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Synthesis of optical systems for data processing*

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Applications of systems to optical data processing (ODP) are examined. The main requirements with respect to the lenses and the optical systems for Fourier analysis and ODP are pointed out. A module method is proposed for the synthesis of lens and mirror systems used in the devices for ODP. The ORTHO-RUSSAR type orthoscopic telecentric lenses which possess a number of advantages were computed. Conclusions for potential possibilities of the ODP systems and their applications in the hybrid data machines and computers are made.

1. Introduction

The optical systems for optical data processing (ODP) are used in devices for correlation analysis, pattern recognition, image quality improvement, etc. [1, 2, 4–6]. This work is devoted to the synthesis of ODP lens and mirror system, and illustrated by some computed lenses produced in Bulgaria.

The realization of ODP systems depends on the development of special lenses and opto-electronic elements [2–4]. The requirements with respect to the image quality and light-spreading in the coherent ODP systems are rigorous [1, 4]. The light-spread reduction is made by simplification of optical system and application of aspheric surface [3, 4]. In the general case, at equal quality of the image, the lens systems are more complex and have much more coherent noise because of the spreading into the optical glasses and coatings. The mirror systems for ODP are more compact and their construction is simple. They have high aberration quality and can be made with minimal cosmetic defects and layers inhomogeneity [2, 4].

A configuration with two successively located transform lenses is usually employed in the ODP devices which are single reproduction lenses with spatial frequency filtering in the plane of the aperture stop. ODP [1, 3] requires constant quality across the entire image field, with admissible fan aberrations exceeding the Airy Disc by about 20% and distortion not greater than 0.01%.

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2. ODP lens synthesis

Most of the well-known ODP systems are built of conventional lenses that do not fulfil the requirements necessary for operating in those devices. While constructing some real ODP devices we followed two directions: 1 — development of schematic solutions for ODP lens and mirror systems, 2 — synthesis of some basic lenses which can be used as building elements in the devices.

We offer a module method for synthesis of lens and mirror objectives and ODP optical systems which consist of the following. A constant basic optical element with known aberration properties is used to compose the optical configurations. Some lens compensators together with the basic element are computed for realization of lenses with the required quality. We are aware that the orthoscopic telecentric configurations are the most suitable for ODP as they guarantee the orthogonal orthoscopic projecting of the images processed with reduced distortions. The module method can be expanded on the designs with a reflecting filter and a mirror Fourier transforming element.

In optics such an approach is used when a starting system is chosen and its configuration becomes gradually complicated while a concrete lens is being computed. Our method, however, is more flexible and it allows the development of a number of lenses which acquire interesting properties with the synthesis of their successive configuration. A plano-parabolic lens (PPL), computed as a basic optical element, is orthoscopic, telecentric, anastigmatic, and has small spherical aberration and limited coma [3]. For F-number and angular field development of the lenses some aberration jacks, correcting the field curvature, the spherical aberration, and the meridional coma, are added to the PPL. We have examined the properties of the parabolic mirror as a basic element in the reflecting ODP configurations.

In this way some optical elements with a determined aberration quality have been made, from which lenses for different applications can be composed (Fig. 1). In Figure 2 the sketches and aberration curves of the basic lenses are shown. They are of the ORTHO-RUSSAR (OR) type and have been synthesized by the module method since 1977: OR-1 (a), OR-2 (b), OR-2M (c), and OR-2M (d) a model lens. The main point of our method consists in the fact that the PPL

