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Investigation of the Imaging Characteristics of a Kinoptic 9.8-mm Lens

FRANK A. DASPIT

Optical Warfare Branch
Optical Sciences Division

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NAVAL RESEARCH LABORATORY
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ABSTRACT

In the process of evaluating the overall performance of the wide-angle camera system used aboard the USNS Mizar (TAGOR-11) for underwater search, it was decided to investigate the imaging characteristics of the Kinoptic 9.8-mm lens used with the camera in order to isolate its limitations from those of the other components of the system.

In use the lens is mounted behind a watertight hemispherical glass dome. The water/glass, glass/air interfaces formed by the dome act as a negative lens, forming a virtual curved image of the (relatively) flat ocean bottom. This image in turn serves as the object for the camera lens. Tests were made of the len's ability to image both flat and curved objects in air, extending across its field of view.

The tests show that the resolving power of the lens falls off greatly at the edge of the field of view for curved objects, so much so that only the general form of the resolution target can be distinguished. For both flat and curved objects, radial resolution is nearly twice as good as tangential resolution. Any method which could be found to effectively flatten the object viewed by the lens would improve the overall resolution of that object.

PROBLEM STATUS

This is the final report on one phase of the problem. The problem has been discontinued.

AUTHORIZATION

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INVESTIGATION OF THE IMAGING CHARACTERISTICS OF A KINOPTIC 9.8-mm LENS

INTRODUCTION

In the process of evaluating the performance of the wide-angle camera system used on board the USNS Mizar (TAGOR-11) for underwater search, it was decided to investigate the imaging characteristics of the Kinoptic 9.8-mm lens used on the camera in order to isolate its limitations from the other components of the system.

In use the camera is towed approximately 20 ft above the ocean bottom, which, for the most part, is relatively flat. The lens is mounted behind a watertight, glass, hemispherical dome having a 3-in. outside radius and a thickness of 3/8 in. When the front nodal point of the lens is put at the center of curvature of the dome, image distortion caused by refraction of the light at the water/glass and glass/air interfaces is negligible because the light entering the camera passes through the interfaces at almost a right angle. However, the interfaces formed by the dome act as a negative lens and form a virtual image of the ocean bottom on a surface roughly concentric with the dome and having a radius of 10 in. (see Fig. 1). Thus instead of having to form an image of a real flat object located 20 ft in front of it, the lens is required to form an image of a virtual curved object lying roughly on the surface of a sphere centered on the front nodal point of the lens and having a 10-in. radius. Because the field of view (FOV) of the lens is about 110 deg and object distances are measured along and parallel to the axis of the lens (see Fig. 2), the curved object extends from roughly 6 to 10 in. in front of the lens, which is a large depth of field for a lens to image, even for one with a 9.8-mm focal length.

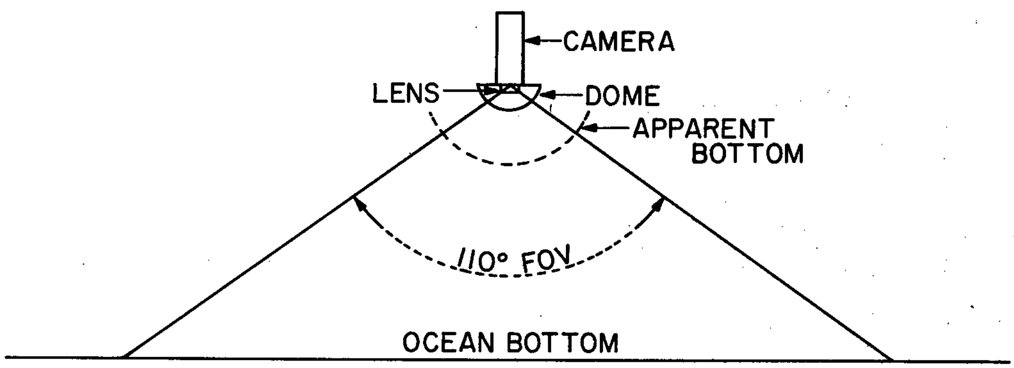

Fig. 1 - Relative positions of the camera and of the apparent and actual ocean bottom. The apparent bottom is caused by the negative-lens effect of the water/dome/air interfaces. (Not to scale).

