In-the-Spectacle-Lens Telescopic Device for Low Vision

Eli Peli[a], Fernando Vargas-Martín[a,b]
[a]Schepens Eye Research Institute, Harvard Medical School, Boston MA 02114; [b]Laboratorio de Óptica, Dept. Física, Univ. Murcia, Spain 30071

ABSTRACT

Spectacle mounted telescopic systems have been prescribed for visual impairment, providing magnified images of objects at farther distances. Typically, bioptic telescopes are mounted toward the top of spectacle lenses or above the frame with the telescope eyepiece positioned above the eye's pupil. This allows the wearer to alternate between the magnified narrow field of view available through the eyepiece and the unmagnified wide view through the carrier lens using head motion. The main obstacles to acceptance are the obvious appearance, limited field of the smaller Galilean telescopes, and weight of the larger Keplerian telescopes. We designed a spectacle-mounted wide-field Keplerian telescope built completely inside the spectacle lens. The design uses embedded mirrors inside the carrier lens for optical pathway folding and conventional lenses or curved mirrors. The small size of the ocular and its position with additional mirror tilt enable the user to view the magnified field simultaneously and above the unmagnified view of the uninterrupted horizontal field that is important for user's safety. This design enables the construction of cosmetic telescopes that can be produced as a commodity lens blank and surfaced to include the patient prescription. These devices may be also of utility in military and civilian use.

Keywords: Visual multiplexing, bioptic telescope, optical visual aid.

1. Background

Magnification is useful for individuals who have resolution loss due to defects in the optics of the eye or of the retina, specifically of the fovea (i.e., the central part of the retina), which provides detail vision for reading, facial recognition and other fine discrimination tasks. Bioptic telescope systems have been prescribed for use by the visually impaired for many years[1,2]. These multi-element devices provide magnified images of objects at further distances as compared to single element lenses that can only provide magnification at very close working distances. Typically, bioptic telescopes are mounted toward the top of a pair of eyeglasses frames with the telescope eyepiece positioned directly above the pupil of the wearer's eye (Figure 1). This positioning allows the wearer to look under the eyepiece using their unaided vision, and to tilt their head downward to sight through the telescope eyepiece to see the magnified image. Bioptic telescopes are available in small, compact Galilean designs that provide narrow fields of view (e.g., about 9° in a 3× magnifier[3]) and generally provide relatively dim images. Alternative bioptic telescopes are available in larger, heavier Keplerian designs that provide brighter images and wider fields of view (e.g., 13º in a 3× magnifier[3]) as the Galilean designs. Bioptic telescopes are typically mounted through a spectacle (carrier) lens by drilling a hole through it.

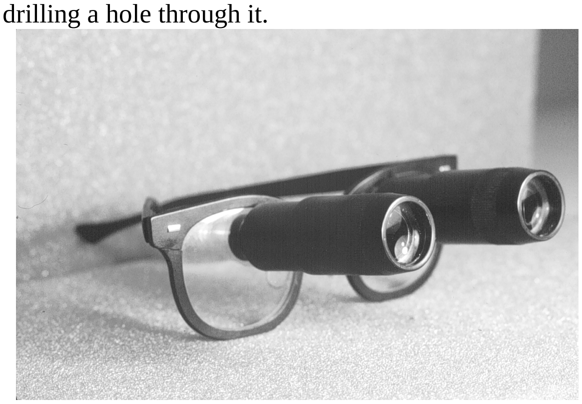

Figure 1: A binocular Keplerian bioptic telescope. The device is mounted at the top of the spectacle lens and is slightly tilted upwards.
Photo courtesy of Designs for Vision Inc. NY

Although these types of visual aids can be effectively used in a variety of settings, a large number of visually impaired people reject them [1]. The obvious and unsightly appearance of these prosthetic devices has been identified as one major reason for the reluctance of the visually impaired to use bioptic telescopes.

Previous attempts to improve the cosmetic appearance of bioptic telescopes include the use of very small Galilean telescopes, small mostly behind-the-spectacle-lens Keplerian telescopes[4], and horizontal telescopes folded above the spectacle lenses[5]. While each of these devices improves the cosmetics of bioptic telescopes, they remain obtrusive and telescopes continue to be rejected by many patients that could benefit from them. In addition, conventional attempts at miniaturization[3] invariably result in optical compromises such as reductions in field-of-view or image brightness, or both.