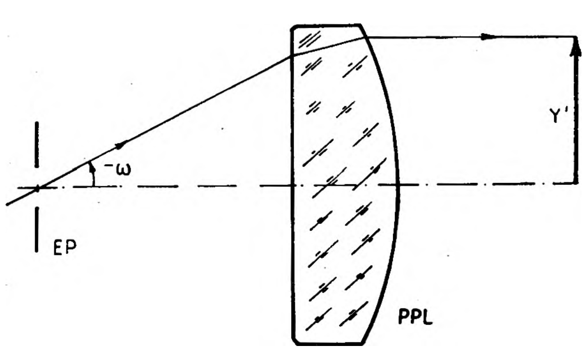
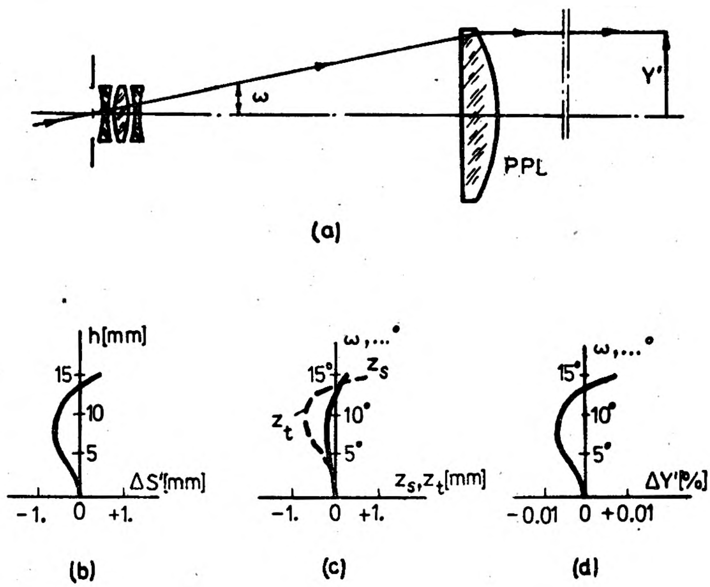


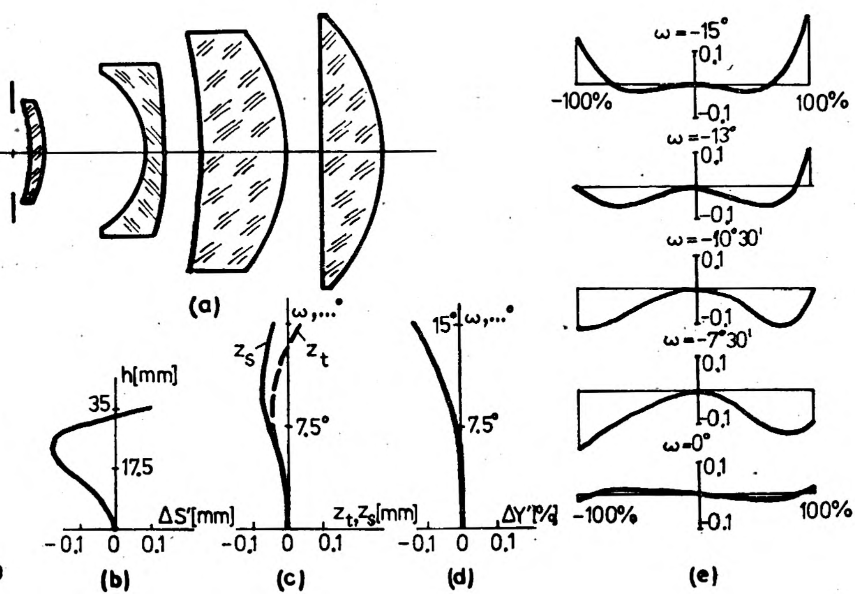
Fig. 1. A plano-parabolic lens (PPL). Y' — image height, EP — entrance pupil

determines the focal length and the angular field of lenses, while the lens compensators correct the determined aberrations for preliminary F-numbers without destroying the orthoscopics and anastigmatics of the basic lens.

