MINIATURIZED AMD VISION AIDS: PRINCIPLES AND REALIZATION

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ABSTRACT

In this paper we discuss two kinds of adapted vision aids for people suffering from Age-Related Macular Degeneration (AMD). Both concepts aim at redirecting the central visual information which cannot be seen by AMD patients to the outer, unimpaired parts of the retina. The first kind of vision aid redirects the central field of view using prismatic elements and magnifies it homogeneously with Galilean telescopes. The second principle is based on anamorphic prism pairs and leads to a one dimensional magnification of the full field of view. In both cases we apply segmented optics to realize the complex optical functions with low-weight components suitable for all day use. Replication in PDMS is discussed as an efficient fabrication process for segmented elements.

Index Terms **–** Age-related macular degeneration, vision aids, optical design, array optics, microoptics, PDMS replication.

1. INTRODUCTION

Worldwide, about 30 million people suffer from Age-Related Macular Degeneration (AMD), a disease that causes progressive damage to the macula, the central part of the retina [1, 2]. It causes a gradual loss of central vision which renders patients unable to read texts, to drive cars, or to recognize faces. Fig. 1a illustrates the visual perception of AMD patients. While the central part of the retina is damaged its outer region stays functional. Currently, there exists no cure for AMD and vision in the damaged central region can usually not be restored. Specialized vision aids support patients in optimally using the healthy outer regions of the retina. As the density of cone cells reduces with growing distance to the center of the retina, current vision aids often provide a magnified view [3-5]. Additionally, the full field of view is sometimes shifted with the help of prisms [4, 6]. While the severity of the AMD and the affected area vary from patient to patient, these vision aids are typically generic.

In this contribution we discuss two different principles for realizing adapted vision aids which address the individual needs of AMD patients. Both principles aim at the magnification and the redirection of the central information onto the unimpaired parts of the retina. In the first case an array of miniaturized Galilean telescopes magnifies the central part of the image which is then redirected to the outer parts of the retina by an array of prisms (Fig. 1b) [7, 8]. The second principle of redirecting the central information is illustrated in Fig. 1c. An anamorphic prism pair is used to magnify the field of view in one direction. To maximize the wearing comfort the prisms are segmented and can thus be reduced to a thickness of less than 2 mm.

Fig. 1 Compensation of the AMD-related loss of central vision (a) through the displacement and redirection of the central information (b) or through a distortion of the field of view (c)

For both principles the required segmented optical elements can be manufactured as flexible PDMS elements. As no mechanical parts block the area surrounding the PDMS elements, the loss of information at the edge of the PDMS elements is minimized. The necessary steps of the PDMS replication process are discussed using the example of Galilean telescope arrays. We show first examples of replicated elements.

2. MAGNIFICATION AND SHIFT OF THE CENTRAL FIELD OF VIEW

In this section we discuss the optical methods for the magnification and redirection of the central field of view according to Fig. 1b. The necessary optical components are a telescope system for the magnification and prisms or mirrors for the redirection (Fig. 2b). From the various available telescope systems a refractive setup based on the Galilean telescope is chosen due to its small size and the correct orientation of the magnified image. To minimize the weight and to maximize the wearing comfort the traditional multi-lens design is replaced by a single optical element. The front surface of this element has positive power and resembles the objective while the back surface with its negative power replaces the eye piece. Further miniaturization of the magnifying optical element is achieved through a segmentation process which results in a thin plate or foil with microlens arrays on its front and back surfaces. These miniaturization steps are illustrated in Fig. 2 which also shows the selected approach to miniaturizing the prism used for redirecting the visual information. For this purpose the prism is reduced to an array element with a saw tooth profile whose faces are parallel to the faces of the macroscopic prism.

The resulting arrays can be fabricated cost-effectively using various kinds of replication methods like hot embossing, injection molding, or lithography. In Section 4 we will discuss a PDMS replication process for self-adhesive Galilean telescope arrays. For the redirection of the visual information we use off-the-shelf prism foils. Fig. 2c shows a possible implementation where self-adhesive foils are attached to the front and back surfaces of a supporting structure. Fig. 3 illustrates the positioning of the AMD vision aid in front of the human eye. This figure also shows a different possible implementation with rigid telescope and prism arrays fabricated by injection molding.