Low magnification telescopes can be created by combining a high negative power contact lens[6] or intra-ocular (i.e., surgically implanted) lens with a high positive power spectacle lens[7]. While such telescopes are limited in magnification and severely restrict the field-of-fixation they offer an advantage in cosmetic appearance. However, patients also reject these devices due to the unsightly appearance of the high power spectacle lens[8].

A fully implanted intra-ocular telescopic lens is available[9]. It offers the potential of normally looking spectacles and eyes but requires a surgical procedure, severely reduced field-of-view (but wide open field-of-fixation), dim image, and possible difficulties with future eye care.

What is needed is a low vision bioptic telescope that provides a relatively wide field-of-view, high-magnification, and a bright-image while being cosmetically appealing and permitting the wearer's eye to appear natural.

2. Device description

The principal novelty of the presented device is that all the optical elements needed to compose a terrestrial telescope can be embedded within a carrier spectacle lens. The necessary "tube" length for the focal coupling of the objective and ocular lenses is mostly orthogonal to the visual axis of the instrument, and light is transmitted across the carrier lens body, permitting wide field of view when the telescope is not in use. In addition to quick and easy access to the magnified image this design also permits simultaneous view of the magnified view above the unmagnified view, which can be safer and helps in image navigation.

We describe below the design of a Keplerian telescope including image erection for terrestrial use. The Keplerian configuration has advantages to the Galilean because of the accessible exit pupil, which can be placed at the eye's pupil. This provides wider visual field with smaller lens sizes and without vigneting. The main disadvantages are the larger dimension of the Keplerian telescope (for the same magnification and objective lens power) and the need of an optical erecting element, but both are overcome with the proposed in-the-lens erecting design. Nevertheless a Galilean version of the in-glass telescope is also possible.

Figure 2 shows a front view of the device. The system uses a spectacle lens (mounted in a conventional eyeglass frame) as carrier for the optical elements. It includes an objective lens in front of mirror M1 (not shown) and an ocular lens behind mirror M4 (not shown). The erecting system is achieved by using four mirrors fully embedded within the carrier lens at 45 deg (M1, M2, M3, and M4) in a configuration similar to the reflections obtained in the Abbé's version of the Porro prisms[10].

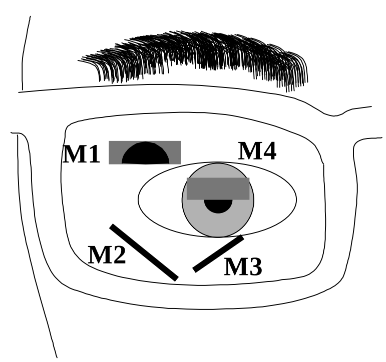

Figure 2: Front view of the telescope.

Figure 3 shows a side view of the device. The spectacle carrier lens (dotted line) has a thickness *d*. The ocular and objective lenses are meniscus lenses glued to the spectacle lens surfaces. Arrows show the direction of the light travel across the erecting mirrors. The mirrors are fully embedded within the carrier lens, and their 45° tilt are visible. The ocular and M4 can be placed in front of the user eye, as shown, or slightly decentered up to achieve a bioptic configuration.

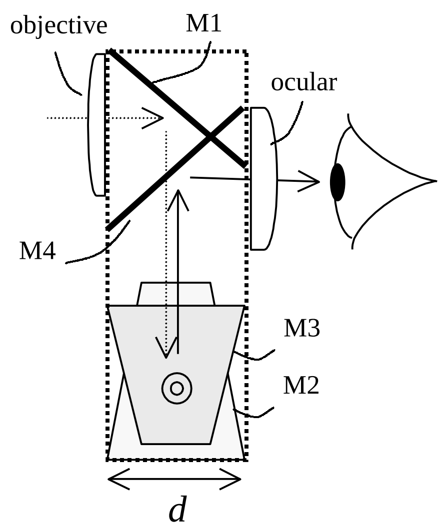

Figure 3. Side view of the telescope with meniscus lenses and flat mirrors.