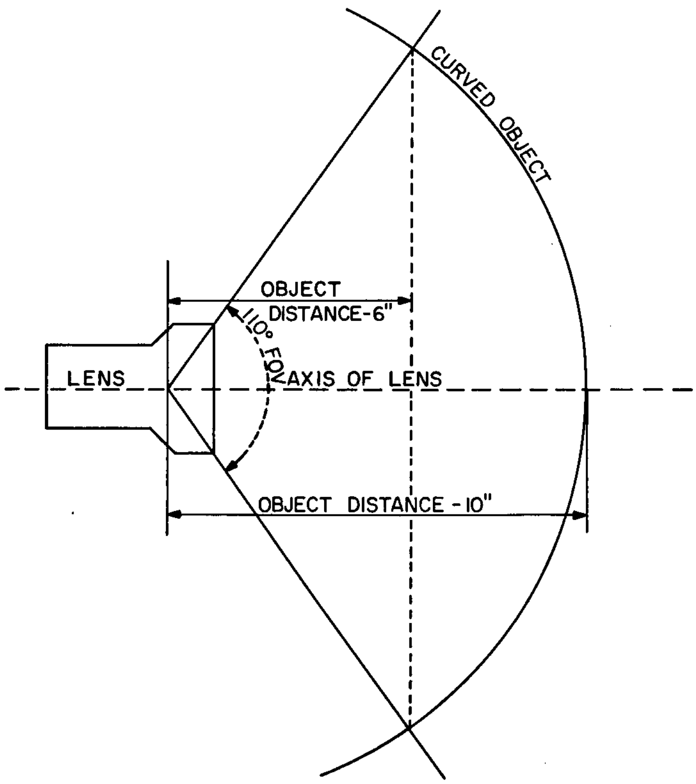

Fig. 2 - Object distances for curved objects

EXPERIMENTAL PROCEDURE

In investigating the imaging characteristics of the lens, it was desired to know, first, what the lens was capable of, and second, how it performed under the conditions imposed by the dome. Assuming that the lens was designed to sharply image a flat object lying in a plane normal to the axis of the lens, the first case was tested by photographing a flat object lying in a plane normal to the axis of the lens and 10 in. away from the front nodal point of the lens. Although the lens was probably designed to operate with conjugates characteristic of greater object distances, the 10-in. flat field distance seemed to offer a more direct comparison with the real curved-field situation. In the second case, conditions were approximated by a curved object lying in a spherical surface, centered on the front nodal point of the lens and having a 10-in. radius.

For these tests the lens was mounted on a Leica camera body by means of a commercial adaptor.

Initially, Kodak Plus-X film was used. However, it turned out that the resolving power of the film was less than that of the lens; consequently, checks were run on Kodak Panatomic X and Kodak High Contrast Copy film, and the latter was chosen as having sufficient resolution for the purposes of these tests.

The target used was a backlighted high-contrast reduction (1 in. × 1 in.) of the 1952 NBS resolution test chart (Fig. 3).

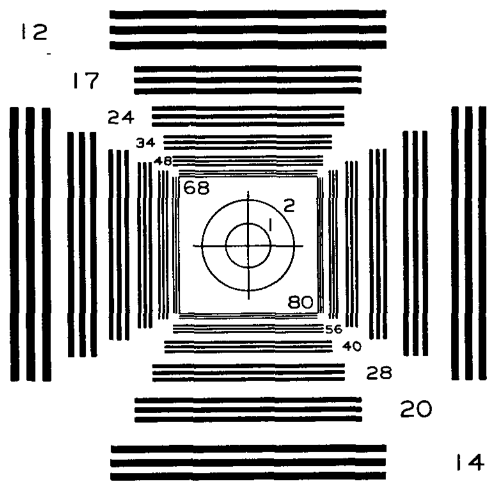

Fig. 3 - NBS resolution test chart used in tests of the 9.8-mm kinoptic lens

With only one target it was necessary to make multiple exposures in order to obtain a photograph of a flat object filling the field of view of the lens. The target and camera were mounted on separate optical benches set at right angles to each other, as shown in Fig. 4, such that the target plane was 10 in. in front of the lens. Exposure of the test negative (Fig. 5) was started with the axis of the camera 20 in. to the left of the center of the target. An exposure was made and the camera was moved 2 in. to the right. A second exposure was made without advancing the film. This procedure was repeated until the camera was 20 in. to the right of the target, and 21 exposures had been made on the single frame of film. The film was then advanced and the next test negative made.

