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Determination of Sensitivity Vectors in Hologram Interferometry From Two Known Rotations of the Object

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The fringes generated in holographic interferograms by independent rotations of an object are used to determine the sensitivity vectors of a hologram recording setup. This is done by identifying the fringes observed on the surface of a 3-D object with a fringe vector, which, in turn, equals the vector product of the sensitivity vector with object rotation. These vector relationships are formulated in terms of the projection matrices, and a least square error solution is derived that extracts the sensitivity vectors from the fringe data from two or more known rotations.

I. Introduction

In the holographic analysis of body deformations, both the illumination $\mathbf{K}_1$ and the observation $\mathbf{K}_2$ directions must be known before the sensitivity vector, $\mathbf{K} = \mathbf{K}_2 - \mathbf{K}_1$, can be computed (Fig. 1). The process of determining these quantities is both inaccurate and time-consuming when done with standard measuring instruments, particularly when several of the holograms (with the same recording and observation geometries) are to be analyzed. Further complications arise (1) for objects of complicated 3-D shape, (2) for wide-angle or multiple illumination directions, (3) when mirrors are used for back or side views of the tested objects [often needed to satisfy condition (1)], etc.

If an object is illuminated from a stationary point source of light, two (or more) double-exposure (calibration) holograms can be made, each recording a different but known rotation of the object. Then the sensitivity vectors may be determined directly from these holograms, ensuring that each recorded hologram is analyzed from a number of the same directions of observation. These sensitivity vectors can, in turn, be used to analyze (data) holograms recording unknown motions of an object, providing the illumination and observation geometries remain unchanged for all the (calibration and data) holograms.

It was shown previously[1] that three independent rotations are necessary to provide pertinent information to calculate sensitivity vectors. However, this study indicates that the vector relationships between the fringes observed on the surface of a 3-D object, the sensitivity vectors, and object rotation may be reformulated in terms of the projection of the sensitivity vector onto a plane perpendicular to the object rotation. In this form it becomes apparent that even two object rotations provide more data than are necessary to solve for the sensitivity vector.

II. Theory

If an object undergoes a rotation about any axis, the fringes generated appear to be the lines resulting from the intersection of equidistant laminae with the object's surface; for example, Fig. 2 shows the object that rotated about a vertical axis located 15 cm away from its center. The laminae may be described by fringe vector[2] $\mathbf{K}_f$, whose magnitude is inversely proportional to the normal distance between these laminae and whose direction coincides with the direction of this normal and points toward a fringe lamina of higher order. Fringe vector $\mathbf{K}_f$ may also be expressed as a vector product of the sensitivity and rotation vectors[1,2] $\mathbf{K}$ and $\boldsymbol{\theta}$, respectively, that is,

$$\mathbf{K}_f = -\boldsymbol{\theta} \times \mathbf{K}. \tag{1}$$

The rotation vector $\boldsymbol{\theta}$ appearing in Eq. (1) can be written as a product of the rotation magnitude $|\boldsymbol{\theta}|$, which is scalar, with the rotation unit vector $\hat{\theta}$, as follows:

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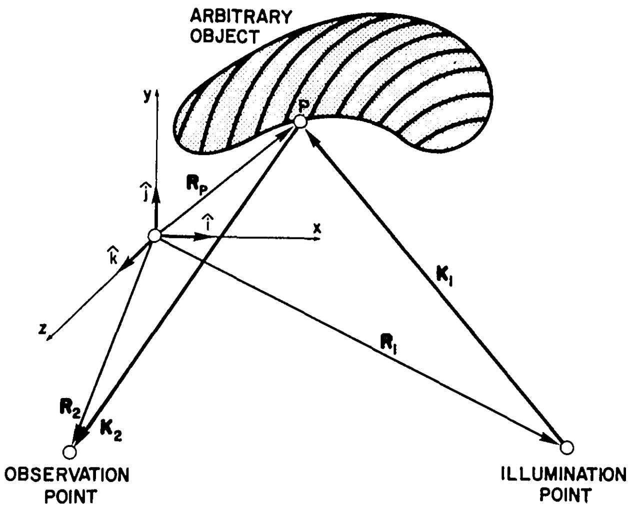