The convergent elements that act as objective an ocular lenses can be either conventional meniscus lenses attached to the carrier lens, curved mirror (e.g. using parabolic mirrors for M1 and M2), Fresnel lenses, diffractive lenses, or holographic elements. The mirrors M2 and M3 can be also curved to increase the equivalent focal length of the objective or to act as a field lens, increasing the visual field. Using curved mirrors has several advantages: the mirrors are free of chromatic aberration, all the elements would be embedded into the spectacle lens, and curved mirrors yield more optical power with the same curvature comparing with plano-convex meniscus lenses, thus reducing the dimension requirements for the carrier lens. Furthermore, the distance between mirrors to become an afocal optical system does not depend of the refractive index of the carrier lens, but the mirrors power.

Figure 4 shows three different views (zenithal, front and side) of a possible device using only curved mirrors.

Design considerations for the telescope will be discussed next. Features are described for the case of the Keplerian version with meniscus lenses, for the ocular and the objective, and flat mirrors. As it is known the visual magnification M of an afocal telescope (with an erecting system with unity magnification) is determined by the ratio of focal length of the objective lens f'_{ob} to the focal length of the ocular lens f'_{oc}:

$$M = \frac{f'_{ob}}{f'_{oc}} \qquad (1)$$

The afocal condition is achieved when the optical path between objective and ocular lenses, called tube length, is equal to the sum of the image focal lengths of both lenses, assuming the thin-lens approximation. Since the light travels through the carrier lens of refractive index n, this sum corresponds to the reduced distance $\overline{L}$. Using the magnification equivalence, it derives into:

$$\overline{L} = f'_{ob} + f'_{oc} = (M+1)f'_{oc} \qquad (2)$$

Finally, the physical tube distance L is related to the optical path as:

$$L = n\overline{L} \qquad (3)$$

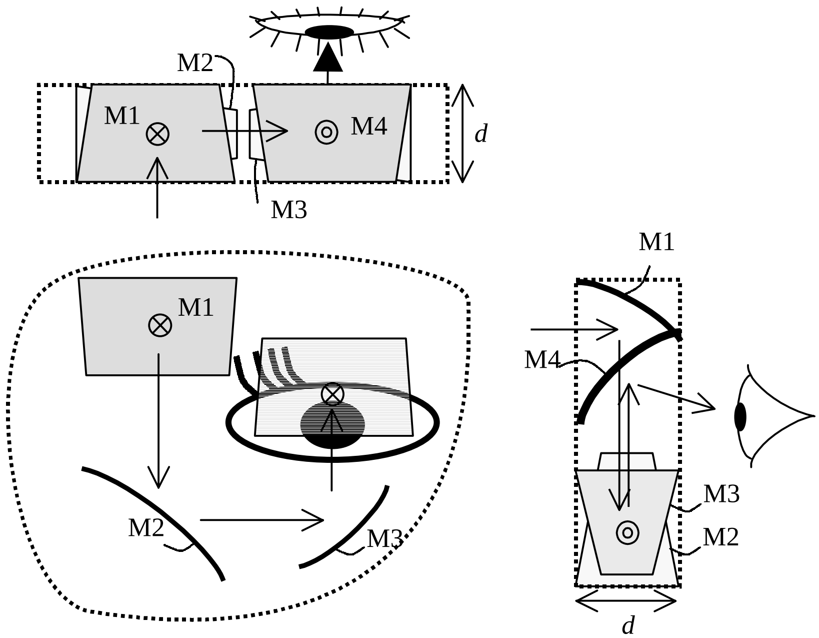

Figure 4. Zenithal, front, and side view of the device with only curved mirrors.

An important feature of the bioptic telescope is the eye relief *e*, defined as the distance from the last surface of the device (i.e. ocular lens) to the eye pupil position. To obtain a better performance it is best to match this distance with the distance of the exit pupil. This can be done in a Keplerian telescope, not in a Galilean configuration. Assuming that the objective lens is the entrance stop, it can be derived:

$$e = f'_{oc} + \frac{{f'_{oc}}^2}{f'_{ob}} = f'_{oc}\,\frac{M+1}{M} \qquad (4)$$

Using equation (3), we obtain the relation:

$$\bar{L} = e \cdot M \qquad (5)$$

This equation (5) and equation (2) relate the variables that rule the design of the built-in-glass Keplerian telescope. The distance *e* is usually fixed to a practical value (e.g. 12mm) as that used in conventional spectacle dispensing. The magnification *M* is determined by the needs of the user. Conventional values for low vision application would be magnifications 3× to 4×. These requirements establish the size of the frame needed to achieve both the magnification and the eye relief desired.

