RESULTS OF A SEQUENTIAL ADJUSTMENT PROCEDURE FOR ULTRASONOGRAPHY USING AN OSCILLOSCOPE CAMERA

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ABSTRACT

Use of Ultrasonic equipments result in two-dimensional photographs of cross-sections of the body through which the ultrasonic waves are propagated. These waves have the ability of penetration through different materials or tissues and be reflected at their boundaries. Extraction of information from these photographs may be classified as unconventional technology in photogrammetry.

In this paper the problems of dealing with invisible objects having no control points as well as using a non-metric camera in a system subjected to a variety of distortions are addressed. Mathematical models are presented and a sequential adjustment procedure is followed to obtain object coordinates. Final results are given accessing the accuracy of the system and supported by statistical testing.

INTRODUCTION

Photogrammetry is defined as the science or art of obtaining reliable measurements by means of photography (American Society of Photogrammetry and Remote Sensing, 1966). Although this definition is rather traditional, and inspite of the new areas of application that are continuously emerging, this definition is still valid and capable of containing them. Accordingly, photographs obtained by ultrasonic equipments are categorized as non-conventional photographs and metric information could thus be extracted from them by photogrammetric means. The possibility of obtaining accurate metric measurements from ultrasonographs may be utilized in different disciplines, particularly in medical science where these photographs are used as a tool for diagnosis and measurements of internal human tissues (Bernstine and Thompson, 1978) and (Hobbins and Winsberg, 1977). This application using ultrasonic photographs is classified under unconventional close-range photogrammetry. The problems inherit to this present application could be summarized as follows:

- Non-availability of control points (dealing with invisible objects).

- Use of Non-metric camera (unknown inner orientation parameters).
- Image distortions (inherit to the imaging and ultrasonic systems).

The Oscilloscope camera used is the Greatone III Sonograph, a gray-scale processor introduced by the Unirad corporation to give the full dynamic range of ultrasound imaging. Figure (1) shows a block diagram of the basic ultrasonic system used in the research where the display is obtained by synchronizing the time base sweep voltage applied to the X-axis deflection plates of the CRT display and the processed signal voltage from the echoes returning from tissue interfaces which are applied to the Y-axis of the display.

