Development of microprojection system of mixed and augmented reality

M S Rudakova
Saint-Petersburg State University of Informational Technologies, Mechanics and Optics, 197191, 49 Kronverksky prospect, Saint-Petersburg, Russian Federation

e-mail: RudakovaMS@bk.ru

Abstract. The paper deals with the problems of development and designing of microprojection system of mixed and augmented reality designed so that an observer could see the information of the microdisplay and the surrounding space as the background at the same time. The combiner on planar waveguides screens based on the composite structure of the prism elements was developed. In this work different results of the simulation with the TracePro software are considered and also the main problems encountered in the development of such systems are considered.

1. Introduction
In the last decade in patent literature and articles a lot of information about the input image systems in the observer's eye from the reflective microdisplays can be found. Such systems consist of the image generator (most often it's the microdisplay with the illumination system if the display is not self-luminous), the lens that forms an image at infinity and the combiner which creates the required field of view and ensures the formation of images in the form of a raster-character information on the retina at the background of the surrounding space [1]. Field of application of such systems is quite wide: civil and military avionics, training systems, automobile production, etc.

The present work is devoted to the development of new methods of calculation and design of microprojection systems of mixed and augmented reality.

Among the patent literature the most common method to provide the operation of the combiner is the use of holographic optical elements. However, the reflectivity of the holographic combiners strongly depends on the incidence angle and wavelength, thus limiting the development, primarily color displays [2]. Moreover, most software can not realize the full and correct operation with holographic elements, because there are no exact calculation models and algorithms for solving the ray tracing from the object plane to the image plane. The relevance of the work related to the solution of these problems and is dedicated to the development of calculation models of microprojection display systems.

2. Theoretical model
One of the ways to build combiners is that the radiation is delivered to the observer's eye through the prism elements, the surface of which has a reflective/transmissive coating. This prismatic structure of the display allows to increase the size of the pupil area. However, the combiner of this type has some disadvantages. For example, an increasing of the pupil area requires an increasing of the size of the combiner. This leads to an increasing of the number of components of the combiner prism elements. And that presents some technical difficulties and increases the cost of production. But this solution provides a significant gain in overall dimensions.

The figure 1 shows a radiation transport scheme: image from microdisplay 1 enters the optical system 2, and then on the screen 3-8, and transfers to the observation plane 9. The main structural elements of the screen 3-8 are two crossed prismatic blocks: block 3, 4, 5, referred to as a multiplier of the horizontal field and block 6, 7, 8 – multiplier of the vertical field. The number of elements in multipliers can be different depending on the thickness of the device *d* and the required field of view.

Radiation enters multiples through input prism 3, 6, whose surface is formed as a mirror [3]. The inclination angle of the input prisms in the multipliers is equal to α.

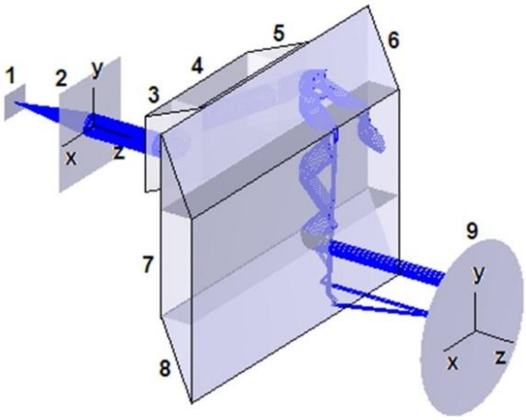

Figure 1. Planar waveguide screen

Were obtained analytical expressions that allow to modify the system according to the changing conditions of input radiation, the value of the field angle and allow to change system parameters such as the thickness and inclination angle of prisms.

The angle of total internal reflection α_{tir} defined by equitation (1):

$$\alpha_{tir} = \arcsin\left(\frac{n_1}{n_2}\right), \quad (1)$$

where n_1 - the index of refraction of the medium from which the light falls (n_1=1 for air); n_2 - refractive index of the medium in which the radiation is incident (the refractive index of the material multiplier).

In order the total internal reflection of radiation on the edges occurs, it is necessary that the angle of incidence β was greater than the angle of total internal reflection α_{tir}.

Entering radiation to the multiplier can be implemented in different ways: using a diffraction grating, a semitransparent mirror, a reflecting mirror, and so on. In this case, we assume that the radiation is introduced through the input prism one surface of which a mirror. The angle of incidence on the faces of the multiplier will be, in this case, $\beta = 2\alpha'$:

All layers in the structure are at a distance from each other, the structure is called the period T. If you have a field angle ω between the layers, period must be equal to $T = b + c$, where b - the height of the prism, and c - the distance from the end of one layer to the next (figure 2).