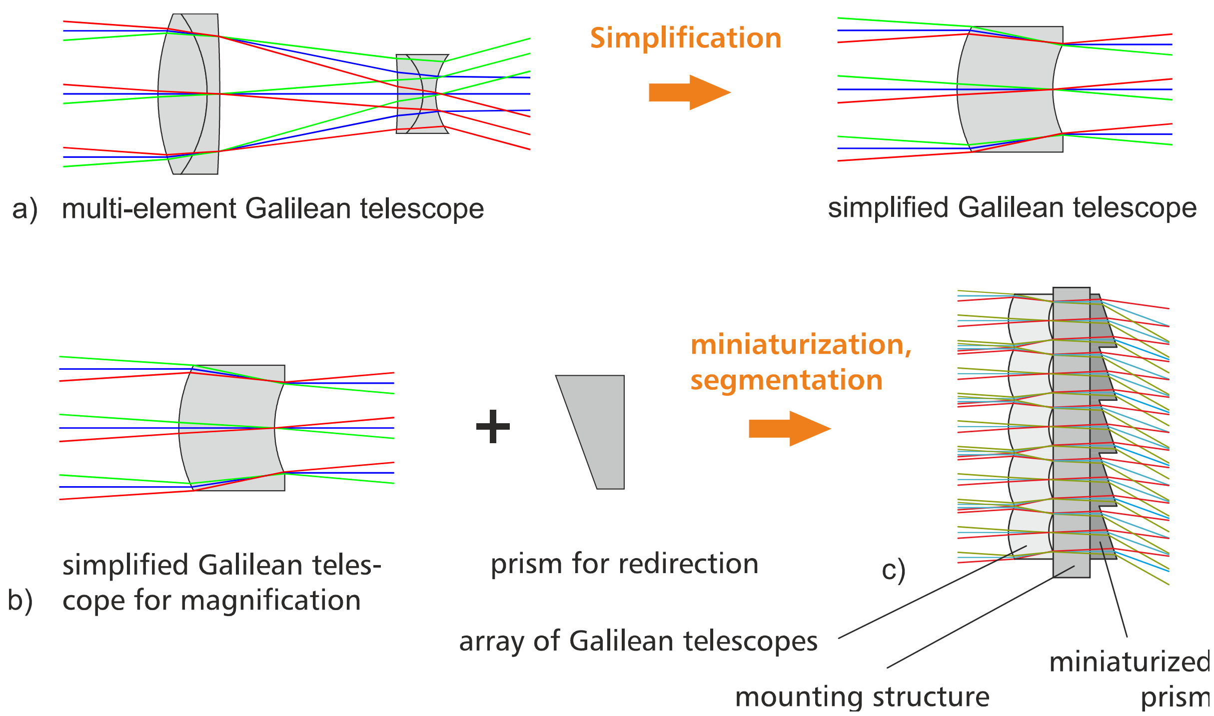


Fig. 2 a) Simplification of the Galilean telescope system. b) Normal and c) miniaturized components for the magnification and the redirection of the central field of view.