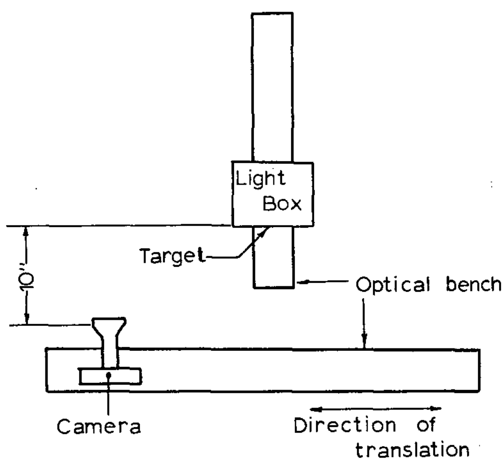

Fig. 4 - Arrangement of the equipment used to test the 9.8-mm lens on a flat object

The photograph of the curved object was obtained in a similar manner. The target and camera were mounted on a single optical bench, as shown in Fig. 6, with the target again 10 in. in front of the lens, and the camera was set to be rotatable about its front nodal point. The test negative (Fig. 7) was obtained by multiple exposures on a single frame of film as before, except that this time the camera was rotated from 60 deg left to 60 deg right in 10-deg steps, instead of being moved sideways. The net result is an object contained in a curved surface having a radius of 10 in. Although the target is actually

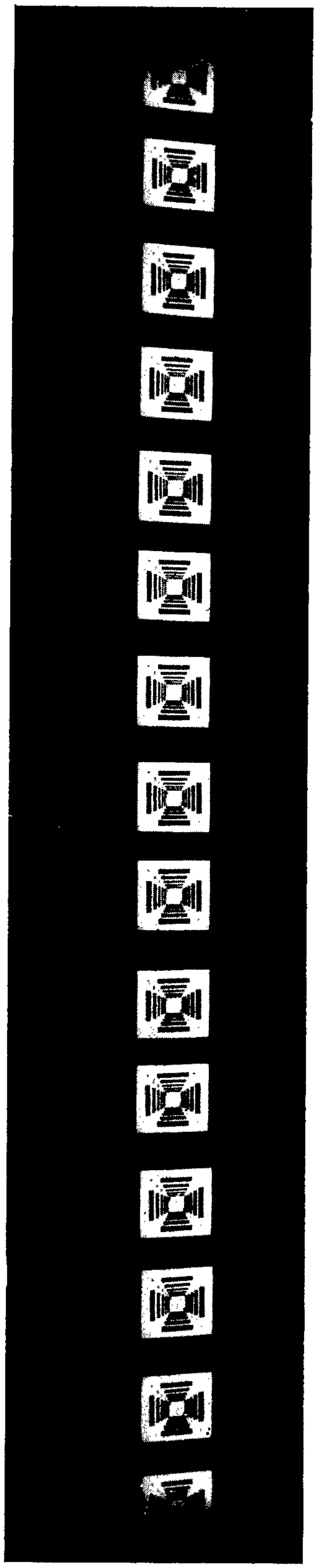

Fig. 5 - Photograph of flat object (multiple exposure of NBS resolution test chart) across the field of view of the 9.8-mm lens

flat, not curved, its dimensions (1 in. × 1 in.) are sufficiently small, compared to the radius, that departures from a true curve are not significant.