Fig. 1. Illumination and observation geometry in hologram interferometry. Hologram recording and reconstruction geometry are defined with respect to an x-y-z coordinate system. Point P on an object, specified by space vector $\mathbf{R}_P$ (from origin of coordinate system to point on object), is illuminated from a point source located by space vector $\mathbf{R}_1$ and observed from a point at $\mathbf{R}_2$. $\mathbf{K}_1$ and $\mathbf{K}_2$ are illumination and observation vectors, respectively.

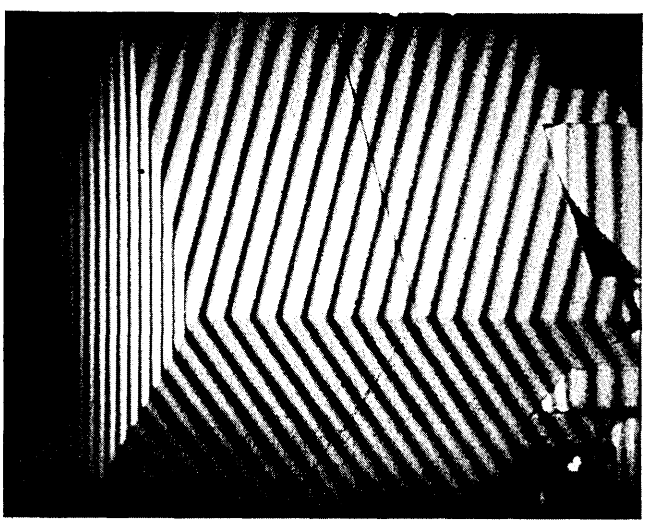

Fig. 2. Reconstruction from a typical double-exposure hologram recording rigid-body rotation of an object.

$$\boldsymbol{\theta} = |\boldsymbol{\theta}|\hat{\theta}, \tag{2}$$

where the magnitude of the rotation is defined as the square root of the sum of the squares of components θ_x, θ_y, and θ_z of the rotation vector, namely,

$$|\boldsymbol{\theta}| = [(\theta_x)^2 + (\theta_y)^2 + (\theta_z)^2]^{1/2},$$

and the unit rotation vector is defined simply as

$$\hat{\theta} = \hat{\theta}_x\hat{i} + \hat{\theta}_y\hat{j} + \hat{\theta}_z\hat{k},$$

with $\hat{\theta}_x$, $\hat{\theta}_y$, and $\hat{\theta}_z$ being Cartesian components of $\hat{\theta}$. Premultiplying both sides of Eq. (1) by the rotation vector defined in Eq. (2), we obtain

$$|\boldsymbol{\theta}|\hat{\theta} \times \mathbf{K}_f = -|\boldsymbol{\theta}|\hat{\theta} \times (|\boldsymbol{\theta}|\hat{\theta} \times \mathbf{K}). \tag{3}$$

Since $|\boldsymbol{\theta}|$ is a scalar, Eq. (3) may be simplified to

$$(\hat{\theta} \times \mathbf{K}_f)/|\boldsymbol{\theta}| = -\hat{\theta} \times (\hat{\theta} \times \mathbf{K})$$

and written in matrix form as

$$(\hat{\theta} \times \mathbf{K}_f)/|\boldsymbol{\theta}| = -\underset{\sim}{\hat{\theta}}\underset{\sim}{\hat{\theta}}\mathbf{K}. \tag{4}$$