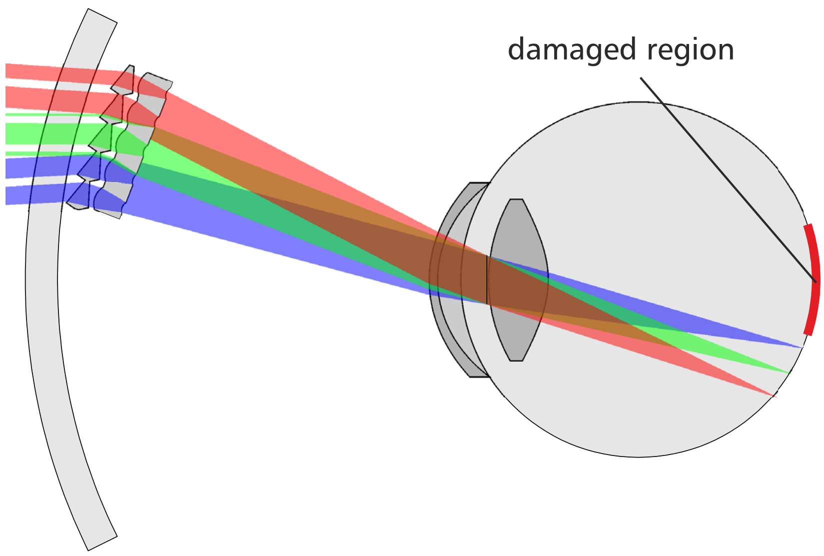


Fig. 3 Position of rigid telescope and prism arrays in front of the human eye.

In contrast to the prism array which only reduces contrast and introduces lateral chromatic aberrations, the Galilean telescope array is prone to aberrations. Thus, we concentrate on the telescope array in the following discussion. Typically, several channels of the telescope array contribute to the imaging of a single object point onto the retina of the AMD patient. Three main requirements have to be fulfilled by the telescope array:

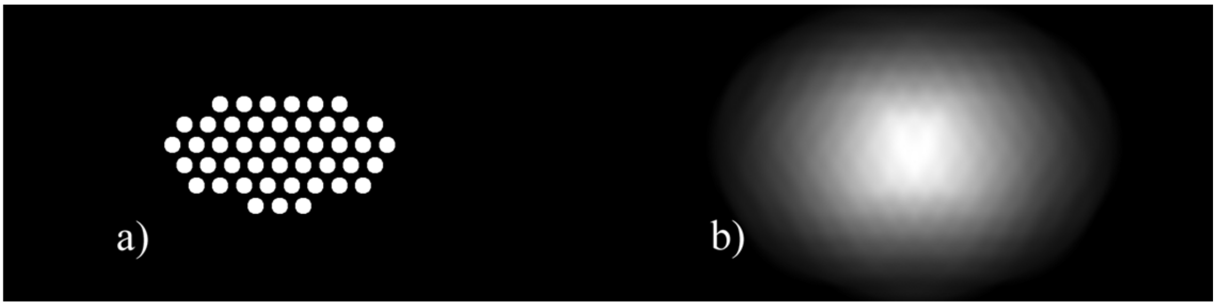


Fig. 4 a) Aperture array for the reduction of crosstalk between the channels of the telescope array. b) Resulting intensity distribution on the retina.

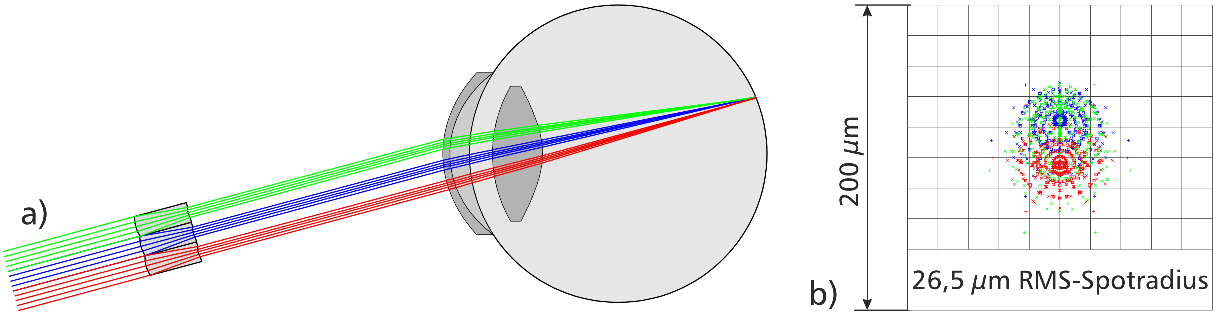


Fig. 5 a) Three channels of the telescope array which image the same object point. b) Resulting spot diagram on the retina. Each color represents a single channel.

