14th INTERNATIONAL CONGRESS
OF THE
INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY
HAMBURG 1980
COMMISSION I
WORKING GROUP I/6

UNDERWATER PHOTOGRAMMETRY

Invited Paper

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Abstract

This report summarizes the initiation of Underwater Photography Committee in 1966 and the commencement of ISP Underwater Photography Session in 1972 and continued to the present. Basic ideas are presented in this report for verbal expansion and integration by the attendants of Working Groups I/6 and V/1 during the discussion and recommendation sessions on Underwater Photogrammetry with the presentation of proposed resolutions for 1980-1984.

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REPORT ON THE ACTIVITIES OF WORKING GROUP I/6 UNDERWATER PHOTOGRAMMETRY

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This report summarizes the initiation of Underwater Photography Committee in 1966 and the commencement of ISP Underwater Photography Session in 1972 and continued to the present. Basic ideas are presented in this report for verbal expansion and integration by the attendants of Working Groups I/6 and V/1 during the discussion and recommendation sessions on Underwater Photogrammetry with the presentation of proposed resolutions for 1980-1984.

Introduction

During the June 1966 annual convention of the Marine Technology Society in Washington, D.C., the Underwater Photography Committee was organized owing to the initiating capability of Dr. Harold Edgerton. The activities of this committee then served as the influence for the organization of the Underwater Photography Committee, American Society of Photogrammetry, December 1969. The broad aims and objectives of the committee were simply presented as follows:

- To disseminate knowledge and promote education in underwater photography,
- To encourage the perfecting of underwater photography to explore and study the ocean,
- To create a broader understanding of the relevance of underwater photography to other technologies, arts, and human affairs, and
- To exert efforts toward the documentation and improvement of underwater photography standards.

During the 12th Congress of the International Society for Photogrammetry, Ottawa, Canada, July 23-August 5, 1972, the first Underwater Photography Session was presented in accordance with the request by Marvin B. Scher, President, Commission I. The broad aims and objectives, previously presented, were introduced and subsequently presented once again during the Commission I Symposium of the International Society for Photogrammetry, Stockholm, Sweden, August 27-29, 1974, and the 13th Congress of the International Society for Photogrammetry, Helsinki, Finland, July 11-24, 1976.

The proposed plan by Dr. Iawo Nakajima, President, Commission I, for the 14th Congress, Hamburg 1980, presented the W.G. I/6 title of "Underwater Photogrammetry" in lieu of "Underwater Photography". The required performances in the field of "Underwater Photogrammetry" are, indeed, challenging. Specific additions to the outline of the broad aims and objectives are proposed. Determination, with due consideration, of the primary role for responsibility of "Underwater Photogrammetry" by: (1) W.G. I/6, (2) W.G. V/1, or (3) W.G. I/6 and W.G. V/1.

The general outlines of some preliminary fundamentals of underwater photography conditions are subsequently presented in this report to serve only as the basic ideas for verbal expansion and integration by the attendants of Working Groups I/6 and V/1 during the discussion and recommendation sessions. The final recommendations are presented for consideration by Dr. Nakajima. The proposed resolutions of Commission I for 1980-1984 are then presented by Dr. Nakajima for approval during the closing business meeting of the Hamburg Congress.

Division of Underwater Photography Mission

In the interest of simplifying the means of communication, the division of the complete utilization of the underwater photography mission is presented with fundamental components as follows:

- Primary Data Acquisition
  or obtaining photographs,
- Photogrammetry
  or determining the sizes of things on photographs, and
- Photo Interpretation
  or determining the kinds of things on photographs.

Natural and Unnatural Lighting

In aerial photography, the sun serves as the natural, inexpensive, and effective light source for the exposure of negatives in aerial cameras. Weather conditions are so chosen for the efficient transmission of the sun light falling on the ground. These light conditions in aerial photography are not as deeply regarded and personally appreciated until one is involved in underwater photography. The paper by Dr. L. E. Mertens (Reference 1) has covered the actual reality of one of the most difficult and challenging problems in underwater photography that consists of the various degradations of natural and unnatural light in the water path.

Stereo Photographs

The paper by V. A. Seifert (Reference 2) outlines underwater imaging systems with a forecast of future systems. Also of particular interest that is presented in the paper by V. A. Seifert are the highlights of underwater stereo photography test in the Gulf of Mexico by the Naval Photographic Center for fundamental stereoscopic studies of objects and corresponding shadows.

Prof. Kennert Torlegård, President, Commission V, presented Reference 3 during the Underwater Photography Session of the Commission I Symposium, Stockholm, August 27-29, 1974. The underwater camera, electronic flash unit, and reference frame are used to record stereoscopic color transparencies at close-distance for the efficient photogrammetric function in support of marine research. Reference 3 is undoubtedly a classical reference that simply fulfills the recording of the underwater stereo photographs and the programming of the normal case of stereophotogrammetry.