While optimizing the lenses a separate aberration correction method was worked out as the inner corrector acted on the spherical aberration and the field curvature, but the front doublet influenced the meridional coma and the distortion. Some systematic investigations for establishing the influence of constructive



2a



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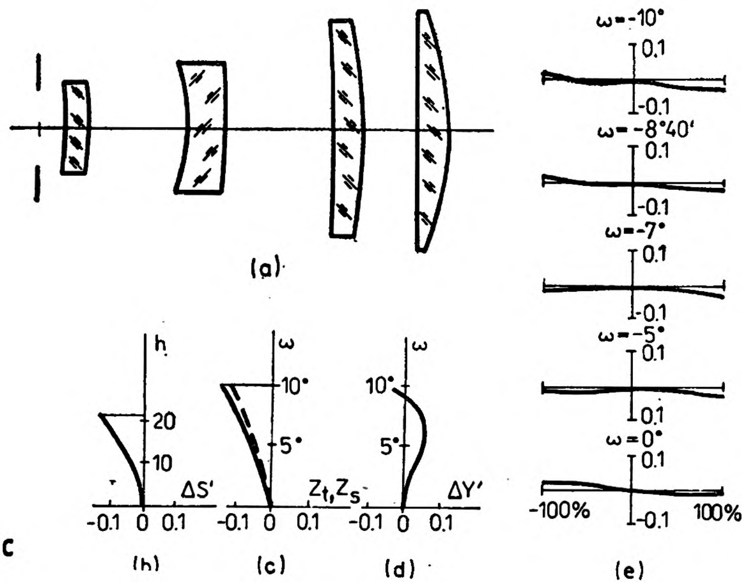


2c

2d

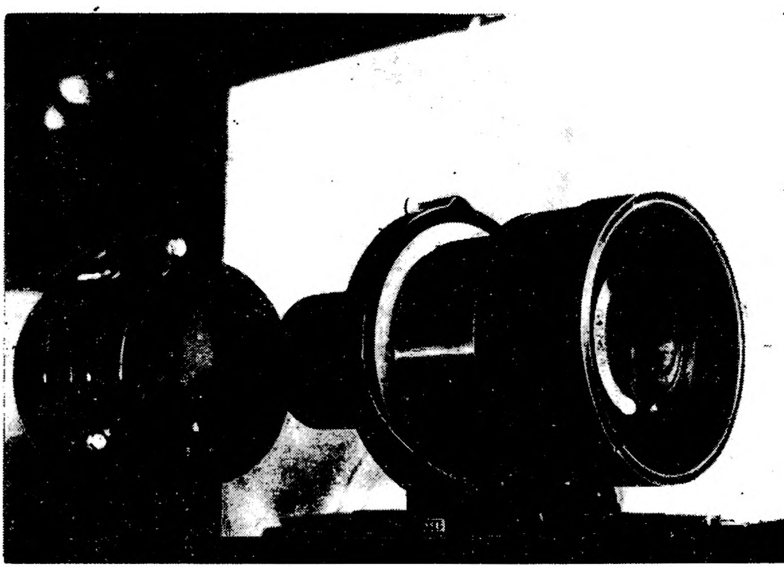
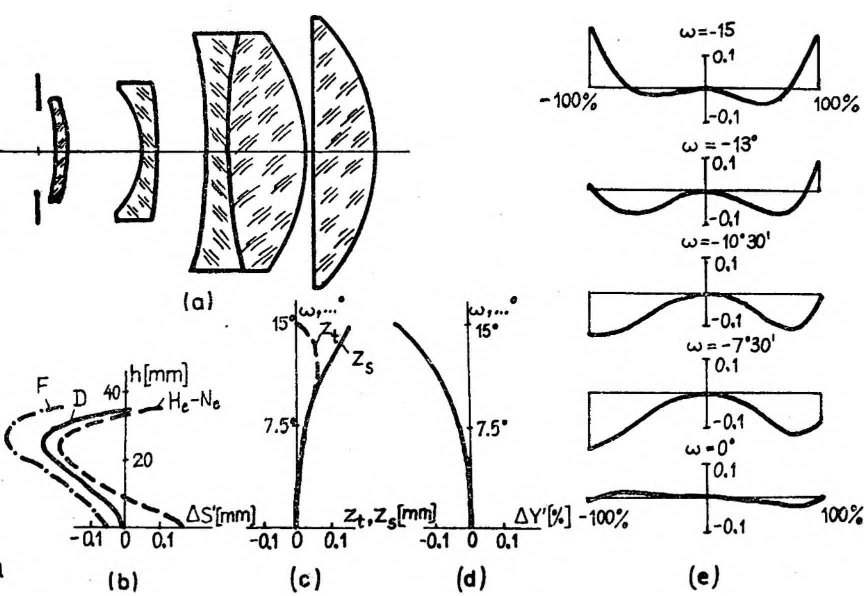