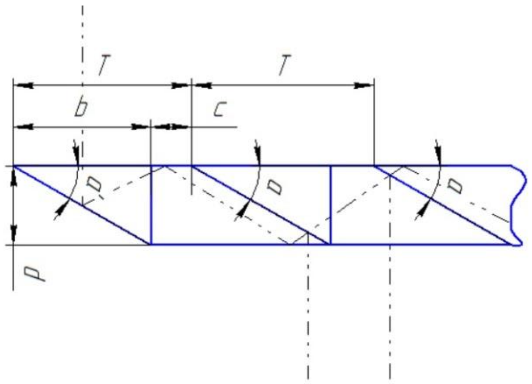

Figure 2. The period T of the structure

The value of c (as in equitation 2) defines the interval at which rays will be reflected.

$$c = d \cdot \mathrm{tg}(\omega_2), \tag{2}$$

where d – thickness of the multiplier; ω_2 - angle of refraction at the transition from a medium with a refractive index n_1 (in this case, from the air) in a medium with a refractive index n_2 (refractive index of the material of the prism). If the radiation falls directly on the input prism, the angle ω_2 is the angle of Snell's law (equitation 3).

$$\omega_2 = \arcsin(\frac{n_1 \cdot \sin\omega}{n_2}). \tag{3}$$

The last issue is the provision of necessary reflection and transmission of layers. It can be done by applying a special coating on each profiled layer. That is, for a system of three layers is enough that the first layer reflects 33.3%, the second - 50%, and the third - 100%. According to the equitation 4 can be calculated reflection coefficient ρ_i of the layer depending on the overall reflectivity and the number of layers in the multiplier.

$$\rho_i = \rho_0 \frac{1}{(N - i + 1)}, \tag{4}$$

where ρ_0 - reflectance multiplier; N - number of layers; i - layer number ($i = 1, 2 ... N$).

3. Simulations in TracePro software

On the basis of analytical expressions in TracePro software were simulated several variants to evaluate image quality and system performance. Analysis of the distribution of power density on the screen was carried out on the brightness of the image in the pupil area, uniformity of illumination of the image, the presence of blind spots and losses in the optical path.

Table 1 shows the variants of multipliers to be modeled in the software TracePro. The initial number of beams is 119401, the radiation power P=1W. The wavelength λ=0,534 μm. The refractive index of the material of multipliers n_c=1,65. Horizontal field of view of ± 11.3 °, vertical field of view of ± 8.5 °. The thickness of the device in all cases d=4 mm and the number of layers n=3. Rays emerging from the multiplier register on the screen, with a diameter of 50 mm at a distance of 28 mm from the last surface of the multiplier. The analysis was conducted also on the distribution in the pupil area, which was located at the same distance from the device (multiplier) as the screen.

Table 1. Simulation variants

Parameters	Var. 1	Var. 2	Var. 3	Var. 4
Multiplier of horizontal field				
The angle of the input prism α', °	45	30	25	30
Tilt angle α, °	45	30	25	30
Period T_1^a/T_2^b, mm	4/4.47	6.93/7.4	8.57/9.05	6.93/7.4
Multiplier of vertical field				
The angle of the input prism α', °	45	30	25	25
Tilt angle α, °	45	30	25	25
Period T_1^a/T_2^b, mm	4/4.36	6.93/7.28	8.57/8.94	8.57/8.94

[a] *T1* – period between the layers with a parallel ray path.
[b] *T2* – period between the layers in the presence of a field angle ω.

The radiation power of 1 W, it can be assumed that the screen brightness microdisplay B=2100 nt when the value of the emitting area $S = \pi r^2$, that when a beam diameter of 4 mm yields S = 12.56 mm^2 and total aperture angle of 14,4°. We take the value of the pupil of the observer equal to d = 5 mm, which corresponds to the area S'= 19.625 mm^2, and the angular field of 22.6° x17°. The transmittance τ is calculated as the ratio of the number of the transmitted rays to the number of the incident rays.

The brightness of the resulting image B' is calculated by the equitation 5:

$$B' = \frac{\tau B S \Omega}{S' \Omega'}, \tag{5}$$

where τ – transmittance in pupil area; B - the estimated brightness of the screen; S - area of the emitting area; $\boldsymbol{\Omega}$ - full aperture angle of the lens of the microdisplay; S'- the area of the pupil area; Ω '- the angular field of the pupil.

One of the plots that we obtain in our research presented in the figure 2. Here presented the simulation of variant 4. The figure 3 shows, that we have optical lose about 31%, good brightness, sufficiently good uniformity of illumination in horizontal plane and no blind spots. In vertical plane is a redistribution of the intensity if illumination. On the whole obtained results meet the requirements.

