Limiting capabilities of photographing various subjects by the integral photography method

Yu. A. Dudnikov and B. K. Rozhkov

(Submitted 28 December 1978)

Opt. Mekh. Prosmt. 46, 38–41 (December 1979)

The limiting achievable parameter values of possible photography subjects and of the three-dimensional integral image are found on the basis of an analysis of the capabilities of the integral photography method.

PACS numbers: 07.68. + m

The following classification of subject types has been universally adopted in amateur photography: macrophotography, portrait, group portrait, group, landscape.[1,2] When the parameters of a lens-array camera objective, designed for taking pictures by the integral photography method, are matched to the parameters of the lens-array photographing system (LAPS), consisting of an array of spherical lens elements and a film,[3] the field of view of this objective lens cannot exceed 40°. In this case the interrelationship of the parameters of the photography subjects corresponds to the data listed in Table I, which are easy to use in order to find both the dimensions of the integral image for various photography scales as well as the distance at which it is viewed. In the latter case it is necessary to make use of the well-known natural impression condition.[4] It follows from the condition of approximate equality of the integral image viewing distance and the distance from it to the exit pupil of the lens-array camera objective[3] that the focal length of the objective lens, on the one hand, is limited to a value of ~600 mm (on the basis of construction considerations[5,6]), and, on the other hand, by the need to retain a sufficient image depth to produce an impression of three dimensions. According to our data, the minimum depth must be at least 30 mm since in this case a natural impression of the surface contours of a number of specific objects, such as commemorative medals, bas-reliefs, etc., is still possible. The possible photography scale is limited both by the format of the integral plate (on the basis of construction considerations and technological capabilities it can barely exceed 50 X 60 cm) and also by the need to limit the magnitude of image perspective distortions, arising because of the unequal longitudinal and lateral magnifications of the camera objective lens. The fulfillment of these conditions made it possible to determine the parameters of the lens array camera and the integral image (Table II).

In order to determine the possible depths of focus for pictures made by the integral photography method we assume that an ideal lens-array photographing system is used whose resolution does not vary over the field of view of an array element and is determined only by diffraction. In real systems, according to the data of Ref. 7, R_{ar} varies continually over the field of view and is not far from the diffraction limit at the center.

Then, with the Rayleigh criterion[3] taken into account, assuming that the photographed subject or its image are considerably far from the array, we find

$$R_{ar} = cd/f'_{ar},$$

where d is the diameter of a lens element of the array; f'_{ar} is the focal length of the array, c is a constant, equal to 1475.

The functions, interrelating the depth of the sharply imaged space in the integral image to the LAPS and derived for the condition that the resolution in all cross sections of the integral image is no poorer than a certain prespecified value, have been given in Ref. 8. For ideal recording and reconstruction (i.e., when $K_1 = K_2 = 1$ in the formulas of Ref. 8) we find that the angular resolution γ_{ar} of the LAPS is equal to

$$\gamma_{ar} = \frac{1}{R_{ar} f'_{ar}} = \frac{1}{cd}. \tag{1}$$

Substituting (1) into the formulas of Ref. 7, we find

$$T_{\infty\ \lim} = 2cd\left(\frac{1}{R} - 2d\right) \quad \text{for} \quad 2Rd \leqslant 1, \tag{2}$$

$$T_{1\ \lim} = \frac{2\,cda'}{R(2cd^2 - a')} \quad \text{for} \quad 2Rd \leqslant 1,\ \gamma_{ar} \geqslant -\frac{1}{Ra'}, \tag{3}$$

TABLE I.

Subject types	Distance to photographed object, m	Focal length, m	Object depth, mm	Object width, mm
Macrophotography	0.4—0.8	0.5	150	300
Portrait	0.8—1.5	1.0	400	600
Group portrait	1.5—2.6	1.9	700	1100
Group	2.6—8	3.4	1500	2000
Landscape	8—∞	11.0	5800	6000

TABLE II.