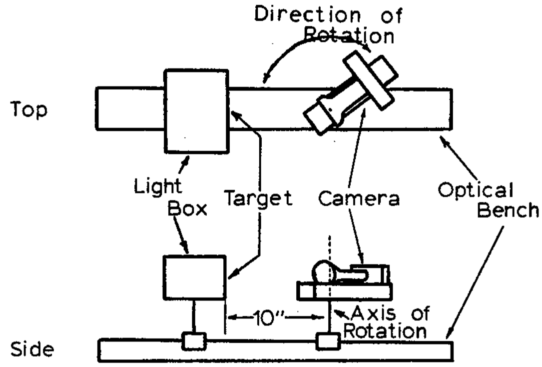

Fig. 6 - Arrangement of the equipment used to test the 9.8-mm lens on a (simulated) curved object

Focusing of the lens was accomplished by adjusting the focusing ring on the lens, which was calibrated in terms of the object-to-film-plane distance. Because the front nodal point was about 5 in. in front of the film plane and the object 10 in. in front of the nodal point, the camera was focused for 15 in. To check the accuracy of this setting, trial exposures were made with settings at 1 ft 3 in., and on either side of this setting. For the flat object at 10 in. a setting of 1 ft 3 in. gave the best resolution in the image and was used for the test negative. Although the setting was important, it was not difficult to make, and a rotation of ±10 deg of the focusing ring had no significant effect on the resolution in the image. For the curved object, one test negative was made with a focus setting of 1 ft 3 in. for purposes of direct comparison with the photograph of the flat object, and others were made at different settings in an attempt to improve resolution in the image. There is no one "best" setting for the focus, since an improvement in the focus of one part of the object results in degradation in the focus of another part of the object. However, with a setting of 1 ft, fairly good resolution was obtained over the central portion of the field of view, very good resolution near the edge, and only the extreme edge was unresolvable. While circumstances might dictate the need for increased resolution at some specific part of the object, in the absence of such circumstances the test negatives evaluated were those taken with the focus ring set at 1 ft.

According to the information furnished, the lens is normally used with a diaphragm opening of F/5.6; hence, the primary test negatives were made at that opening. To check the effect produced by closing the diaphragm opening, negatives were also made at F/8 and F/11.

DETERMINATION OF RESOLUTION

Once the desired test negatives had been obtained, the resolution limits indicated by the various targets were determined for each of the four groups of bars (top, right, bottom, and left) on each target. This was done with the aid of a microscope by determining, first, the smallest set of lines in a group which could be resolved, and secondly, the width, in millimeters, of that set of lines. The width w which was measured represents the combined width of five line elements—three lines and two spaces. Because a line pair consists of two elements—one line and one space—w was converted to line pairs per millimeter by means of the relation

$$\text{Line pairs/mm} = \frac{5}{2w}.$$

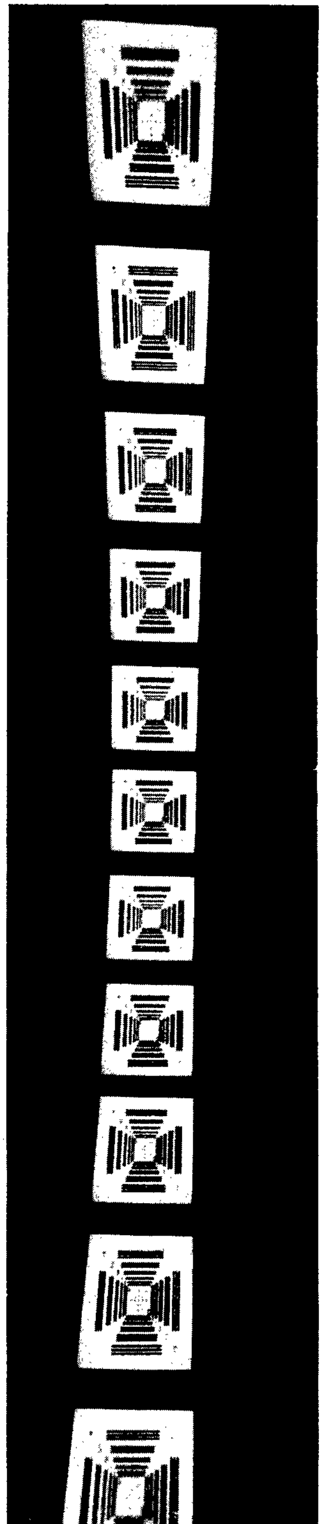

Fig. 7 - Photograph of (simulated) curved object (multiple exposure of NBS resolution test chart) across the field of view of the 9.8/mm lens