Equation (4) relates the ratio of the vector product of the unit rotation vector $\hat{\theta}$ with the fringe vector $\mathbf{K}_f$ divided by the magnitude of the rotation vector $|\boldsymbol{\theta}|$ to the negative vector triple product of unit rotation vector $\hat{\theta}$ with sensitivity vector $\mathbf{K}$. In Eq. (4), unit vector $\hat{\theta}$ is expressed as an antisymmetric matrix whose diagonal terms are zero:

$$\underset{\sim}{\hat{\theta}} = \begin{bmatrix} 0 & -\hat{\theta}_z & \hat{\theta}_y \\ \hat{\theta}_z & 0 & -\hat{\theta}_x \\ -\hat{\theta}_y & \hat{\theta}_x & 0 \end{bmatrix}, \tag{5}$$

and sensitivity vector $\mathbf{K}$ is given in the form of a 3×1 column matrix, namely,

$$\mathbf{K} = \begin{pmatrix} K_x \\ K_y \\ K_z \end{pmatrix}, \tag{6}$$

where K_x, K_y, and K_z are the Cartesian components of $\mathbf{K}$. Defining the negative of the matrix product of unit rotation matrix $\underset{\sim}{\hat{\theta}}$ with itself as projection matrix[3] $\underset{\sim}{P}_\theta$, which is also equal to the difference between identity matrix $\underset{\sim}{I}$ and the matric product (in nonian form) of the unit rotation vector with itself, that is,

$$-\underset{\sim}{\hat{\theta}}\underset{\sim}{\hat{\theta}} = \underset{\sim}{I} - \hat{\theta} \otimes \hat{\theta} = \underset{\sim}{P}_\theta, \tag{7}$$

Eq. (4) may be rewritten as

$$(\hat{\theta} \times \mathbf{K}_f)/|\boldsymbol{\theta}| = \underset{\sim}{P}_\theta \mathbf{K}. \tag{8}$$

However, to solve Eq. (8) for sensitivity vector $\mathbf{K}$, the inverse of projection matrix $\underset{\sim}{P}_\theta$ must be found. Unfortunately, this 3×3 matrix $\underset{\sim}{P}_\theta$, as determined from Eq. (7), is singular if only one rotation is used in its calculation. Therefore, to compute $\mathbf{K}$, more than one equation of the type of Eq. (8) should be used, and this system of equations should be solved simultaneously as follows.

Let us assume that n independent rotations, $\boldsymbol{\theta}_i$, $i = 1,2,\ldots,n$, are recorded on n separate holograms (one rotation on one hologram, respectively). If we are now able to determine fringe vectors $\mathbf{K}_{f_i}$ (by procedures given, e.g., in Refs. 4 and 5) and projection matrices $\underset{\sim}{P}_{\theta_i}$, corresponding to each of the rotations $\boldsymbol{\theta}_i$ for each of the n holograms, Eq. (8) may be written as

$$(\hat{\theta}_i \times \mathbf{K}_{f_i})/|\boldsymbol{\theta}_i| = \underset{\sim}{P}_{\theta_i}\mathbf{K}, \qquad i = 1,2,\ldots,n. \tag{9}$$

The system of equations in the form shown in Eq. (9) can be solved for the sensitivity vector. In holographic analysis, however, one is often using multiple observations (Fig. 3) to determine pertinent parameters, and thus more sensitivity vectors than one need to be determined. Repeated use of Eq. (9) while calculating sensitivity vectors one at a time is rather cumbersome, and, therefore, it would be advantageous to develop an equation that allows calculation of all the necessary sensitivity vectors at the same time. This can be done in an elegant way by noting that observation of a holographic interferogram (recording rotation θ_i) from any direction m ($m = 1,2,\ldots,r$, where r is the total number of observations) defined by a sensitivity vector $\mathbf{K}^m$, as shown in Fig. 3, is accompanied by a corresponding change in the observed fringe pattern; this fringe pattern is uniquely defined by the mth fringe vector $\mathbf{K}_{fi}^m$ corresponding to the ith rotation. Therefore, for each of the m observations we can write an equation of the type of Eq. (9). Since rotation vectors θ_i and projection matrices $\underset{\sim}{P}_{\theta_i}$ are common to all these equations, we can write them as

$$\left.\begin{aligned}(\hat{\theta}_i \times \mathbf{K}_{fi}^m)/|\theta_i| &= \underset{\sim}{P}_{\theta_i}\mathbf{K}^m\\ i &= 1,2,\ldots,n\\ m &= 1,2,\ldots,r\end{aligned}\right\}. \qquad (10)$$