1. To minimize cross talk between neighboring channels, apertures have to be added to the telescope array. These apertures lead to vignetting and an uneven intensity distribution across the field of view, see Fig. 4. To minimize the change of intensity across the field of view, the diameter of and the distance between the channels of the telescope array have to be selected accordingly.
2. The imaging performance of a single channel of the telescope array has to satisfy the resolution requirement of the AMD patient.
3. The same resolution requirement has to be fulfilled by a range of channels which image the same object point. Fig. 5 indicates that this condition is fulfilled by a planar telescope array.

3. DISTORTION OF THE FULL FIELD OF VIEW

The second principle of redirecting the central information is depicted in Fig. 1c. It aims at a one-dimensional magnification of the field of view. The corresponding optical setup is an anamorphic system which can be realized with two cylindrical lenses or with a pair of prisms. As the cylindrical lenses cause several monochromatic aberrations when imaging a large field of view, we use an anamorphic prism pair which only causes lateral chromatic aberrations.

The basic setup used for the design process is shown in Fig. 6. The prisms are oriented in a way that leads to a reduction of the aperture (object space aperture $2y_p$, image space aperture $2y_p''$) while the field of view is magnified by the factor

$$\Gamma' = \frac{2y_p}{2y_p''} = \frac{\tan(w'')}{\tan(w)}. \tag{1}$$

In this equation the object and image space field angles are given by w and w'', respectively. Due to total internal reflection the maximum magnification is limited to a value of $\Gamma' \approx 5\times$. To simplify the design process we used two prisms of the same shape and required the rays from the central field point to be perpendicular to the first surface of the first prism. In this case the required wedge angles ε of the two prisms are given by

$$\varepsilon = \arcsin\sqrt{\frac{1-\Gamma'}{1-\Gamma' n^2}}\,, \tag{2}$$

Where n specifies the refractive index of the prisms. The lateral offset between the input and output beams follows the equation

$$v = d\sin\left(\varepsilon'' - \varepsilon\right). \tag{3}$$

Throughout this section we require an angular magnification of $\Gamma' = 2$ at normal incidence and assume $n = 1.49$ which represents the refractive index of PMMA at the wavelength $\lambda = 588\,\text{nm}$. Fig. 7 shows that the magnification of the anamorphic prism pair grows with increasing angle of incidence. Owing to total internal reflection the achievable image space field angle is limited to $-24.4° < w'' < 36.6°$.

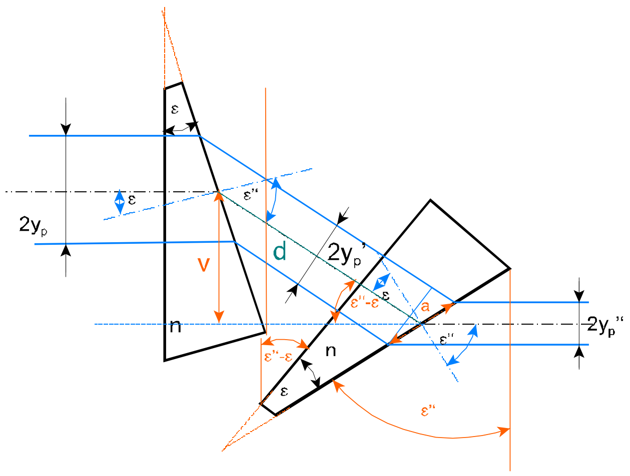


Fig. 6 Schematic of an anamorphic prism pair.

