Design of an anamorphic fisheye lens

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Abstract: The design of a 90 x 30 degrees FOV anamorphic fisheye lens is presented. The F/4.5 lens maps the FOV on a 60 mm square array detector.

1. INTRODUCTION

An anamorphic fisheye-lens design was investigated as the first stage of a tracking system for a fifty square feet virtual-environment. The fisheye lens images infrared light emitting diodes (LEDs) on a 60 mm square detector array. The detector pixels are 10 microns in size. The LEDs can be localized within a 90 degree (x-dimension) x 30 degree (y-dimension) field of view (FOV). The spectral bandwidth of the sources is 150nm with 20% spectral output at both 810nm and 960nm. The design approach is presented. The layout, rayfans, spot diagrams, and the modulation transfer function are then presented for performance assessment. Distortion is constrained to achieve a linear mapping. Achromatization of the lens is addressed. Finally, some cost issues associated with fabrication are discussed.

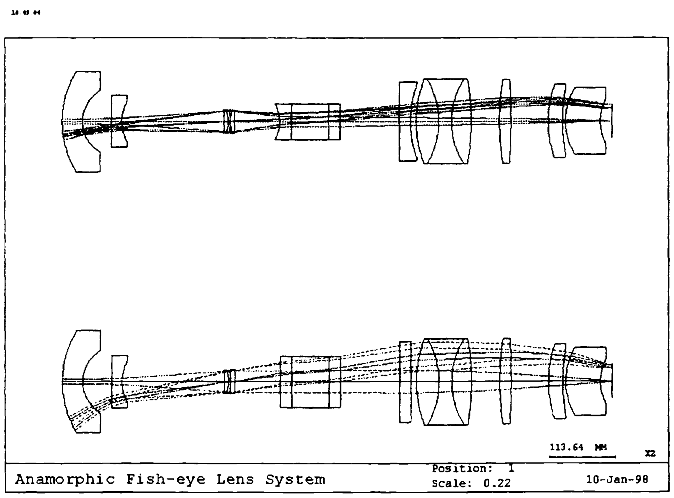

Fig. 1. Layout of the anamorphic fisheye-lens in the y (top) and x (bottom) dimensions.

2. METHODS

Anamorphic fisheye-lenses are most commonly designed by placing an afocal attachment in front of an existing symmetrical fisheye lens. This leads to sub-elegant solutions due to the bulkiness of such a front-end attachment. The solution we propose utilizes an internal afocal sub-system located near the aperture stop. The system aims to satisfy 30 micron RMS spot size over the FOV for the image of an LED to cover at least three pixels from any imaging distance. The F-number is 4.5 in the x-dimension and 13.5 in the y-dimension. Distortion was constrained using a chief ray in the merit function to achieve a linear mapping. We have chosen the lens to be telecentric in image space to facilitate the mapping requirements of the overall optical system. The telecentricity condition was constrained using two chief rays in the FOV, one in each dimension. This constraint could be released for other requirements.

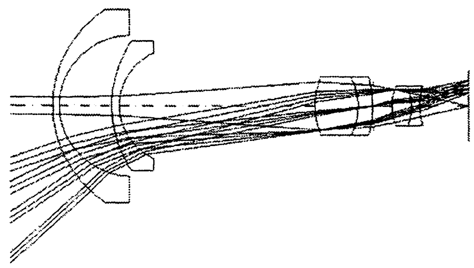

Fig. 2. Starting point for the design of the anamorphic fisheye-lens.

The starting point of the design was chosen to be a symmetrical fisheye lens designed by Edwards and Rolland (1993) for video see-through head-mounted display technology.[1-2] As shown in Fig. 2., this starting-point design lens consisted of two menisci negative lenses typically encountered in fisheye optics and two doublet lenses, one on each side of the aperture stop. This lens was first scaled to satisfy the focal length of 38.2 mm in the x-dimension. An afocal lens made of four y-cylindrical lenses was positioned after the aperture stop between the two doublets. In the early design stage, we constrained the light entering and exiting the afocal assembly to be collimated. The required power of the lenses for the afocal assembly were computed to satisfy a reduction ratio of three in FOV between the x and y dimensions. Most importantly for cylindrical optics, the afocal constraint should be satisfied over the entire FOV. Because such a constraint cannot be reached with afocal optics, the afocal condition was released to balance performance over the FOV.[3] The focal lengths were constrained in the merit function to be 38.2 mm and 114.7 mm in the x and y dimensions, respectively.

3. RESULTS

The layout of the lens, the rayfan plots and spot diagrams, and the modulation transfer function are shown in Figs. 1, 3, and 4 respectively. The RMS spot size is less than 30 microns across 80% of the FOV. Looking at the rayfans, it can be observed that the lens is essentially limited by chromatic aberrations. This result is presented after optimization with varying indexes and dispersion glasses. Some boundaries were set to limit the choice of glasses to second grade glasses for cost considerations.[4] Further achromatization of the lens using conventional optics did not yield much improvement of the rayfan plots.