For example, Fig. 8 is a photomicrograph of a portion of negative No. 17-2 (Fig. 7) with a scale superimposed across the bottom. The large divisions of the scale are 0.1 mm, and the small divisions are 0.01 mm, with a total of about 2 mm of scale shown. The target shown is the second one from the right end of Fig. 7. Those sets of lines considered resolvable for this target were numbers 5, 3, 5, and 4, going clockwise from the top. The corresponding resolutions are 100, 36, 83, and 50 line pairs/mm.

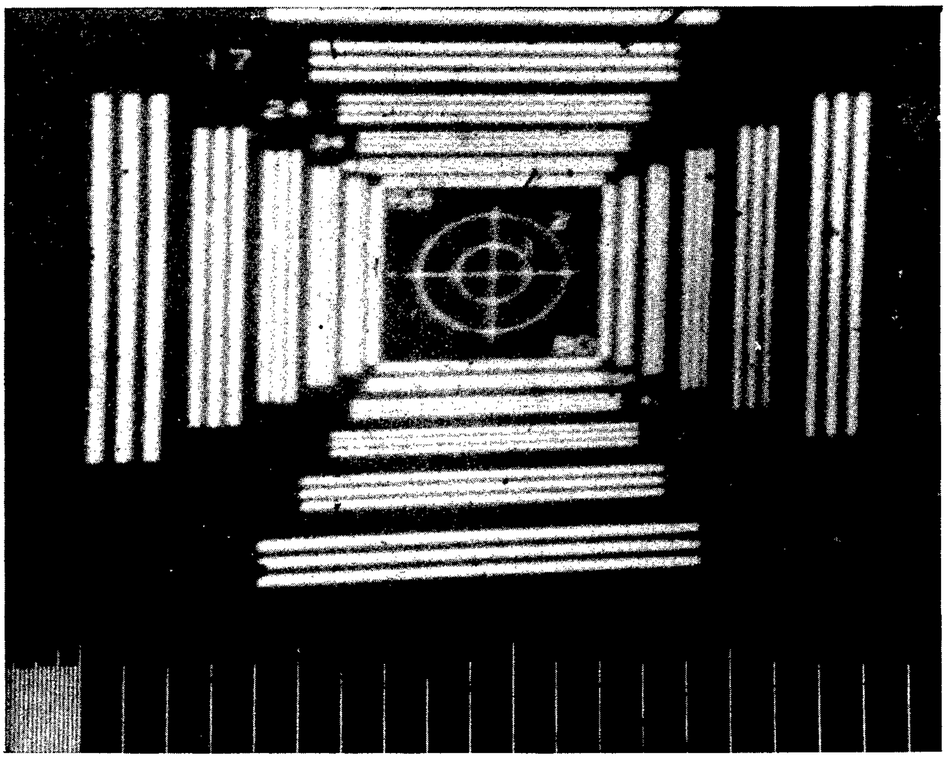

Fig. 8 - Photomicrograph (approx. 50 X) of a portion of negative 17-2. The scale superimposed across the bottom has 0.1-, and 0.01-mm divisions.

DATA

Table 1 lists the five test negatives (Nos. 20-2, 17-2, 17-3, 17-5, and 17-8) which were evaluated, together with data on the type of object photographed (flat or curved), diaphragm opening, and setting of the camera focusing ring.

Table 2 gives the best resolution of each target in line pairs per millimeter. For each target four numbers are given in the form of a cross. Each number, top, right, bottom, and left, gives the limiting resolution for that group of bars which occupies the same position in the target.