The comprehensive coverage of theory and practice in support of the challenging role for obtaining in-water stereo photos is contributed at a high level of performance by Dr. L. E. Mertens in Reference 4.

Refractive Index of Sea Water

Recommend the following proposed resolution for Dr. Iawo Nakajima, President, Commission I, to consider for presentation during the closing session of the Hamburg Congress of the International Society of Photogrammetry: "Acceptance of THE INDEX OF REFRACTION OF SEAWATER by R. W. Austin and G. Halikas, S.I.O. Ref. 76-1, Scripps Institution of Oceanography, Visibility Laboratory, San Diego, California, for underwater camera calibration and other primary data acquisition purposes."

Requested by letter dated 11 January 1980 to Dr. S. Q. Duntley for the consideration of Director R. W. Austin, Visibility Laboratory, to approve the technical report, S.I.O. Ref. 76-1 (Reference 5) for Commission I resolution. Received letter dated 22 January 1980 from Dr. Duntley with the following paragraph: "Austin asked me to assure you that your suggested presentation of a resolution to Commission I for international acceptance of THE INDEX OF REFRACTION OF SEAWATER for underwater camera calibration and other primary data acquisition purposes had his complete concurrence."

References 5, 6, and 7 are referred to for the basic fundamentals of presenting Table 1 which is the reprint from Reference 8. Nine columns of Table 1 are listed under the four headings of depth, pressure, density, and refractive index.

Table 1 is determined from the following recommended standard sea water conditions:

- 0^{o} Celsius temperature of sea water,
- $35^{o}/_{oo}$ salinity of sea water,
- 9.806650 meters/second^{2} gravity at sea level, and
- 500 nanometers wavelength for transmission of blue-green light in sea water.

Reference 5 is a technical report by Austin and Halikas of Scripps that reviews the literature from prior to 1900

DEPTH		PRESSURE				DENSITY		REFRACTIVE INDEX
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Z,meters	Z_1,feet	P_1,db	P,kgf/cm^2	P_2,as	P_3,lbf/in^2	p,g/cm^3	p_1,lbm/ft^3	n
0	0	0	0	0	0	1.02810	64.182	1.34442
1,000	3,280.8	1,010.7	103.06	99.75	1,465.9	1.03287	64.480	1.34601
2,000	6,561.7	2,026.3	206.62	199.98	2,938.8	1.03756	64.773	1.34757
3,000	9,842.5	3,046.6	310.67	300.67	4,418.7	1.04216	65.060	1.34911
4,000	13,123.4	4,071.6	415.19	401.84	5,905.4	1.04668	65.342	1.35063
5,000	16,404.2	5,101.3	520.18	503.45	7,398.7	1.05113	65.620	1.35212
6,000	19,685.0	6,135.5	625.64	605.52	8,898.7	1.05549	65.892	1.35358
7,000	22,965.9	7,174.2	731.56	708.04	10,405.3	1.05978	66.160	1.35502
8,000	26,246.7	8,217.3	837.93	810.98	11,918.2	1.06400	66.424	1.35643
9,000	29,527.6	9,264.8	944.75	914.36	13,437.4	1.06815	66.683	1.35781
10,000	32,808.4	10,316.6	1,052.00	1,018.16	14,962.9	1.07224	66.938	1.35915
11,000	36,089.2	11,372.5	1,159.68	1,122.38	16,494.5	1.07626	67.189	1.36047
12,000	39,370.1	12,432.7	1,267.78	1,227.01	18,032.0	1.08021	67.436	1.36175

Table 1. Nine Columns List Depth, Pressure, Density, and Refractive Index for Standard Sea Water with Constants of 0°C Temperature, 35°/oo Salinity, 9.806650 meters/second^2 Gravity at Sea Level, and 500 nanometers Wavelength for Transmission of Blue-Green Light.

through 1975 and presents closely-spaced interpolation tables for the determination of the refractive index of sea water with the given values of the four parameters of wavelength, pressure, temperature, and salinity. Reference 5 is, indeed, a practical and significant contribution to oceanography and the related fields of science and engineering. Tables of Reference 5 are the standard tables to comply with in the proposed resolution.

Assume an underwater camera calibrator is operated in a laboratory with pure water at the following given values of the four parameters:

λ = 500nm wavelength (light transmission in pure water)

P = approx. zero kgf/cm^2 pressure (pure water in calibrator)

T = 20^oC temperature (pure water in calibrator)

S = $0^o/oo$ salinity (pure water with no salinity)

The refractive index of the pure water in the underwater camera calibrator is determined by entering the Tables of Reference 5 with the given values of the four parameters to obtain the value of

n = 1.33643.