The visual field achieved with this telescope is intrinsically limited by the carrier lens thickness ***d***. This value determines the height of the embedded elements in the orthogonal dimension to the carrier lens (Mirrors M1 and M4). In this configuration this limits mainly the vertical visual field while the horizontal field is affected only by the width and height of the carrier lens or frame. The size of the objective lens and mirror M1 (the closest to the objective lens) affect basically the numeric aperture of the telescope and thus the light efficiency.

The field-of-view of the telescope can be calculated with reference to figure 5, which illustrates the equivalent telescope without mirrors. The intermediate image, y’, is placed at the focal point of the objective F'_{ob} and a distance f'_{oc} from the ocular lens. The size of the intermediate image of the largest viewable image at F'_{ob} is shown as y'. The tangent visual field is therefore given by $2y'/f'_{oc}$..

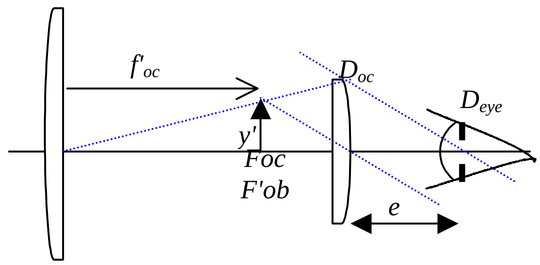

Figure 5. Visual field (half illumination) in a Keplerian telescope.

The field-of-view is typically defined for the field of half illumination. Assuming the desirable situation of the eye pupil placed on the telescope exit pupil, this field-of-view can be expressed in function as:

$$2y' = f'_{oc}\frac{D_{oc}}{e} \qquad (6)$$

Hence, the focal length f'_{oc} and the size of the ocular lens D_{oc} as well as the eye relief e, determine the size of the field-of-view. Depending on the size of the eye pupil diameter D_{eye}, a range of field-of-views with different illumination (from maximum to minimum) can be derived as follows:

$$2y' = f'_{oc}\frac{D_{oc} \pm D_{eye}}{e}, \qquad (7)$$

were + is used for minimum illumination field and – for maximum illumination field.

As we illustrated the in-lens telescope, the ocular lens (mirror) has a rectangle shape. In the horizontal, there is not limitation except for the dimension of the spectacle frame and the chosen value for the telescope length *L*. The vertical dimension is limited by the lens thickness *d*. Although the embedded mirror M4 (the closest to the eye) would be the field stop, we can approximate its limitation with the restriction to the vertical size of the ocular lens of being less or equal to *d*. A reasonable value of thickness would be 5 to 10mm for the carrier lens. For example, a thickness of 10mm and 10mm for the eye relief allows a vertical visual field up to 53°. Nevertheless, the horizontal component (less restricted) is more important for navigation, so thinner carrier lenses would be also tolerable.

3. Simulvision

As previously mentioned, the telescope allows a user to simultaneously view the magnified image and the unmagnified image. Simulvision has been described as one possible strategy for spatial multiplexing in the rehabilitation of low vision [11]. The BITA Reference Manual described the possibility of Simulvision when positioning and tilting the small BITA biotic telescope[12]. In conventional bioptic telescope, tilting the head does select between the normal view and the magnified image of an object (resulting a temporal multiplexing). In simulvision the magnified image is seen through the telescope simultaneously with the unmagnified image. We suggest placing the magnified image a few degrees above the normal view. This provides the user a wide horizontal field (without interruption) at the same level of the object and below it. Alternatively, the magnified image can be shifted in other directions. However, shifting the magnified image above the unmagnified image is preferred because the magnified image occupies an area of the carrier lens that is less likely to include obstacles. Figure 6 illustrates the view obtained with such a Simulvision device.

The magnified view is displaced *T* degrees up to maintain the uninterrupted view of the magnified image (marked in the figure with a dot closed line). The telescope may achieve the simultaneous view in part because there is no opaque frame or mounting structure to block the unmagnified view. In this system the angular displacement ***T*** can be achieved by angularly tilting the *M4* mirror (½*T)* as shown in figure 3 (side view). The Keplerian telescope with its field-of-view limited in height is especially suited to the mode of operation in which the magnified view appears above the unmagnified view. The bioptic position with respect to the eye is also relevant for the good placement of the magnified image in the visual field.