The term $P_{\theta_i}\mathbf{K}^m$ on the right-hand side of Eq. (10) indicates the projection of the mth sensitivity vector $\mathbf{K}^m$ onto a plane perpendicular to the ith object rotation θ_i. Equation (10) can be expanded first with respect to the number of rotations, that is, $i = 1,2,\ldots,n$, yielding

$$\begin{bmatrix}\frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^m}{|\theta_1|}\\ \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^m}{|\theta_2|}\\ \vdots\\ \frac{\hat{\theta}_n \times \mathbf{K}_{fn}^m}{|\theta_n|}\end{bmatrix} = \begin{bmatrix}\underset{\sim}{P}_{\theta_1}\\ \underset{\sim}{P}_{\theta_2}\\ \vdots\\ \underset{\sim}{P}_{\theta_n}\end{bmatrix}[\mathbf{K}^m], \qquad m = 1,2,\ldots,r,$$

then, with respect to the number of observations, that is, $m = 1,2,\ldots,r$, which results in

$$\begin{matrix}\frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^1}{|\theta_1|} & \frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^2}{|\theta_1|}\cdots & \frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^r}{|\theta_1|}\\ \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^1}{|\theta_2|} & \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^2}{|\theta_2|}\cdots & \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^r}{|\theta_2|}\\ \vdots & \vdots & \vdots\\ \frac{\hat{\theta}_n \times \mathbf{K}_{fn}^1}{|\theta_n|} & \frac{\hat{\theta}_n \times \mathbf{K}_{fn}^2}{|\theta_n|}\cdots & \frac{\hat{\theta}_n \times \mathbf{K}_{fn}^r}{|\theta_n|}\end{matrix} = \begin{bmatrix}P_{\theta_1}\\ P_{\theta_2}\\ \vdots\\ P_{\theta_n}\end{bmatrix}[\mathbf{K}^1\mathbf{K}^2\cdots\mathbf{K}^2]. \qquad (11)$$

Equation (11), in turn, may be written in a more condensed form as

$$\Gamma = \mathrm{PK}, \qquad (12)$$

where we have defined

$$\underset{\sim}{\Gamma} = \begin{matrix}\frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^1}{|\theta_1|} & \frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^2}{|\theta_1|}\cdots & \frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^r}{|\theta_1|}\\ \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^1}{|\theta_2|} & \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^2}{|\theta_2|}\cdots & \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^r}{|\theta_2|}\\ \vdots & \vdots & \vdots\\ \frac{\hat{\theta}_n \times \mathbf{K}_{fn}^1}{|\theta_n|} & \frac{\hat{\theta}_n \times \mathbf{K}_{fn}^2}{|\theta_n|}\cdots & \frac{\hat{\theta}_n \times \mathbf{K}_{fn}^r}{|\theta_n|}\end{matrix}, \qquad (13)$$