Because of the manner in which the negatives were made, the targets in the negatives of the flat object represent equal intervals of lateral displacement and do not correspond to the targets in the negatives of the curved object, which represent equal angular displacements of 10 deg. To permit direct comparison of the data from both types of negatives,

Table 1
Parameters Associated with Selected Negatives Made in Tests of the 9.8-mm Kinoptic Lens

Negative No.	Type of Object	Camera Diaphragm Setting	Setting of Camera Focus Ring
20-2	Flat	F/5.6	1 ft 3 in.
17-2	Curved	F/5.6	1 ft
17-3	Curved	F/5.6	1 ft 3 in.
17-5	Curved	F/8	1 ft
17-8	Curved	F/11	1 ft

data is given only for those targets in the negative of the flat object having angular displacements of approximately 10-deg increments.

RESULTS

The resolving power of the lens for a flat object located 10 in. away (negative No. 20-2) ranges from 100 line pairs/mm at the center to 28 line pairs/mm at the edge.

With the same lens settings, the resolution for a curved object 10 in. from the lens (negative No. 17-3) is 125 line pairs/mm at the center, but falls off drastically as the edge is approached until at the edge proper only the form of the target can be seen and the bars cannot be resolved at all. By changing the setting of the focusing ring from 1 ft 3 in. to 1 ft, the resolution in the center drops to 36 line pairs/mm, then increases to 100 line pairs/mm near the edge, where focus is best, and drops off again at the edge, although in this case only the outside group of bars in the end target is unresolvable.

Keeping the same focus, but closing the diaphragm from F/5.6 to F/8 and F/11 (negatives No. 17-5 and 17-8) produces significant improvement in resolution, as might be expected, although the resolution is still well below that for a flat target.

There is a marked difference in the ability of the lens to resolve radial and tangential lines off axis. At the edge of all negatives, the radial resolution, represented by the horizontal lines, is nearly twice as good as the tangential resolution, represented by the vertical lines.

CONCLUSIONS

The tests run on this lens were to be the first of a series conducted on various combinations of components of the underwater camera system. The next tests were to be checks of the lens, in conjunction with several different domes, in an underwater camera calibrator located at the Naval Photographic Center. The results of these subsequent tests would not only serve to determine the effects of the various components, but also to crosscheck the results of the first tests. Unfortunately, due to scheduling difficulties, these tests could not be conducted. Because the data contained in this report were obtained by nonstandard methods, and no crosschecks are available, the results should be viewed with caution. However, the data is adequate to show that a serious degradation of resolution results from the need for the lens to image a curved object rather than a flat one, and any method which could be found to flatten the object would improve the resolution in the image.

Table 2
Resolution in Line Pairs/mm for a 9.8-mm Kinoptic Lens

Negative No.	Camera Focus and Diaphragm Opening	Nominal Angle Between Center of Resolution Target and Camera Axis (Degrees)										
		50	40	30	20	10	0	10	20	30	40	50
20-2	1 ft 3 in. F/5.6	29 42 31 28	100 38 62 100	83 56 62 100	83 83 62 100	83 71 83 100	83 100 100 100	83 71 62 100	83 56 62 100	83 50 56 100	83 50 31 100	42 42 42 42
17-3	1 ft 3 in. F/5.6	— — — —	36 28 21 31	83 28 50 71	125 50 50 100	83 100 62 100	83 125 125 100	83 100 83 100	83 71 71 100	83 62 62 100	50 36 42 42	— 18 — —
17-2	1 ft F/5.6	21 — 21 25	100 42 36 83	42 62 36 50	42 31 36 36	31 36 31 36	31 36 31 36	31 36 31 36	31 31 28 36	42 31 31 50	100 50 36 83	31 25 — 25
17-5	1 ft F/8	38 — 22 33	83 55 55 83	50 55 45 55	55 45 42 50	42 50 42 50	55 50 42 38	42 35 42 50	50 33 35 50	50 30 31 62	62 50 35 83	38 35 12 50
17-8	1 ft F/11	50 21 29 62	83 62 50 71	50 56 50 42	50 62 50 50	56 50 56 71	56 71 62 50	56 71 62 71	71 45 50 71	62 42 42 62	62 50 50 83	56 50 18 71

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