small. As such the diffraction effects would have been so high as to introduce a large diffractive blur.

lenslet of one telescoplet and exit through the rear lenslet of another. This will happen for all light outside the inherent field-of-view of the telescopelets in question. For particular combinations of lenslets this can lead to refraction of secondary images to the position of the viewer. Looking through the device therefore results in a confused jumble of images, rendering the scene unintelligible, Fig 4.

From phase one two main improvements were singled out for trial in phase 2:

- The aperture width of the pixels would be optimised taking account of the magnification of the telescopelets. Care must be taken to balance reduction of diffraction with increased visibility of pixel-related effects.
- The elimination of crosstalk is a priority for usability of any GCLA device. To achieve this it was decided to create devices from discrete, rod-like elements in which neighbouring rods were minimally contacting.

It was hoped that development of the phase 2 devices would enable us to simultaneously check the improvements of both facets at once.

3. PHASE 2

The two required improvements were both tackled within a single phase 2 device. Unlike phase 1, where the device was constructed from a single piece of moulded and machined PMMA, the phase 2 devices were constructed using commercially available cylindrical rods of PMMA and subsequently both ends were machined as desired.

The availability of commercial rods limits the aperture widths to slightly oversized when compared to the optimum. However this was considered acceptable to limit the effects of diffraction and allow the effects introduced by pixellation to be studied in more detail. Additionally the device was constructed to have the rods

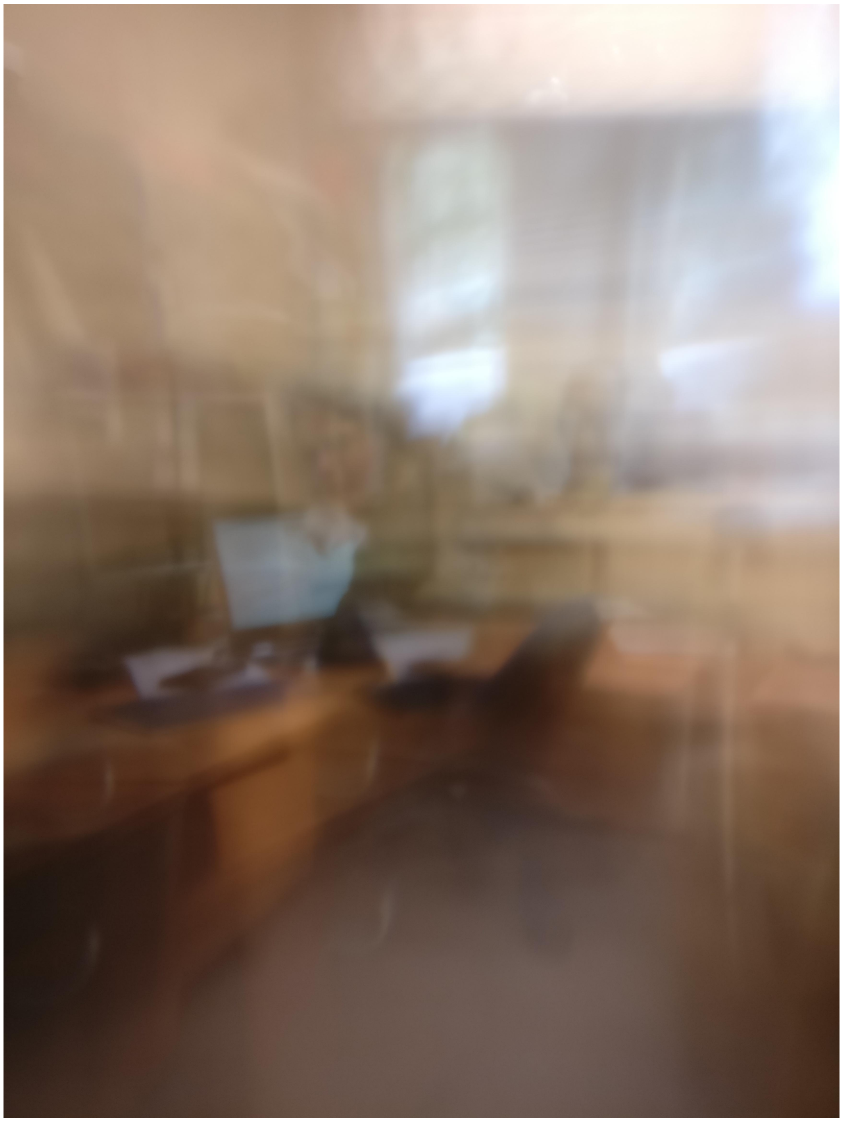

Figure 4. A view through the 0.6 mm sub-array of the phase 1 device. The image is clearly difficult to decipher as a result of multiple overlapping crosstalk images. Whilst broad, brightly coloured objects, such as the desks, are noticeable others, such as a colleague, are almost invisible.