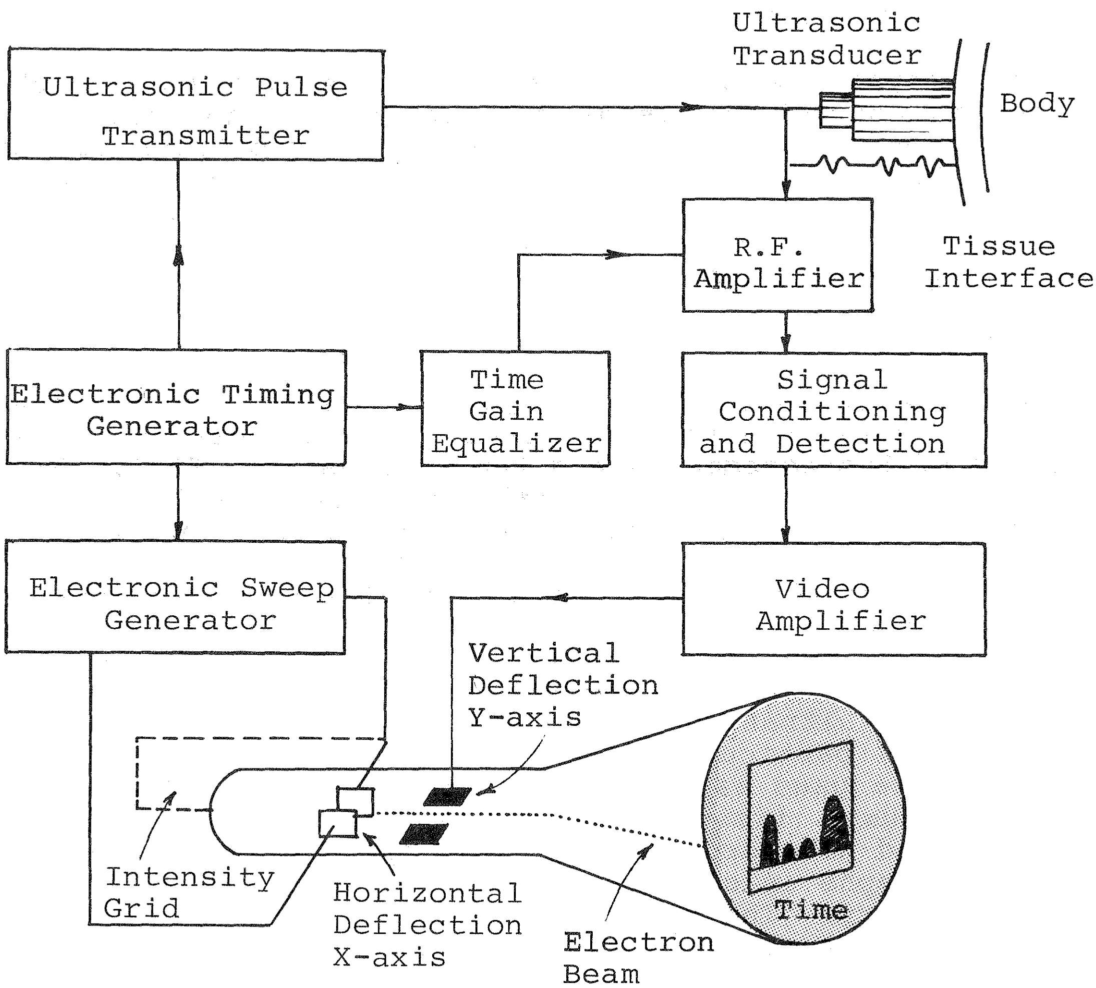


FIG (1) BLOCK DIAGRAM OF BASIC ULTRASONIC SYSTEM

This paper presents a sequential adjustment procedure as well as results of calibrating the ultrasonography system. It implies a general process of non-metric camera calibration and resolves the problem of determining the coordinates of an object having no control points. The missing of fiducial marks has been resolved by using an artificial coordinate system, realised by introducing a standard reseau having the same dimensions of the screen and fixed infront of the CRT.

PRINCIPLES OF ULTRASONOGRAPHY

Ultrasound is a propagation of sound at frequencies beyond the range audible to people (for medical applications these frequencies range from 1 to 10 MHZ). Ultrasonic equipments permit to obtain a two-dimensional display of a cross-section of the body through which the ultrasonic waves are propagated. The reflected waves depend on the difference in densities and acoustic impedances between the two internal bodies and upon the orientation of the reflecting surfaces. These reflected waves have the same form of the transmitted pulse, typically a sine wave of two cycles, but its amplitude will be in the order of $20\text{-}10^6$ times less than the transmitted pulse. Therefore it is necessary to amplify the generated volvage and to process the signal before it is fed to the display systems (Figure 2).

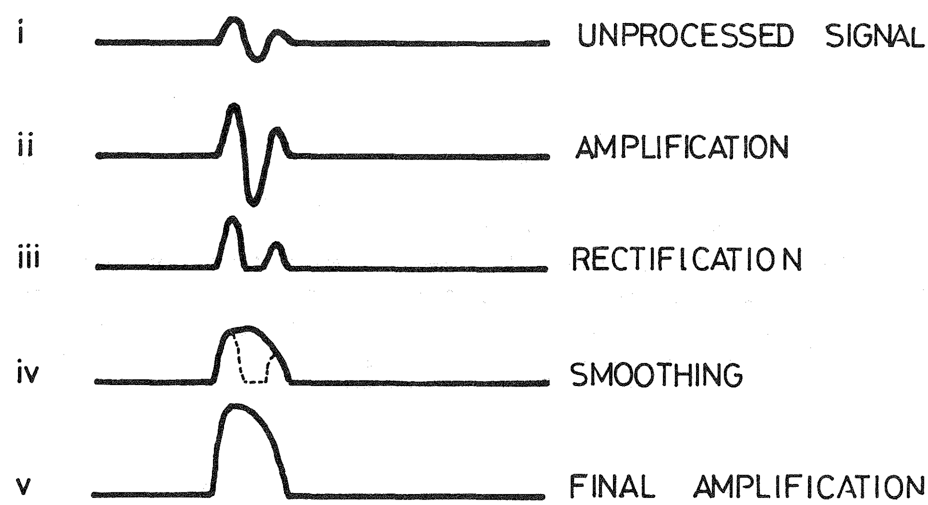


FIG (2) STEPS OF PROCESSING OF REFLECTED SIGNAL

The image formed on the display CRT is photographed using a Hewlett Packard oscilloscope polaroid camera model 197 A. The camera is positioned so that its horizontal axis is parallel with the horizontal axis of the CRT graticule. The 197 A camera has an f/1.9 lens with a focal length of 75 mm. The lens is especially corrected for use to give minimum distortion over the full image area with a flat field of focus.

MATHEMATICAL MODELING

Distortions existing in photographs produced by ultrasonic waves (ultrasonography) may be attributed due to two different groups, the camera group I and the ultrasonic equipment group II (Figure 3).