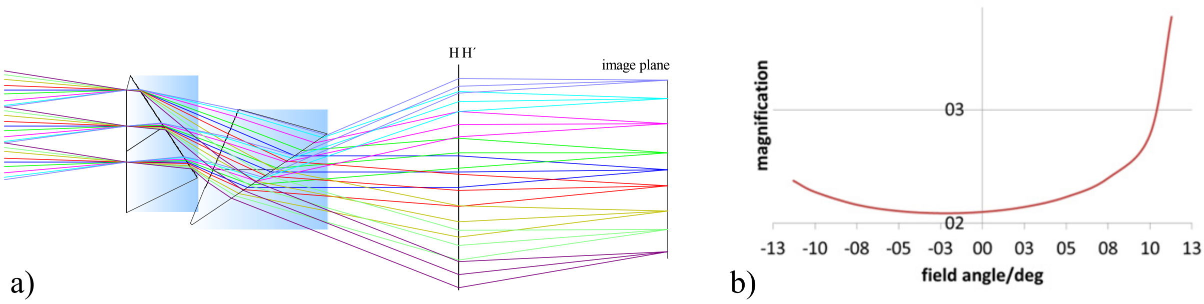
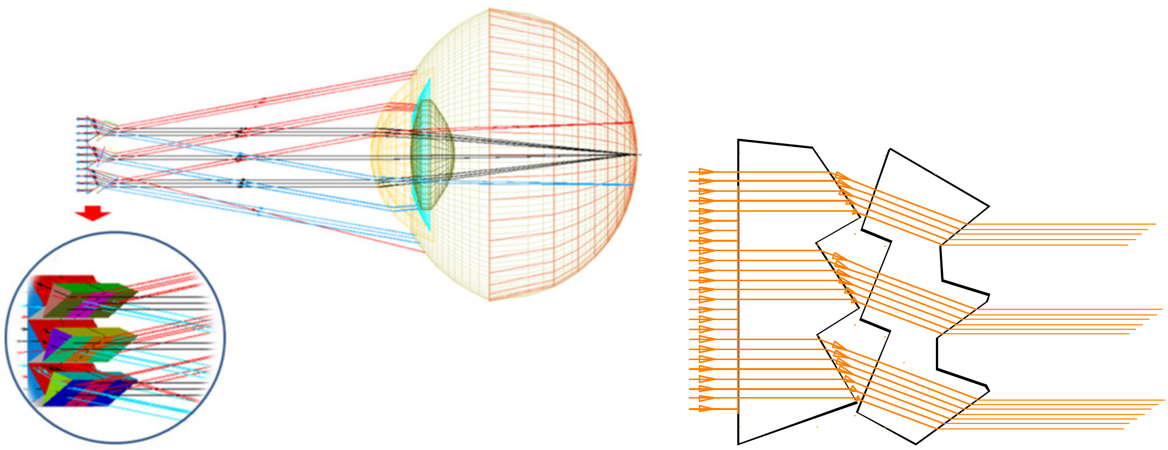


Fig. 7 a) Anamorphic prism pair imaging multiple field angles. b) Magnification of the anamorphic prism pair.



a) b)

Fig. 8 a) Raytracing model with an anamorphic pair of miniaturized prisms placed in front of the eye b) Cross section through the pair of miniaturized prisms.

To minimize the weight and to increase the wearing comfort of the vision aid the prisms have to be fabricated as thin array elements. Similarly to the system of Sec. 2, the prisms are reduced to saw tooth profiles with thicknesses of less than 2 mm. Fig. 8 shows a possible layout with miniaturized prism arrays. One major challenge of this principle is related to the lateral chromatic aberration visible in Fig. 1c. To compensate for this error the two prism arrays have to be achromatized either by combining different materials or by adding diffractive structures to the elements. Both approaches increase the complexity of the manufacturing process. On the other hand this principle excels through the absence of monochromatic aberrations.

4. PDMS REPLICATION PROCESS

In this section we discuss the replication of optical elements in Polydimethylsiloxan (PDMS) as a possible method for producing AMD vision aids [9]. PDMS is a silicone-based polymer which can be cast at room temperature. The replication at room temperature avoids shrinkage, stress, and other negative effects of high temperature replication processes like injection molding. The PDMS casting process consists of the following steps:

- Mixing of the PDMS base material (Dow Corning Sylgard Elastomer 184) with a curing agent
- Removal of bubbles in a desiccator
- Filling and alignment of the mold
- Curing (48 hours at room temperature)

With curing times of several hours this process is far too slow for mass production but it can be well suited for cost effective prototyping. The replication of Galilean telescope arrays in PDMS is linked to several challenges. For optimum performance the lens arrays on the front and back surfaces of the resulting foils have to be well aligned with respect to each other. To address this challenge we fabricated the molds in transparent PMMA substrates by micro-milling. Besides the lens structures the mold parts contain alignment structures which can be observed with a microscope during the whole casting process and are transferred to the replicated element. The mold parts are attached to an off-the-shelf mechanical positioning system which allows for precise alignment in the x, y, and z directions. Additionally a rotation about