The addition of a binary optical component located on the flat surface of the smallest cylindrical lens in the afocal assembly was investigated. Performance was significantly

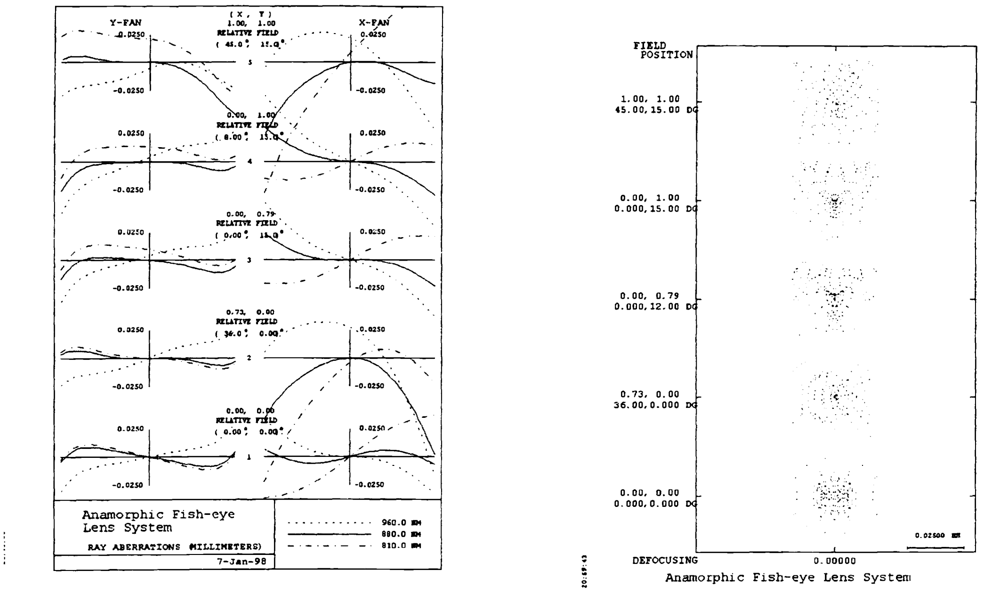

Fig. 3. (a) Rayfan plots and (b) spot diagrams of the anamorphic fisheye lens

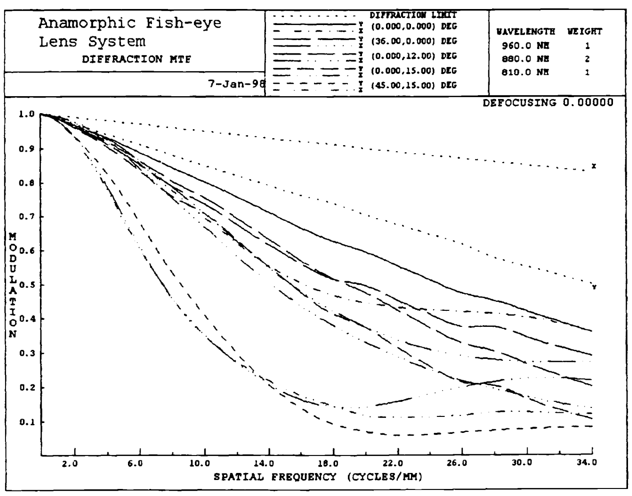

Fig. 4. Modulation transfer function (MTF) of the anamorphic fisheye lens. Except at the upper corner point of the FOV that we included in the optimization of the lens to insure acceptable quality on diagonal points as well as on the two main directions, the MTF is greater than 20% for spatial frequencies less than 28 cycles/mm.

improved over the spectral range. Typical cost of fabricating a cylindrical lens with a binary optics component is \$5K-\$10K. For cost effective optics, we may use a spectral filter located close to the detector array to further reduce the effective spectral range of the overall system, which would be a viable solution in our case.

Fabrication costs were estimated to be around \$40K without the addition of the binary optical component. Part of this high cost is due in part to the large front end of the system and the cylindrical lenses. The glass selection of the first lens should be given special consideration because it is 180mm in diameter and therefore, the cost of fabrication of the first lens can significantly increase by several thousand dollars depending on the selected glass. If performance allows, constraining the first glass to be a BK7 lens would help the overal cost. Because of the length of the system (i.e. 950 mm), a folding prism with 64 millimeter on one side represented as a cube in the unfolded layout shown in Fig. 1 was inserted within the afocal assembly. Such a folding scheme would allow mounting of the optics along the wall of a room where tracking is performed, thus maximizing the effective working volume.

4. CONCLUSION

We have described an approach to design an anamorphic fisheye-lens with an internal afocal subsystem. The system presented has an anamorphic ratio of 1 to 3. The layout of the system has been presented and its performance demonstrated. Further achromatization of the lens using diffractive optics is possible at the expense of some significant increase in cost.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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