hex-packed. This resulted in minimal contact between neighbouring cylindrical rods, contact being made only radially. As the source of crosstalk was light entering and exiting through a pair of non-corresponding lenlets this is all but eliminated in this set up. The device, with its holder, can be seen in Fig. 5.

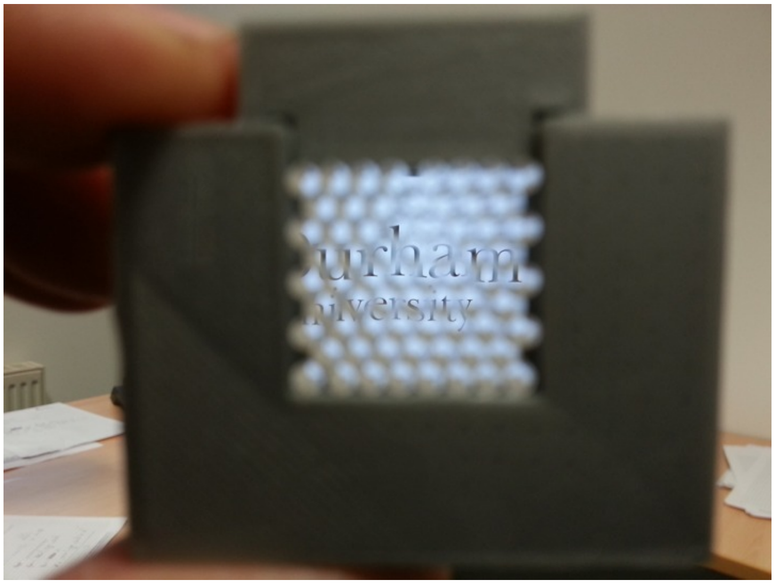

Figure 5. A view of the phase 2 device, in magnifying orientation. The discrete rods are packed into a custom 3D-printed holder to ensure correct pressure is applied to the PMMA.

This design has obvious limitations, being both more intensive in manufacturing. Also, despite hex packing being the most efficient way to arrange cylindrical rods, it introduced of a larger amount of dead area within the device compared to phase 1.

The larger pixels do introduce more notable pixellation effects than in the phase 1 devices, as anticipated. For example it can be seen that straight lines running over dead space can be discontinuous, Fig 5. Additionally it is clear that, although the image forming crosstalk has been eliminated, that unwanted, "stray", light is still present in the system, as seen by the bright halo in Fig. 6. This is especially clear for the demagnifying use of the device, where the a ring of light which meets the total internal reflection condition is seen around the centre, core, image.

Obvious improvements include eliminating the stray light, perhaps by roughening the surface of the rods or by blackening them. This would not increase the field of view but may eliminate the bright stray light and improve the relative contrast of the intended image. Secondly, constructing the device from square or hexagonal rods would be an improvement in effective surface area, albeit with a reduction of availability in off-the-shelf commercial bases.

Work is currently underway to measure and understand the relative effects on image resolution within the device resulting form pixellation and from diffraction. It is also hoped that work can be carried out to increase the field-of-view of the devices, which is currently quite narrow, especially in the demagnifying case where this is pronounced due to the tunnel of stray light.