Subject types	Possible photography scale	Image width, m	Photograph viewing distance, mm	Minimum objective lens focal length, mm	Image depth, mm
Macrophotography	2 : 1	580	1260	420	750
	1.5 : 1	390	900	360	380
	1 : 1	290	600	300	170
	1 : 2	140	300	200	40
Portrait	1.5 : 1	870	1500	600	1200
	1 : 1	580	800	400	400
	1 : 2	290	400	270	100
	1 : 3	190	270	200	40
Group portrait	1 : 2	540	750	500	180
	1 : 3	380	500	370	80
	1 : 4	270	370	300	40
	1 : 5	220	300	250	30
Group	1 : 4	470	650	520	100
	1 : 5	380	520	430	60
	1 : 6	320	430	370	40
	1 : 7	270	370	320	30

$$T_{2\,\mathrm{lim}} = \frac{4cd^2 a' (cd + Ra')}{R(4d^4c^2 - a'^2)} \quad \text{for} \quad 2Rd \geqslant 1, \qquad \gamma_{\mathrm{ar}} \geqslant -\frac{1}{Ra'}, \tag{4}$$

where $T_{\infty\,\mathrm{lim}}$ is the maximum depth of sharply imaged space when the lens array is focused at infinity; $T_{1\,\mathrm{lim}}$ is the maximum depth of the sharply imaged space in the case when the lens array is focused at a finite distance for $2Rd \leqslant 1$; $T_{2\,\mathrm{lim}}$ is the maximum depth of sharply imaged space when the lens array is focused at a finite distance for $2Rd \geqslant 1$; a' is the distance from the front principal point of an array element to the focusing plane of the latter; R is the specified resolution in the integral image at the limits of the depth of the sharply imaged space.

Differentiating with respect to d we find the maximums of these functions, expressed by the relationships (5)-(7):

$$T_{\infty\,\max} = \frac{375}{R^2} \quad \text{for} \quad d_{\mathrm{opt}} = \frac{1}{4R}, \tag{5}$$

$$T_{1\,\max} = \frac{cd}{R} \quad \text{for} \quad a'_{\mathrm{opt}\,1} = 2cd^2 \text{and} 2Rd \leqslant 1, \tag{6}$$

$$T_{2\,\max} = \frac{a'_{\mathrm{opt}\,2}}{2dR} \quad \text{for} \quad a'_{\mathrm{opt}\,2} = 2cd^2\left(2Rd - \sqrt{4R^2d^2 - 1}\right) \text{and } 2Rd \geqslant 1, \tag{7}$$

where d_{opt} is the diameter of an array lens element at which the function (2) has the maximum (5); $a'_{\mathrm{opt}\,1}$ is the value of a' at which the function (3) has the maximum (6); $a'_{\mathrm{opt}\,2}$ is the value of a' at which the function (4) has the maximum (7).

Figure 1 shows graphs describing the functions (5)-(7) for different lens element diameters d. The curve (for each diameter d) consists of two branches, separated by a point discontinuity. The left part of the curve is the graph of the function $T_{1\,\max}$, and the right is the function $T_{2\,\max}$. The envelope, passing through the discontinuity points, is described by the function $T_{1,2\,\max} = c/2R^2$ for $2dR = 1$ (dashed curve in figure); in this situation $a'_{\mathrm{opt}} = T_{1,2\,\max}$.

Hence, assuming that the limiting resolution R_{lim} at the limits of the depth of the sharply imaged space in the integral image corresponds to the limiting angular resolution of the eye, equal to 1′, and the acceptable resolution R_{acc} is an angular resolution of 2.5′ (taking into consideration the loss in visual acuity when real objects are viewed[9]), we can use the figure to find the limiting and acceptable depth of focus in the integral image corresponding to these resolutions (Table III).

It follows from an analysis of the figure that the LAPS is not capable of forming an integral image with a resolution R at the depth limits (the minimum of which is equal to 30 mm) in excess of 5 mm^{-1}. Let us recall that the resolution can be considerably higher at the middle of the sharply imaged space.[7] It turns out that for a low resolution in the image the transmitted depth is strongly dependent on the array lens element diameter, and with an increase in resolution this dependence becomes less pronounced. In addition, the

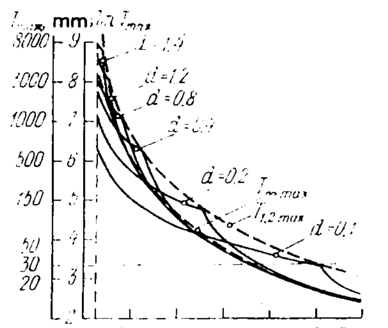

FIG. 1. Dependence of limiting depths of sharply imaged space $T_{\infty\,\max}$, $T_{1\,\max}$, $T_{2\,\max}$, $T_{1,2\,\max}$ in integral image on the resolution at the limits of this depth for different array lens element diameters d.