Underwater Camera Calibration

Aerial camera calibration has been performed with reliable data for the correction of image distortion. The calibration processes, in the supporting role of primary data acquisition, were well established many decades ago with succeeding years of refinements. The due regard for and appreciation of the progress and performance record of aerial camera calibration processes are not associated in the slightest to the progress and performance record of the underwater photogrammetric calibration processes. Aerial camera calibration data, resulting from the refractive index of air under laboratory test of the camera lens focused at infinity, does not appreciably vary owing to the refractive index of air under aerial operation. This valid condition for aerial cameras is not effective for underwater cameras since the refractive index of the object space of pure water under laboratory test is appreciably lower than the value of the refractive index of sea water. The refractive index of sea water is determined when given the values of the four parameters consisting of wavelength, pressure, temperature, and salinity. Owing to the appreciably higher volume absorption and scattering coefficients encountered in sea water as compared with the atmosphere, the finite focusing distances vary but are less than the infinity setting of aerial cameras. Underwater camera calibration is presented with principles of instrumentation, standard sea water refractive index for sea water depth, and change in back focal distance to mechanically fix position of camera lens during and subsequent to calibration for underwater operation.

Commission I, Working Group I/2, Image Geometry with Camera Calibration, has submitted the following resolution:

"Improvements in reliability, efficiency and accuracy are based on realistic knowledge of all primary physical factors bearing on the photogrammetric system. During the last four year period, the Working Group on 'Image Geometry' has emphasized the determination of lens distortion. Attention should now be turned to other physical factors causing departures from the collinearity concept, and to the incorporation of this knowledge into camera design."

Underwater camera calibration has been conducted over a few decades with efforts associated with preliminary pioneering. The fundamental principles of underwater camera calibration have not been generally established. The goal of the collinearity concept is to compensate for physical factors in camera design so that straight lines from object points through their corresponding image points intersect at the lens point or perspective center. The goal of fulfilling the collinearity concept is underway for aerial cameras but is not underway for underwater cameras.

Some of the primary considerations of fundamental interest pertaining to laboratory calibration and operation of aerial and underwater cameras are outlined as follows:

Laboratory Calibration

Items	Camera: Aerial	Camera: Underwater
Object Distance	Infinity	Less than Infinity
Refractive Index	1	1.33643

Operation

Items	Camera: Aerial	Camera: Underwater
Object Distance	Infinity	Less than Infinity
Refractive Index	1	Approx. 1.33 to 1.36

In summary, the aerial camera is fixed at infinity object distance and unity refractive index for laboratory calibration and operation. The underwater camera is adjustable at less than infinity object distances for camera calibration and operation. Also, the underwater camera is fixed at 1.33643 refractive index for laboratory calibration and is variable from approximately 1.33 to 1.36 refractive indexes for operation. It is very obvious that the underwater camera becomes exceedingly more involved in performing the requirements of laboratory calibration and operation than the aerial camera.

A brief history and numerical example is presented for an expedient and appreciative understanding of primary considerations of the previous paragraph. In 1964, Underwater Camera Calibrator was delivered to the Naval Photographic Center, Washington, D.C. (Reference 9). Nine collimators at angular intervals of $7^{\circ}30'$ cover a total angular field of 60°. Each collimator contains an object distance scale so that each collimator can be adjusted for nodal object distances from 6 feet to infinity. Assume the tank is filled with pure water at $20^{\circ}C$.

The nodal object distance is equal to the distance from the object plane to the first nodal point of the lens system. It is of interest to note that the first and second nodal points of a lens system are translated along the optical axis as the refractive index of the object space of water varies. For an example of the translation of the first and second nodal points relative to the variation of the water refractive index, refer to Table 4 of Reference 7.

The following formula, modification of Reference 10 presentation, is effective for paraxial rays:

$$D_o = \frac{n_o}{\dfrac{n}{D_n - k_n} + \dfrac{n - n_o}{r_1}} + k_o \qquad (1)$$

where D_o = nodal object distance setting on collimators

n_o = refractive index of pure water in calibrator tank

n = refractive index of sea water for operation of underwater camera

D_n = nodal object distance specified for operation of underwater camera

k_n = distance from front vertex to first nodal point of lens system for refractive index of n

k_o = distance from front vertex to first nodal point of lens system for refractive index of n_o

r_1 = radius of first surface of underwater camera lens.

When the first surface of the lens is planar, the radius r_1 of the first surface of the lens is equal to infinity. Substituting infinity for r_1 in Formula 1,

$$D_o = \frac{n_o(D_n - k_n)}{n} + k_o \qquad (2)$$

Simplified Formula 2 is effective for a lens system with a flat or plane first surface.