Fig. 2. The lenses of the ORTHO-RUSSAR (OR) type. (a) the schemes: 2a — OR-1, 2b — OR-2, 2c — OR-2M, 2d — a model lens OR-2M. The aberration curves: (b) spherical aberration ($\Delta S'$); (c) field curvatures (Z_t, Z_s); (d) distortion ($\Delta Y'$), (e) meridional coma (h — front telecentric stop height, ω — field angle)

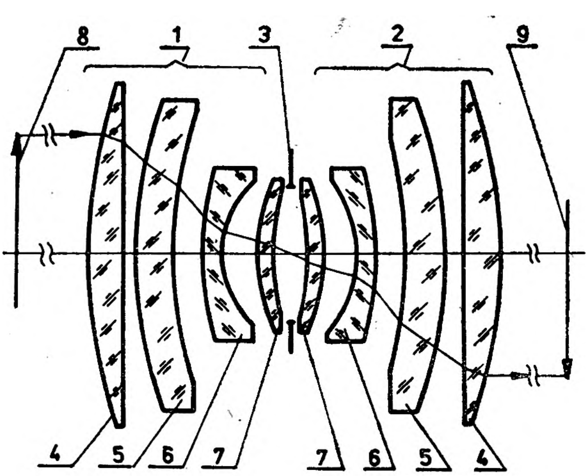
structural parameters upon the aberrations of separate lenses have been carried out. As a result of computing a number of original lenses with interesting properties has been obtained. Such lenses can be used in the ODP systems (see Fig. 3: OR-3 (a), OR-REPRO (b), OR-4 (c), and OR-4A (d)). For example, the

OR-4 lens is telecentric, orthoscopic, anastigmatic and simultaneously corrects field curvature. It has a higher image quality over a 150 mm field and allows a correct matching of the input-output characteristics of the opto-electronic elements in the ODP devices.

While solving the problem of the ODP optical systems synthesis the conditions of simultaneous aberration correction of coma and distortion have been examined in the configuration of a front telecentric stopped lens and some theoretical conclusions have been made. The influence of the meridional coma radii which determine the value and the sign of the coma in a double-lens