TABLE III.

Subject types	Photograph viewing distance, mm	Resolution, mm^{-1}		Depth, mm	
		limiting	acceptable	limiting	acceptable
Macrophotography	1300	2.4	1.0	150	700
	900	3.3	1.3	70	530
	600	5.0	2.0	30	190
	300	10.0	4.0	—	40
Portrait	1500	2.0	0.8	190	1100
	800	3.7	1.5	50	330
	400	7.5	3.0	—	80
	270	11.0	4.4	—	40
Group portrait	750	4.0	1.6	40	280
	500	6.0	2.4	—	130
	370	8.0	3.2	—	70
	300	10.0	4.0	—	40
Group	650	4.6	1.8	30	250
	520	5.8	2.3	—	140
	430	7.0	2.8	—	90
	370	8.0	3.2	—	70

abrupt rise of the T_{max} functions for low resolution in the image provides a basis for assuming that it is most advisable to produce large lens-array photographs for which the low resolution is completely acceptable because of the increase in the viewing distance. It also follows from the figure that in view of the fact that the ordinate of the $T_{1,2\ max}$ curve lies above the ordinate of the $T_{\infty\ max}$ curve for all R it is advisable to focus the array on the object being photographed.

CONCLUSIONS

1. If the specified resolution at the depth of sharpness limits of the integral image is not below the limiting angular resolution of the eye (1′), then the integral photography method makes it possible to do macrophotography and portrait photography.

2. If, however, this resolution is not below the acceptable angular resolution, equal to 2.5′, then it is possible to photograph all subjects except landscapes.

1. T. M. Lesina *et al.*, Opt. Mekh. Promst. No. 5, 46 (1968) [Sov. J. Opt. Technol. 35, 329 (1968)].
2. Phototech. Wirtschaft No. 9, 379 (1965).
3. Yu. A. Dudnikov, Opt. Mekh. Promst. No. 8, 13 (1974) [Sov. J. Opt. Technol. **41**, 426 (1974)].
4. V. N. Churilovskii, Teoriya opticheskikh priborov (Optical Instrument Theory), Mashinostroenie Press, Moscow-Leningrad, 1966.
5. V. G. Komar, Tekh. Kino Televid. No. 4, 32 (1975).
6. L. V. Akimakina *et al.*, Tekh. Kino Televid. No. 3, 17 (1976).
7. L. V. Akimakina and N. V. Mel'nikova, Opt. Mekh. Promst. No. 3, 42 (1968) [Sov. J. Opt. Technol. 35, 186 (1968)].
8. Yu. A. Dudnikov and B. K. Rozhkov, Opt. Mekh. Promst. No. 7, 6 (1979) [Sov. J. Opt. Technol. **46**, 385 (1979)].
9. E. M. Goldovskii, Vvedenie v kinotekhniku (Introduction to Motion Picture Engineering), Goskinoizdat Press, Moscow, 1947.

Errors in exposure meters during color printing

B. V. Petukhov

(Submitted 1 March 1978)

Opt. Mekh. Promst. **46**, 41–45 (December 1979)

The operating principle of simple exposure meters, designed for color photographic printing, is examined, and the instrumental errors of these devices are calculated. Optimum blue, green, and red filters are chosen to minimize the errors.

PACS numbers: 07.68. + m

Exposure meters, designed for color photographic printing, can be divided into two groups in terms of operating principle: computational and compensational. Computational exposure meters measure th optical densities of areas of the color negative and on the basis of the results they perform a calculation and assign the exposure parameters required for the printing. Compensational exposure meters are simpler in construction but less convenient to use since the procedure by which they are used to determine the exposure parameters is more lengthy. These devices have no computer