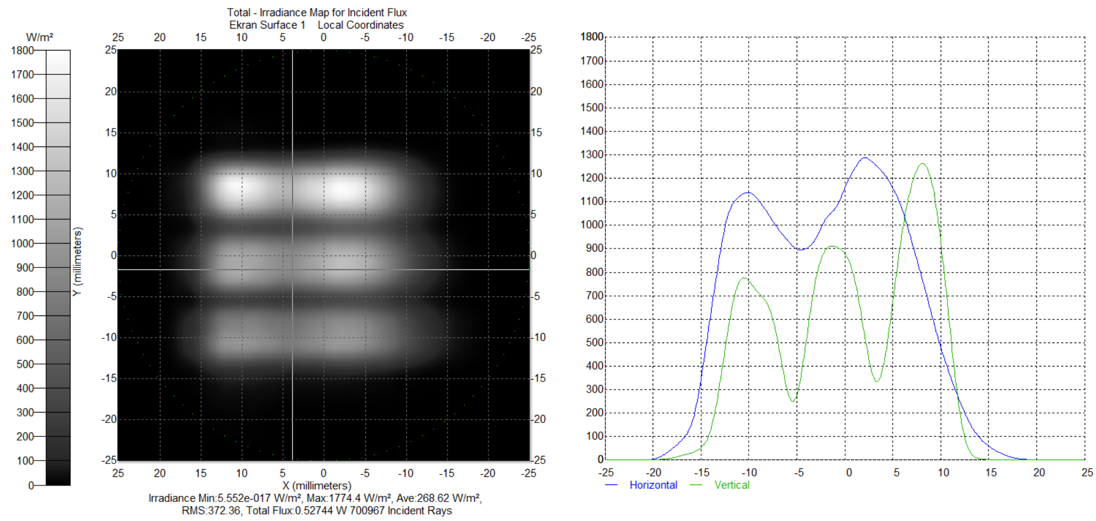

Figure 3. Distribution of power density on the screen

The figure 4 shows the distribution of power density in pupil area. The displacement of the pupil center relative to the center of the screen was: x =2 mm, y =-1.5 mm. The transmittance for the pupil: τ = 25420/119401 = 0.21 (or 21%). The brightness of the image is B'= 152.4 nt.

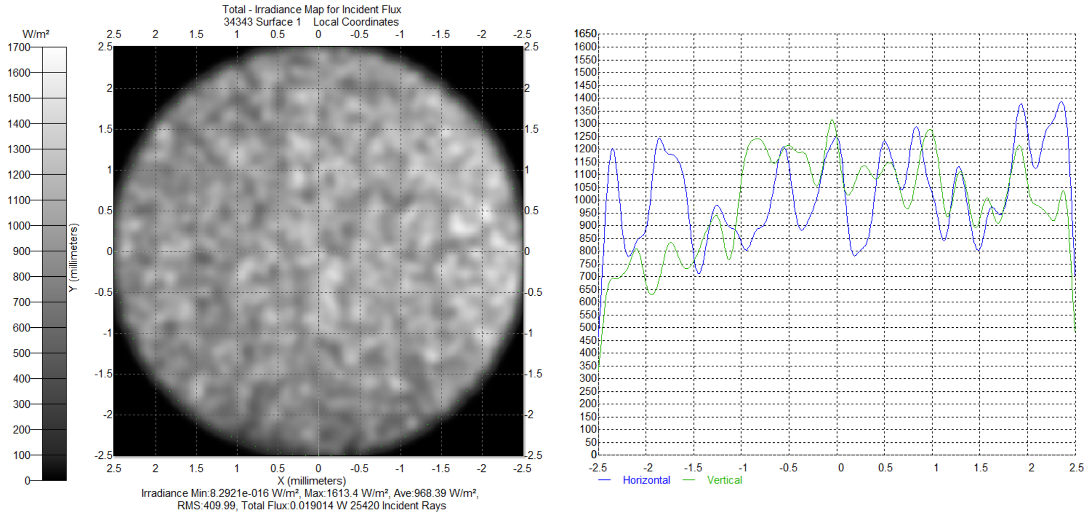

Figure 4. Distribution of power density in pupil area

The system considered efficient if the brightness of the image in the pupil area was not lower than 50 nt and the path loss don't exceed 40%. All of the variants satisfy this condition, but in the distribution of power density are some distortions such as wrong color image, phantom glare, «blind» spots, that can be connected to the frustrated total internal reflection and polarization.

In this case also issues related to the propagation of polarized radiation in the system were discussed. It is necessary to define system performance and the cause of the problems associated with distortion in image.

4. Conclusion

It was found, that the system works and provides replication of the light rays that fill the exit pupil of the collimator lens. Variants that can be considered more suitable for further study and analysis have been identified. In general the fulfilled work matches to the aim, i.e. the calculation model for combiner on planar waveguide screens was developed. In prospect is planned to implement a prototype of the combiner.

References

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