3a



3b

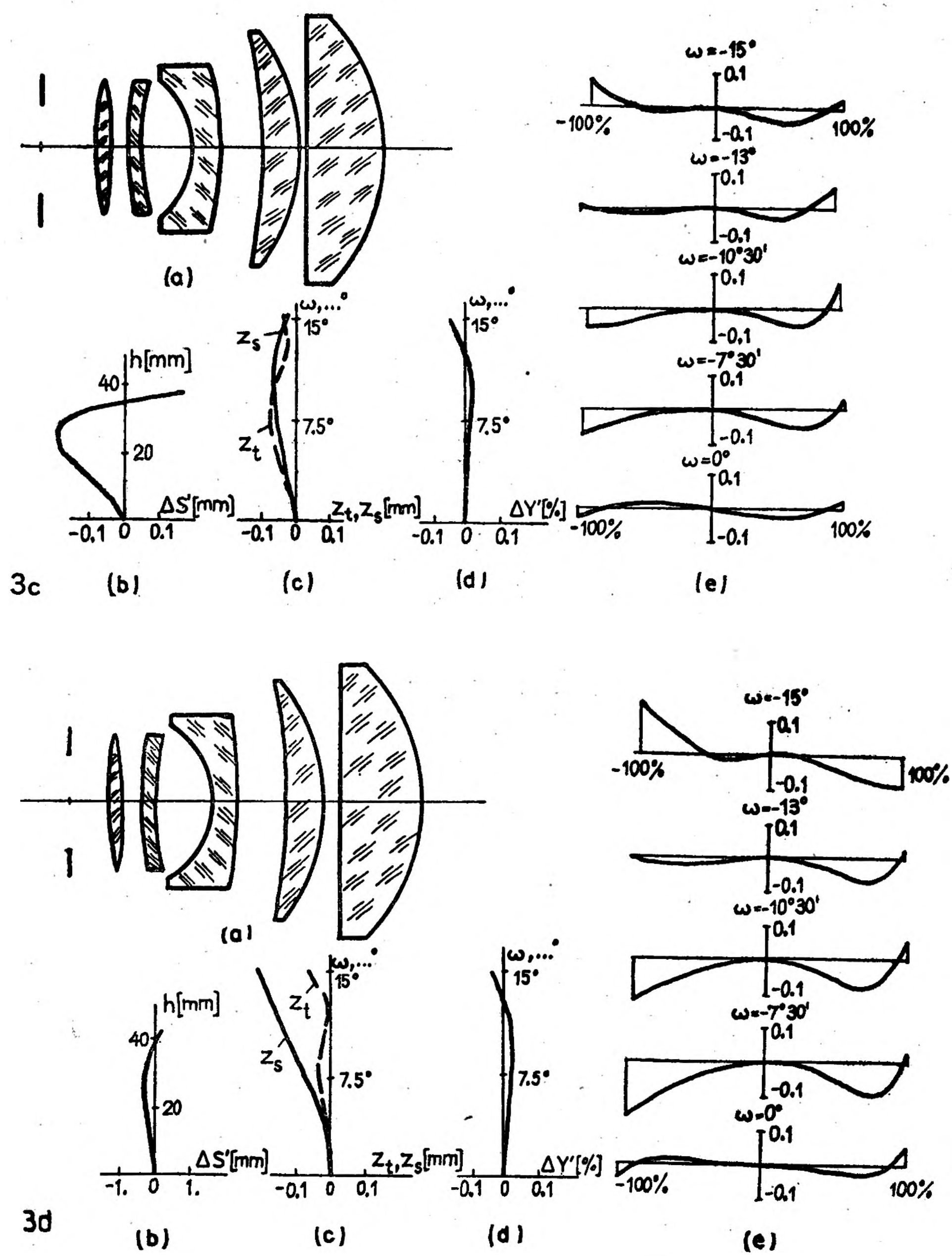


Fig. 3. The ORTHO-RUSSAR lenses. (a) configurations: 3a — OR-3, 3b — OR-REPRO, 3c — OR-4, 3d — OR-4A. The aberration curves: (b) spherical aberration, (c) field curvatures, (d) distortion, (e) meridional aberrations

corrector is studied. The doublet constructive parameters, with the help of which the lens aberrations are controlled during its optimization, have been determined. It is for the first time that the coma and distortion correction in an unsymmetrical optical configuration proved to be possible over the entire image field. The OR-4 lenses illustrate the correctness of theoretical conclusions and the applicability of the method suggested in optical synthesis with a separate aberration correction.

The synthesis of some simple mirror ODP systems, built of a parabolic mirror and a processing plane, is examined in paper [4]. In these configurations the spherical aberration and astigmatism are corrected but the mirror acts as an objective for the first and second Fourier transformations. A similar system can be built from one off-axis parabolic mirror with a reflecting filter. The Fourier transforming mirror possesses some residual aberrations in the filtering plane, which, however, are admissible for $F/8$ ratio and a limited (about 20 mm) filter field (Fig. 4a).

An ODP configuration has been synthesized of four off-axis parabolic mirrors, in which the field curvature has been corrected (Fig. 4b). This system is free of chromatism, astigmatism, spherical aberration and of coma on the optical axis. This optical system, built by module method, consists of two basic mirrors