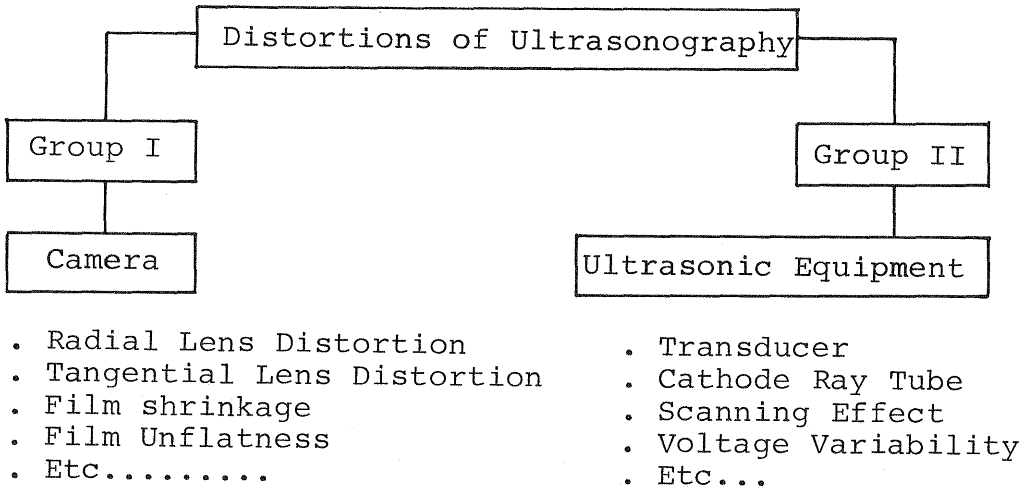


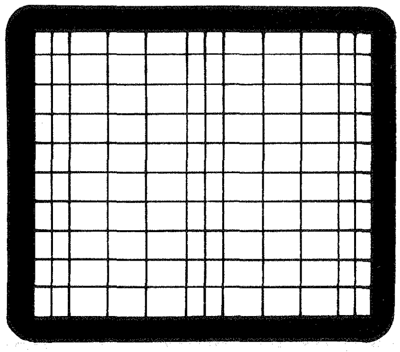
FIG (3) SOURCES OF IMAGE DISTORTIONS IN ULTRASONOGRAPHY

Accordingly, two different photos (photo I & photo II) were exposed to enable the mathematical modeling of each group seperately. The mathematical models describing the parameters of each group is based on an error's successive elimination process factor by factor, leading to two mathematical models with parameters as functions of the camera distortions (Group I) and the entire ultrasonic equipment (Groups I & II) respectively. Photo I is affected by distortions due to factors of group I only. This is realized by using a reseau of dimensions 9.5x7.5 cm consisting of a frame containing aluminum wires spaced at selected intervals in X & Y directions (Figure 4). It is positioned infront of the CRT into the bazel surrounding it, i.e. between the camera and the film from one side and the CRT on the other side. Accordingly photo I shows only the reseau and as such the ultrasonic effect is not included. The mathematical model describing the relationship between the reseau coordinates $(\bar{X},\bar{Y})$ and their corresponding comparator coordinates $(\bar{x},\bar{y})$ has been derived and is given in equations (1) and (2), (Wishahy 1984 & 1985) and (Abdelaziz and Karara 1974).

$$\bar{X} = \frac{a_1\bar{x} + b_1\bar{y} + c_1}{a_o\bar{x} + b_o\bar{y} + 1} + d_1\,\bar{x}\bar{y} + k\,(\bar{x}^3 + \bar{x}\bar{y}^2) + \alpha_1 \;........(1)$$

$$\bar{y} = \frac{a_2\bar{x} + b_2\bar{y} + c_2}{a_o\bar{x} + b_o\bar{y} + 1} + d_2\,\bar{x}\bar{y} + k\,(\bar{y}^3 + \bar{y}\bar{x}^2) + \alpha_2 \;\ldots\ldots\ldots (2)$$

FIG (4)
THE 9.5 x 7.5 cm STANDARD RESEAU USED TO PRODUCE PHOTO I



where:

a_i, b_i, c_i are parameters describing the projectivity relationship between planes of film and reseau.

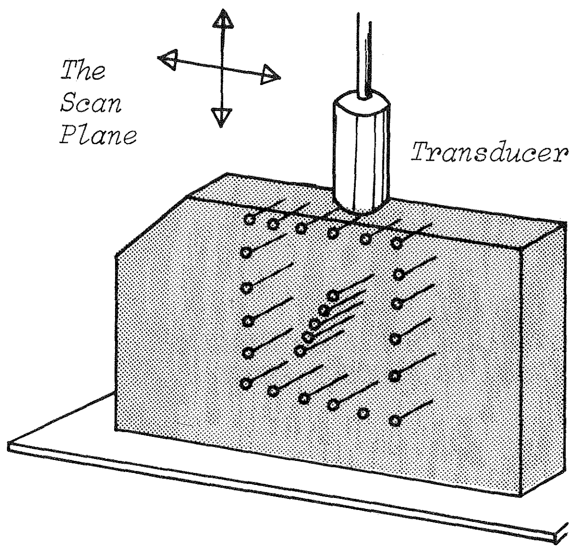
k is the coefficient of symmetrical lens distortion.

d_i are parameters accounting for the non-linearity of poloroid film deformations.