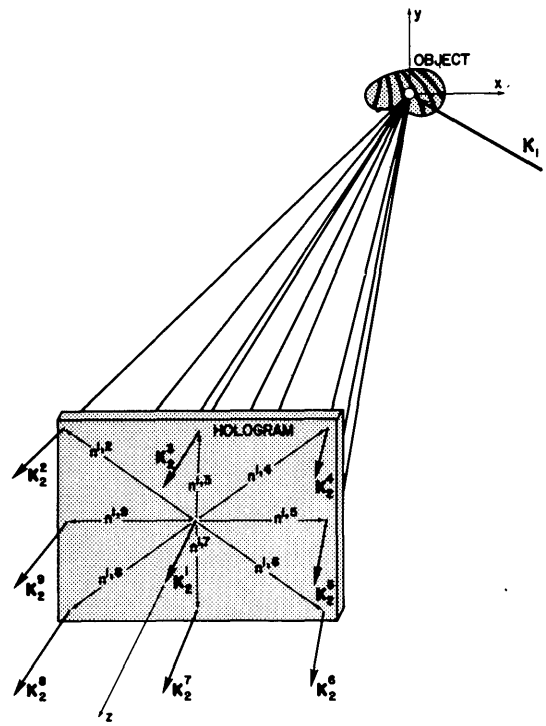

Fig. 3. Schematic representation of multiple observations of a holographic image. $\mathbf{K}_1$ is the illumination vector; $\mathbf{K}_2^1, \mathbf{K}_2^2, \ldots, \mathbf{K}_2^9$ are observation vectors.

$$\underset{\sim}{P} = \begin{bmatrix}\underset{\sim}{P}_{\theta_1}\\ \underset{\sim}{P}_{\theta_2}\\ \vdots\\ \underset{\sim}{P}_{\theta_n}\end{bmatrix}, \qquad (14)$$

$$\underset{\sim}{K} = [\mathbf{K}^1\mathbf{K}^2\cdots\mathbf{K}^r]. \qquad (15)$$

Premultiplying both sides of Eq. (12) by a transpose of rectangular matrix $\underset{\sim}{P}$ we obtain

$$\underset{\sim}{P}^T\underset{\sim}{\Gamma} = \underset{\sim}{P}^T\underset{\sim}{P}\underset{\sim}{K}. \qquad (16)$$

This procedure reduces the rectangular $3n \times 3$ matrix $\underset{\sim}{P}$ to a square 3×3 matrix $\underset{\sim}{P}^T\underset{\sim}{P}$. The resulting Eq. (16) may then be solved for matrix $\underset{\sim}{K}$ of the sensitivity vectors, which has the least square error

$$\underset{\sim}{K} = [\underset{\sim}{P}^T\underset{\sim}{P}]^{-1}[\underset{\sim}{P}^T\underset{\sim}{\Gamma}]. \qquad (17)$$

Studying the above vector relationships, formulated in terms of the projections of the sensitivity vector onto a plane perpendicular to the object rotation, it becomes apparent that even two object rotations provide more data than are necessary to solve for the sensitivity vectors. In the case of only two object rotations Eq. (11) becomes

$$\begin{bmatrix}\frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^1}{|\theta_1|} & \frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^2}{|\theta_1|}\cdots & \frac{\hat{\theta}_1 \times \mathbf{K}_{f1}^r}{|\theta_1|}\\ \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^1}{|\theta_2|} & \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^2}{|\theta_2|}\cdots & \frac{\hat{\theta}_2 \times \mathbf{K}_{f2}^r}{|\theta_2|}\end{bmatrix} = \begin{bmatrix}\underset{\sim}{P}_{\theta_1}\\ \underset{\sim}{P}_{\theta_2}\end{bmatrix}[\mathbf{K}^1\mathbf{K}^2\cdots\mathbf{K}^r]. \qquad (18)$$

Equation (18) can readily be solved to obtain the sensitivity vectors $\mathbf{K}^1, \mathbf{K}^2, \ldots, \mathbf{K}^r$ by the least squares procedure shown in Eq. (17).

III. Procedure, Results, and Discussion

To implement the above procedure for determination of the sensitivity vectors, a computer program was developed to solve Eq. (17), and a sample calculation was made. In this calculation, two independent rotations

$$\theta_1 = 46\hat{\imath}, \tag{19}$$

$$\theta_2 = 8\hat{\imath} + 32\hat{\jmath}, \tag{20}$$

where coefficients are rotations in microradians, were recorded on two separate double-exposure holograms, respectively. For both of these recordings, the object was illuminated from a point source defined by a space vector

$$\mathbf{R}_1 = 499.5\hat{\imath} + 440.25\hat{k}, \tag{21}$$

where coefficients are coordinates of a point source of illumination given in millimeters with respect to the origin of a coordinate system (Fig. 1). After processing, each reconstructed image was observed from five different points defined by the space vectors