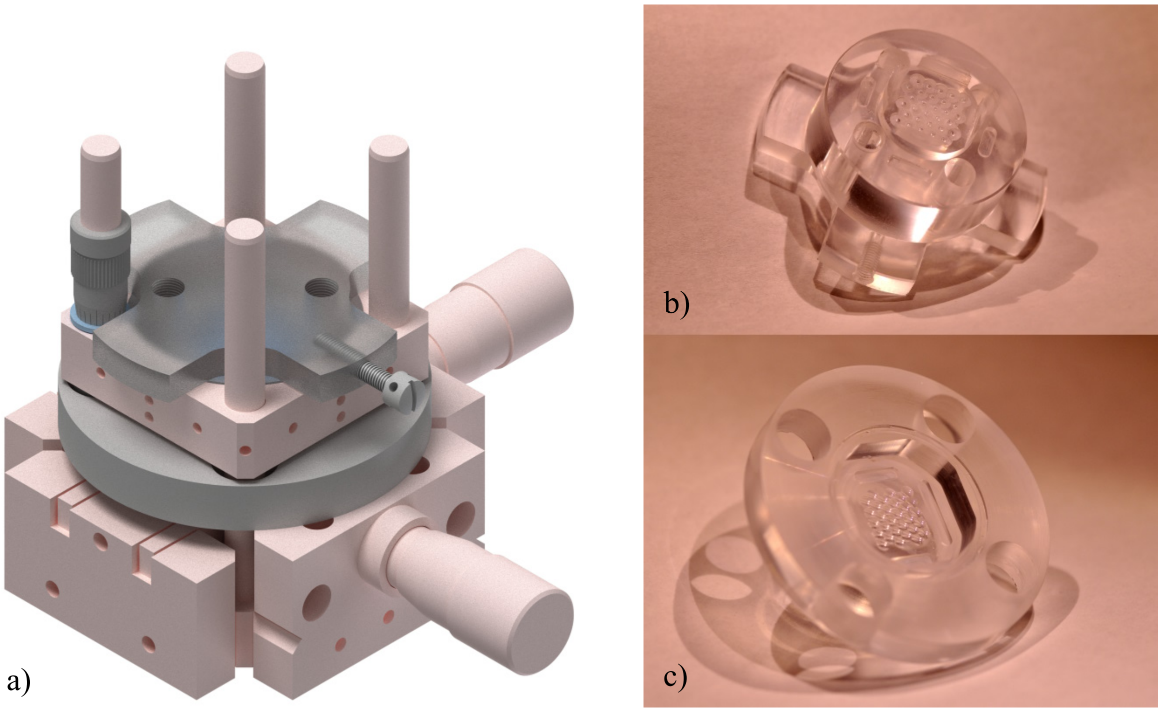


Fig. 9 a) Mold for the PDMS casting. b) Upper and c) lower part of the mold which are both fabricated in PMMA.

the optical axis of the telescope lenses is possible through a rotation of the upper mold part within the mechanical mount. Figure 9 shows the assembled mold and enlarged views of the two mold parts.

Further challenges relate to the bubbles which may enter the mold during the filling process and to the possible cross talk between neighboring channels of the Galilean telescope array. To minimize this cross talk apertures have to be added.

5. CONCLUSION

Age-Related Macular Degeneration (AMD) is an eye disease which causes loss of vision in the central region of the retina. We presented two methods for redirecting the information which cannot be seen by AMD patients to the unimpaired parts of the retina. The first principle magnifies the centre of the field of view with an array of miniaturized Galilean telescopes and shifts the magnified information to an outer part of the retina with a miniaturized prism. The second principle realizes a one-dimensional magnification of the full field of view with an anamorphotic prism pair. Similarly to the first principle, the prisms are miniaturized to increase the wearing comfort of the resulting vision aid. A PDMS casting process was introduced as a straightforward and cost-effective way of fabricating a series of prototype systems.

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