The value of the refractive index n_o of the pure water in the calibrator tank is 1.33643 as previously determined from Tables of Reference 5. Assume the underwater camera operation is planned for a depth of 5,000 meters in standard sea water. From Table 1, the value of the refractive index n of the sea water is equal to 1.35212. Further assume that the specified nodal object distance D_n is 20 meters for operation of the underwater camera. The determined value for k_n is 0.105 meter and, also, k_o is 0.157 meter. The value of the radius r_1 of the first surface of the underwater camera lens is determined to be 100 millimeters or 0.100 meter from lens drawing or diopter gage.

PROBLEM

To Find: D_o

Given: $n_o = 1.33643$
$n = 1.35212$

$D_n = 20m$
$k_n = 0.105m$
$k_o = 0.157m$
$r_1 = 0.100m$

Solution by Formula 1:

$$D_o = \frac{1.33643}{\frac{1.35212}{20-0.105} + \frac{1.35212-1.33643}{0.100}} + 0.157$$

$$D_o = 6.100m.$$

The solution and calibration are simply summarized as follows:

- All collimators of the Underwater Camera Calibrator are set at the nodal object distance of 6.100 meters in pure water with a refractive index of 1.33643.
- Underwater camera with 100mm radius of first lens surface is focused on the Underwater Camera Calibrator.
- Underwater camera is then fixed in focus so that when operated at the standard sea water depth of 5,000 meters and the sea water refractive index of 1.35212, the specified nodal object distance of 20 meters is in focus.

W. Mandler, in Reference 11, describes a devise for testing underwater lenses. The devise was subsequently manufactured for laboratory testing.

Air Photography Versus In-Water Photography

As an introduction to serve as a fundamental base for the subsequent informal discussion and recommendation sessions, the following is presented from Reference 10 that was delivered in 1968, under the first edition, to the Naval Photographic Center:

"It seems evident that the vast areas of the ocean bottom will be initially covered by a lower resolution sensor system than the photographic camera as a compromise to gain significant factors in ocean bottom area per time. The photographic system will be used for local surveys of special significance. It seems that, because the photographic system is initially relegated to the role of the local environment, the three types of cameras (frame, strip, and panoramic) will be used for the exploitation of their salient features.

Photographs covering extensive ground areas are commonplace in air photography as the flying height is relatively high. The ground coverage is directly proportional to the square of the flying height. Flying heights typical of underwater photography are not commonplace in air photography. For example, the ground area covered by a vertical photograph exposed from 25,000 feet is 1,000,000 times as large as the area of an exposure made from a flying height of 25 feet.

The attenuation of light in water is hundreds of times greater than the attenuation in air. The high transmission losses in sea water by absorption and scattering restricts underwater photography to mini-flying heights. In many instances, the coverage of the ocean bottom by normal angle cameras is no greater than the area of a living room rug. As nearly 300,000 living room rugs are required to cover 1 square mile, it is evident that the critical underwater photography requirement is to increase the ocean bottom coverage per exposure and to decrease the time interval between exposures.

The procurement of personnel, vehicles, camera instrumentation materials, support facilities, etc., have as the ultimate objective successful photographic mission time on the ocean bottom. Ocean bottom area coverage per unit of time is the objective of the underwater photo search mission.

Bottom coverage per exposure is increased by increasing the flying height and the angular field of the lens. Increasing the flying height is restricted owing to the attenuation of light by sea water. Means must be devised to increase the image illuminance on the final imaging surface and to increase the ratio of image-forming light to non-image forming light. Increasing the angular field of the lens is within the capability of the lens designer and his associated tools, materials, and techniques. Greater utilization of wide-angle and ultra-wide angle water lenses will evolve when the illuminance problems associated with this increased outer area on the image surface are solved.

The time interval between exposures is decreased by increasing the velocity of the photographic vehicle. The establishment of ground control for underwater photography is far more involved and complex than for air photography. The ideal system to augment the implementation of control extension consists of recording, the tilt, swing, azimuth of the principal plane, the X-, Y-, Z-coordinates of each exposure station. The photogrammetric data reduction procedures for underwater mapping are fundamentally compatible with the procedures and the refinements that materialize for air photography. As the distortion characteristics of underwater lens systems most probably will not match existing air lens systems, the compensation plates in currently available projection printers and plotting machines will require replacement. Cams on those plotting machines that compensate distortion by varying the principal distance will also require replacement. As the nodal-image distances of underwater cameras are usually much shorter than the focal lengths of aerial cameras, the magnification of projection printers will require revision.

The imagery that is characteristic of underwater photography is substantially portrayed by a lack of the kind and size of things that represent man's culture. The integrated knowledge and experience of the oceanographer, marine scientist, and earth scientist bring to bear a level of expectation that is so fundamentally effective in the image interpretation process. With the support of the scientific and engineering disciplines in conjunction with the manipulations of instrumentation, information is processed into intelligence through the mental faculty of the image interpreter."

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