4. FUTURE DEVELOPMENT

The problem of stray light has been highlighted as the most significant issue with the phase 2 devices. Without a satisfactory solution to this any attempt to increase the functional area of the device will see a return to the crosstalk seen in phase 1. To investigate the potential of any solution the device in phase 3, they will be manufactured similarly to those in phase 2: from discrete rods of PMMA instead of a single moulded paddle. Two methods of stray light mitigation will hopefully be trialled in this phase, both modifying the long side of each individual rod. First will be roughening the outside of the rod, increasing scattering and reduce total

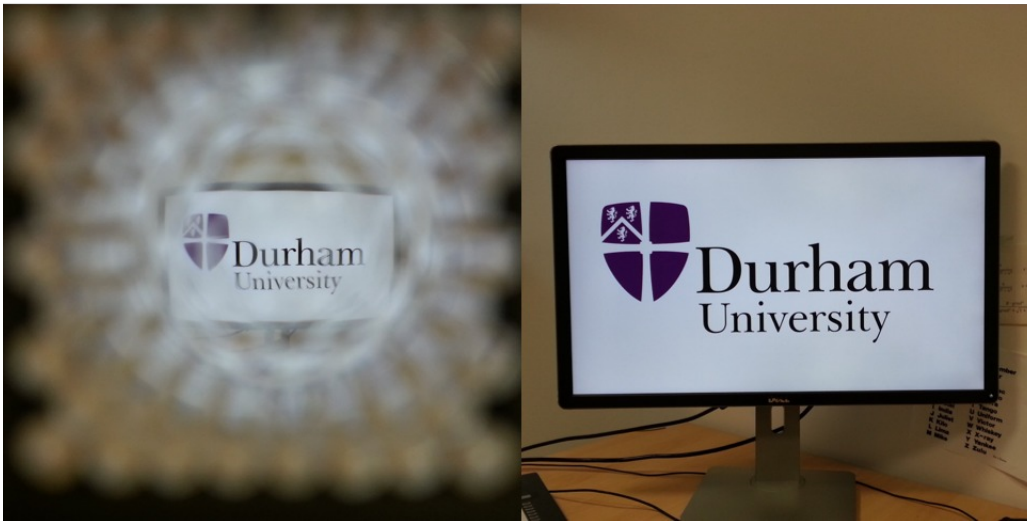

Figure 6. The phase 2 device, shown here in demagnifying orientation. A clear ”tunnel” of unwanted light can be seen around the core image.

internal reflection. For the second variation a black coating will be applied to the outside of the rods. Both should allow for simultaneous reduction of all known forms of stray light, both that from internal reflection and, looking forward, from crosstalk.

A second concern at the early stages of investigation is to increase the field of view of each telescopelet. One issue with using telescopes, either conventional LVA telescope glasses or our novel approach, is the restricted field of view. An initial study is underway to see if the optical design can be improved to allow for a wider field of view. Whilst there may be improvements that can be made it is unlikely this method will return a large improvement.

A more radical method that utilises the unique strengths of our design is to rethink the manufacturing and, instead of a single wall of telescopelets, construct something closer in form to traditional eyeglasses. Current LVAs can be designed as a microtelescope, where part of the lens has a protruding telescope but the rest can be left unaffected. With our system these areas can be built in to the curvature of the lens and take up less room. This can allow multiple areas over the surface of the lens to be given an telescoplet array, with perhaps different magnifications and fields of view for each area. The device would then be analogous to currently available bifocal lenses, where one section of the overall lens is a different power to that of the remainder. This idea is in early design stages but may offer the best compromise between use of telescopes and covering a broad field of view. It is hoped that such a design would then allow the user to look around without excessive head rotation, as well as perhaps allow a single device to be designed for a multitude of uses for the single user.

5. CONCLUSION

Our continued development of Generalised Confocal Lenslet Arrays for a variety of porposes has allowed us to investigate how best to use them as Low Vision Aids. Though there is still a lot of development required to bring these devices to full prototype stage, it is clear that there has been great progress made through the first 2 phases of development. Development over the next few months will focus on correcting for the remaining stray light issues, especially to try and improve image quality for the magnifying case as this is of greatest potential use as a LVA. Further work my be possible to design a device for the demagnifying orientation which also increases the field of view and reduces the ”tunnel” effect. This could then be used to increase the field of view of people with tunnel vision. Once an optical prototype is produced will will look to work with ophthalmic partners to design and trial a prototype for use on patients who would currently benefit from LVAs.

Acknowledgements

This work was supported by the Engineering and Physical Sciences Research Council [grant numbers EP/N/509668/1, EP/M010767/1 and EP/M010724/1].

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