$$\left.\begin{aligned} \mathbf{R}_2^1 &= 3.5\hat{\imath} + 2\hat{\jmath} + 177\hat{k} \\ \mathbf{R}_2^2 &= -32.5\hat{\imath} + 28\hat{\jmath} + 177\hat{k} \\ \mathbf{R}_2^3 &= 31\hat{\imath} + 24.5\hat{\jmath} + 177\hat{k} \\ \mathbf{R}_2^4 &= 23\hat{\imath} - 27\hat{\jmath} + 177\hat{k} \\ \mathbf{R}_2^5 &= -38.5\hat{\imath} - 27\hat{\jmath} + 177\hat{k} \end{aligned}\right\}. \tag{22}$$

Corresponding to these observations, there were two sets of five fringe vectors (in mm^{-1}), one for each of the two independent rotations:

$$\left.\begin{aligned} \mathbf{K}_{f1}^1 &= -0.759\hat{\imath} + 0.352\hat{k} \\ \mathbf{K}_{f1}^2 &= -0.746\hat{\imath} + 0.262\hat{k} \\ \mathbf{K}_{f1}^3 &= -0.748\hat{\imath} + 0.421\hat{k} \\ \mathbf{K}_{f1}^4 &= -0.750\hat{\imath} + 0.401\hat{k} \\ \mathbf{K}_{f1}^5 &= -0.744\hat{\imath} + 0.246\hat{k} \end{aligned}\right\}, \tag{23}$$

$$\left.\begin{aligned} \mathbf{K}_{f2}^1 &= -0.528\hat{\imath} + 0.132\hat{\jmath} + 0.244\hat{k} \\ \mathbf{K}_{f2}^2 &= -0.519\hat{\imath} + 0.130\hat{\jmath} + 0.170\hat{k} \\ \mathbf{K}_{f2}^3 &= -0.520\hat{\imath} + 0.130\hat{\jmath} + 0.282\hat{k} \\ \mathbf{K}_{f2}^4 &= -0.522\hat{\imath} + 0.130\hat{\jmath} + 0.291\hat{k} \\ \mathbf{K}_{f2}^5 &= -0.518\hat{\imath} + 0.129\hat{\jmath} + 0.182\hat{k} \end{aligned}\right\}. \tag{24}$$

The fringe vectors given in Eqs. (23) and (24) were calculated using procedures developed in Refs. 4 and 5. The necessary parameters were obtained by digitization of photographs of holographically reconstructed images taken along the directions of observation through points (on a hologram) specified in Eq. (22).

The sensitivity vectors $\mathbf{K}_\theta$ (in mm^{-1}) computed from Eq. (17), using rotations given in Eqs. (19) and (20) and the corresponding fringe vectors given in Eqs. (23) and (24), respectively, were

$$\left.\begin{aligned} \mathbf{K}_\theta^1 &= 7652\hat{\imath} + 109\hat{\jmath} + 16{,}500\hat{k} \\ \mathbf{K}_\theta^2 &= 5696\hat{\imath} + 1533\hat{\jmath} + 16{,}219\hat{k} \\ \mathbf{K}_\theta^3 &= 9152\hat{\imath} + 1359\hat{\jmath} + 16{,}255\hat{k} \\ \mathbf{K}_\theta^4 &= 8717\hat{\imath} - 1505\hat{\jmath} + 16{,}307\hat{k} \\ \mathbf{K}_\theta^5 &= 5348\hat{\imath} - 1359\hat{\jmath} + 16{,}179\hat{k} \end{aligned}\right\}. \tag{25}$$

On the other hand, using the space vectors given by Eqs. (21) and (22), sensitivity vectors $\mathbf{K}_R$ were computed to be

$$\left.\begin{aligned} \mathbf{K}_R^1 &= 7645\hat{\imath} + 112\hat{\jmath} + 16{,}492\hat{k} \\ \mathbf{K}_R^2 &= 5703\hat{\imath} + 1527\hat{\jmath} + 16{,}220\hat{k} \\ \mathbf{K}_R^3 &= 9146\hat{\imath} + 1341\hat{\jmath} + 16{,}256\hat{k} \\ \mathbf{K}_R^4 &= 8714\hat{\imath} - 1485\hat{\jmath} + 16{,}301\hat{k} \\ \mathbf{K}_R^5 &= 5358\hat{\imath} - 1358\hat{\jmath} + 16{,}176\hat{k} \end{aligned}\right\}. \tag{26}$$