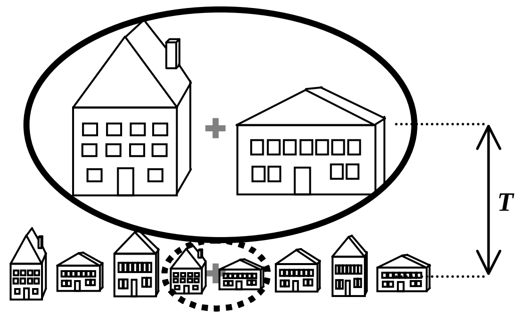

Figure 6. Simulvision concept. The magnified (solid line oval) is angularly displaced to permit the direct view of the unmagnified object (doted line oval).

4. Aesthetic and applications

Although the telescope is visible to observers other than the wearer, it does not attract attention due to its compact and concealed design. The visibility of the telescope to observers is similar to that of bifocal or trifocal segments in spectacle lenses. Figure 7 shows a realistic simulation of the in-the-glass Keplerian telescope. Since the curved mirrors are totally embedded in the carrier lens, using only mirrors make the telescope substantially invisible to a casual observer making it more cosmetically acceptable to patients.

Figure 7: Simulation of the expected appearance

The telescope can be used to simultaneously view the magnified image and the unmagnified image of the same area. This feature improves user orientation and navigation. The user can easily locate an object or determine his position relative to the object. The spectacle lens can include the user's correcting prescription.

The powers of the objective and the ocular lenses (or mirrors) can be configured to provide minification instead of magnification if desired (for example to expand the field of persons with tunnel vision due to glaucoma).

A distance scale can be provided on or embedded in the carrier lens for estimating distance. The distance scale should be located such that a user can simultaneously view the distance scale and the magnified image. This might be useful in military applications or in playing golf.

ACNOWLEDGMENTS

Supported in part by NIH grant EY 12890.
Authors thank Morey Waltuck for mechanical design help.

REFERENCES

1. H. A. Greene and J. Pekar, "Bioptic telescope utilization survey," *Journal of Vision Rehabilitation*; **1**, pp. 39-48, 1987.
2. C. Dickinson, *Low Vision: Principles and Practice*. Butterworth-Heinemann, Oxford, 1998.
3. T. Harkins, "The BITA telescope: a first impression," *JAOA*; **62**, pp. 28-31, 1991.

4. L. Spitzberg,R. T. Jose, and C. L. Kuether, "Behind the lens telescope: A new concept in bioptics," *Optom Vis Sci*; **66**, pp. 616-620, 1989.
5. H. A. Greene and *et al.*, "The Ocutech vision enhancing system (VES): utilization and preference study," *JAOA*; **62**, pp. 19-27, 1991.
6. W. M. Ludlam, "Clinical experience with the contact lens telescope," *Am J Optom*; **37**, pp. 363-372, 1960.
7. T. R. Willis and V. Portney, "Preliminary evaluation of the Koziol-Peyman teledioptric system for age-related macular degeneration," *European Journal of Implant Refractive Surgery*; **1**, pp. 271-276, 1989.
8. L. Moore, "The contact lens for subnormal visual acuity," *British Journal of Physiological Optics*; **21**, pp. 203-204, 1964.
9. E. Peli,I. Lipshitz, and G. Dotan. "Implantable miniaturized telescope (IMT) for low vision." In: *Vision Rehabilitation: Assessment, Intervention and Outcomes*. Stuen C, Arditi A, Horowitz A, Lang MA, Rosenthal B, Seidman K, eds. pp. 200-203, Swets & Zeitlinger, Lisse, 2000.
10. W. B. Wolfe. "Nondispersive Prisms", In: *The Handbook of Optics*. Bass M, van Stryland EW, Williams DR, Wolfe WI, eds. vol II), pp. 4.1-29, McGraw Hill, New York, 1994.
11. E. Peli, "Vision multiplexing: an engineering approach to vision rehabilitation device development," *Optom Vis Sci*; **78**, pp. 304-15., 2001.
12. *BITA Reference Manual*. Edwards Optical Corporation, 1989.