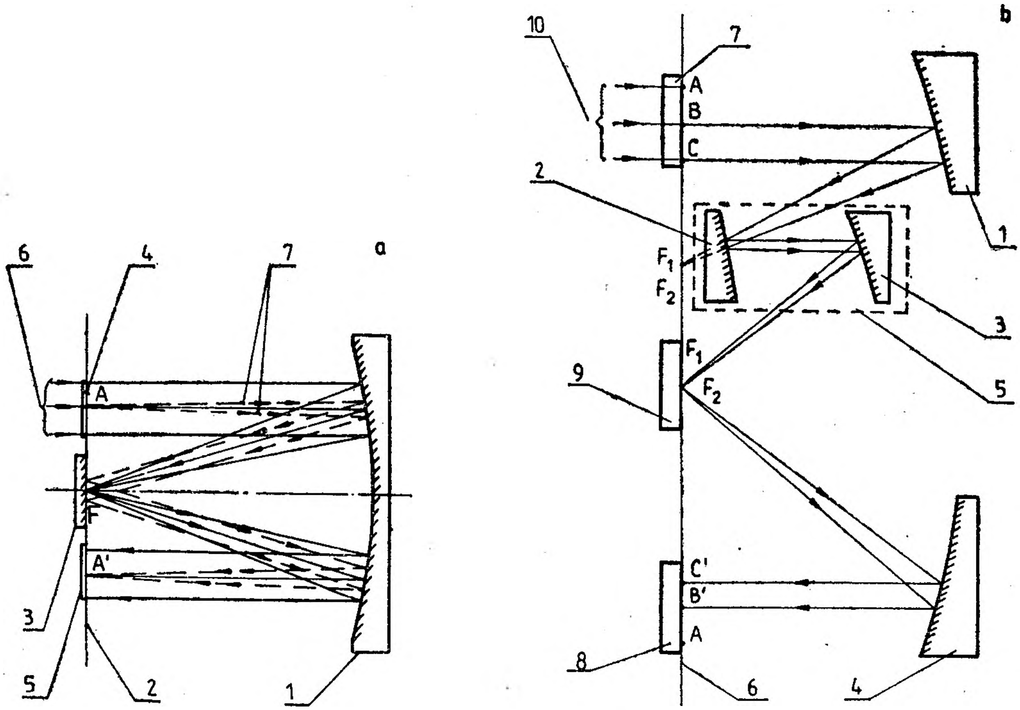


Fig. 4. A simple mirror ODP system (a): 1 — parabolic mirror, 2 — processing plane, 3 — reflecting filter, 4 — transparent, 5 — image receiver, 6 — illuminating beam, A — processing object, A' — final image. A four off-axis parabolic mirror configuration: 1, 2, 3, 4 — off-axis mirrors, 5 — double-element aberration corrector, 6 — processing plane, 7 — transparent, 8 — receiver, 9 — reflecting filter, 10 — illuminating beam, ABC — processing object, $A'B'C'$ — image, F_1, F_2, F_3, F_4 — focusses of the mirror (b)

and a double-element aberration corrector which allows the changes of the image scale. Further complication of the mirror ODP systems is not recommended because of the light losses from the reflecting surfaces which become considerable.

3. Discussion and conclusion

As a result of the research some original lens and mirror optical systems have been developed. They can be used as unified optical moduli in construction of ODP devices. The orthoscopic telecentric path of rays directed by lenses at the object and image spaces simultaneously, guarantees a convenient matching of the energy and frequency characteristics of the opto-electronic elements in the ODP systems. The optical arrangements can be produced without technological difficulties; they possess a high aberration correction, and can be combined in various configurations. Moreover, by accomodating the mirror systems with some adaptive optical elements and optical feedback control, different images can be processed.

The following modifications of the ODP optical systems can be made:

i) To use aspheric optical surfaces simplifying the configurations and improving the lens quality.

ii) To use heavy optical glasses in the lens objective.

iii) To increase quality by making the design more complex and adding some new aberration correctors.

iv) To construct complex ODP systems from optical modulus with well-known aberration and optical properties.

Our experience shows that without well-developed base of elements the construction of any installable ODP devices cannot be started. In the recent years a trend for the development of computer-aided technique for opto-electronic systems with a large data storage capacity has been observed. In these systems the functions of the information storage and processing are combined. In these information systems the image input and output in a dialogue regime are intended. Therefore for such hybrid machines some processing optical systems with a high information processing capability are necessary.

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