To compare the resulting sensitivity vectors shown in Eq. (25) with those given in Eq. (26), let us define error E between $\mathbf{K}_\theta$ and $\mathbf{K}_R$ as the difference between their magnitudes $|\mathbf{K}_\theta|$ and $|\mathbf{K}_R|$, respectively, divided by the magnitude $|\mathbf{K}_\theta|$, that is,

$$E^m = (|\mathbf{K}_\theta^m| - |\mathbf{K}_R^m|)/|\mathbf{K}_\theta^m|. \tag{27}$$

Then, using Eq. (27) we obtain a set of the following five numbers:

$$\left.\begin{aligned} E^1 &= 0.056\% \\ E^2 &= 0.016\% \\ E^3 &= 0.018\% \\ E^4 &= 0.045\% \\ E^5 &= 0.001\% \end{aligned}\right\}, \tag{28}$$

giving the percentage errors between $\mathbf{K}_\theta$ and $\mathbf{K}_R$. From Eqs. (28) it is obvious that the largest error between sensitivity vectors $\mathbf{K}_\theta$ (computed from rotations) and sensitivity vectors $\mathbf{K}_R$ (based on the actual space vectors) is <0.06%.

IV. Summary

The method presented for determination of the sensitivity vectors directly from holograms is very accurate and, no doubt, will prove very useful in holographic analysis. For example, if mirrors are employed to obtain side or back views of the object, the very cumbersome and inaccurate usual procedures for determining illumination and observation directions can be eliminated by the procedure presented in this paper.

The main problem remaining, however, is to choose the technique for performing the observations through the hologram. This can vary from the simple observation through the hologram with the naked eye to the sophisticated approach using the four-degrees-of-freedom positioners carrying the photographic or TV cameras. The required positioners would need adjustments in the vertical and horizontal directions (e.g., parallel to the plane of the hologram) and must be free to rotate with respect to these axes. The photographs or TV images obtained in such a way would be digitized, and the corresponding sensitivity vectors are obtained using a relatively straightforward computer program. These results in turn can be integrated with the interactive computer graphics procedure to solve for unknown rigid-body motions and deformations of the object.

Portions of this paper were presented at the Annual Meeting of the Optical Society of America at Rochester, New York, Oct. 1979.

References

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2. K. A. Stetson, J. Opt. Soc. Am. **64**, 1 (1974).
3. K. A. Stetson, "The Use of Projection Matrices in Hologram Interferometry," in press J. Opt. Soc. Am.
4. K. A. Stetson, Appl. Opt. 14, 2256 (1975).
5. R. J. Pryputniewicz and K. A. Stetson, Appl. Opt. **15**, 725 (1976).

Meetings Calendar *continued from page 2195*

1981
April

6–9 ISA/81 Industry Oriented Conf. & Exhibit, St. Louis *ISA/81 St. Louis, Instrument Soc. of America, 67 Alexander Dr., P.O. Box 12277, Research Triangle Park, NC 27709*

6–10 6th Inter. Symp.: Noise in Physical Systems, NBS, Gaithersburg *R. Mountain, A-311, Physics Bldg., NBS, Wash., D.C. 20234*

7–10 Los Alamos Conf. on Optics '81, Los Alamos, N.M. *Chairman, Los Alamos Conf. on Optics'81, Los Alamos Scientific Lab., E-10, MS 430, P.O. Box 1663, Los Alamos, N.M. 87545*

27–29 Integrated Optics and Optical Fiber Communication, 3rd Int. Conf., San Francisco *OSA, 1816 Jefferson Pl. N.W., Washington, D.C. 20036*

6–7 Lasers-Optics III, Andover, Mass. *M. Fournier, U of Lowell, Cont. Ed., One University Ave., Lowell, MA 01854*

June

? American Astronomical Society, Mtg., Calgary *L. W. Frederick, Box 3818, Univ. Sta., Charlottesville, Va. 22903*

7–12 8th Canadian Congress of Applied Mechanics, Moncton, Canada *N. Srivastava, Faculty of Sci. & Eng., Universite de Moncton, Moncton, N.B., EIA 3e9, Canada*

8–12 Int. Conf. on Fourier Transform Infrared Spectroscopy, S. Carolina U *J. Lephardt, Philip Morris R&D, P.O. Box 26583, Richmond, Va. 23261*

8–12 2nd Inter. Conf. on Precision Measurement and Fundamental Constants, NBS, Gaithersburg *B. Taylor, B-258, Metrology Bldg., NBS, Wash., D.C. 20234*

10–12 **Lasers and Electro-Optics Conf.,** Wash., D.C. *OSA, 1816 Jefferson Pl. N.W., Wash., D.C. 20036*

15–19 Int. Joint Conf. on Thermophysical Properties, NBS, Gaithersburg *A. Cezairliyan, Rm. 124, Hazards Bldg., NBS, Wash., D.C. 20234*

July

? Int. Conf. on Luminescence, West Berlin *AIP, 335 E. 45 St., New York, N.Y. 10017*

14–18 XVth Int. Conf. on Phenomena in Ionized Gases, Minsk *Organizing Comm. of ICPIG-15, Inst. of Phys., BSSR Academy of Sci., Leninskii Prospect, 70, Minsk, BSSR 220602, U.S.S.R.*

August

23–28 182nd ACS Natl. Mtg., NYC *A. T. Winstead, 1155 16th St. N.W., Washington, D.C. 20036*

31–5 Sept. ICO-12, Graz, Austria *S. S. Ballard, Phys. Dept., U. Fla., Gainesville, Fla. 32611*

September

8–11 7th European Conf. on Optical Communication, Copenhagen *M. Danielsen, Tech. U. of Denmark, Electromag. Inst., Bldg. 348, DK-2800, Lyngby, Denmark*

21–25 5th Int. Thin Films Congress, Israel *Y. Shapira, School of Eng., Tel-Aviv U., Ramat Aviv, Israel*

October

26–30 **OSA Natl. Mtg.,** Kissimmee, Fla. *OSA, 1816 Jefferson Pl. N.W., Washington, D.C. 20036*

November

2–6 APS Div. of Plasma Physics, Washington, D.C. *W. W. Havens, Jr., 335 E. 45 St., New York, N.Y. 10017*

23–25 APS Div. of Fluid Dynamics, Monterey, Calif. *W. W. Havens, Jr., 335 E. 45 St., New York, N.Y. 10017*

1982

? Remote Sensing of Environment, Int. Symp., Stresa, Italy *J. J. Cook, ERIM, P.O. Box 8618, Ann Arbor, Mich. 48107*

March

14–18 6th Symp. of Temperature—Its Measurement and Control in Science and Industry, Washington, D.C. *L. G. Rubin, Francis Bitter Natl. Mag. Lab., MIT, 170 Albany St., Cambridge, Mass. 02139*

29–2 Apr. 183rd ACS Natl. Mtg., Las Vegas *A. T. Winstead, 1155 16th St. N.W., Washington, D.C. 20036*

April

14–16 **Lasers and Electro-optics Conf.,** Phoenix *OSA, 1816 Jefferson Pl. N.W., Wash., D.C. 20036*

September

12–17 184th ACS Natl. Mtg., Kansas City, Mo. *A. T. Winstead, 1155 16th St. N.W., Washington, D.C. 20036*

October

18–22 **OSA Natl. Mtg.,** Tucson *OSA, 1816 Jefferson Pl. N.W., Washington, D.C. 20036*

continued on page 2239