α_1, α_2 are terms of higher order to be determined and verified by statistical testing.

Unlike photo I; photo II is affected by distortions caused by the entire ultrasonic system including factors of groups I & II shown in figure (3). Photo II is taken for a standard 100 mm test object that is used for aligning, calibrating and measuring the performance of the ultrasonic pulse-echo appratus as a whole, including transducer, electronics, display and mechanical systems. It is consisting of a series of 0.75 mm diameter stainless steel rods arranged in a standard 100x100 mm square pattern with a 100x100 mm triangle across the top. It is full of special liquid giving the same ultrasonic wave's velocity as in the human body (1540 m/sec), (Figure 5). The rods may be considered as objects of known spatial coordinates whose position tolerances equal ± 0.25 mm.

FIG (5)
THE 100 mm TEST OBJECT USED TO PRODUCE PHOTO II



The measured photo II coordinates of the test model rods are substituted in equations (1) & (2) with known parameters as obtained based on photo I to obtain the refined photo II coordinates of the rods. These refined coordinates are thus free from distortions caused by the factors of group I. The mathematical models describing the relation between the test model object rods coordinates (X,Y) and their corresponding refined coordinates (x,y) have been derived and are given in equations (3) and (4), (Wishahy 1984 & 1985) and Wong (1968 & 1974).

$$X = A_o + A_1x + A_2y + A_3xy + A_4x^2 + A_5y^2 + A_6 (x^3 + xy^2) + A_7(x^2 + y^2)^2 \quad \ldots\ldots\ldots\ldots(3)$$

$$Y = B_o + B_1y + B_2x + B_3xy + B_4.y^2 + B_5x^2 + B_6 (y^3 + yx^2) + B_7(x^2 + y^2)^2 \quad \ldots\ldots\ldots\ldots(4)$$

where:

A_i, B_i are parameters describing distortions caused by group II.

RESULTS AND STATISTICAL TESTING

Under this heading the mathematical models developed earlier expressed by equations (1), (2), (3) and (4) are being checked and the significance of their parameters are tested. Since the number of observations exceeds the number of unknowns, least squares adjustment procedure is used to compute the unknown parameters. The mathematical models are linearized according to Taylor's series as follows:

$$0 = F = F^{o} + J \qquad \ldots\ldots\ldots\ldots(5)$$

Equation (5) in matrix notation takes the general form of L.S.A. as follows:

$$AV + B\Delta = f \qquad \ldots\ldots\ldots\ldots(6)$$

The solution of equation (6) proceeds as follows:

$$\underbrace{(B^T(APA^T)^{-1}B)}_{N}\ \Delta = \underbrace{B^T(APA^T)^{-1}}\ F$$

$$N\ \Delta = T$$

$$\Delta = N^{-1}T$$

or

$$AV = F - B\Delta$$

$$A^T PA\ V = A^T P\ (F - B\Delta)$$

$$V = (A^T PA)^{-1}\ A^T P(F - B\Delta)$$

where:

A is the matrix of partial derivatives of the original function w.r.t. observations.

B is the matrix of partial derivatives of the original function w.r.t. unknowns.

P is the weight matrix of observations.

Δ Alteration vector of unknowns.

V Vector of observational residuals.

F Functional model.

F^{o} Function F evaluated from approximate values of parameters.

In order to deduce the form of the two terms α_1 and α_2 of equations (1) & (2), three versions of the mathematical models are tested and each time the validity of the procedure is checked using a Chi-Square (χ^2) test. In this test a computed χ^2 (equation 7) is compared against the statistic tabulated χ^2 at a certain significance level for a certain degree of freedom.

$$\chi^2 = \frac{(D.F)\ \hat{\sigma}_o^2}{\sigma_o^2} \qquad \ldots\ldots\ldots\ldots(7)$$

where D.F is the degree of freedom.

σ_o^2 A priori variance of unit weight.

$\hat{\sigma}_o^2$ A posteriori variance of unit weight.

In order to accept the mathematical model, the calculated χ^2 should not exceed the tabulated value. A summary of the results is given in table (1).

Table (1) Results of Statistical testing for mathematical models, equations (1) & (2).

Mathematical model version based on equations (1) & (2)	DF	$\chi^2_{DF,0.05}$	$\chi^2 = \frac{DF\ \hat{\sigma}_o^2}{\sigma_o^2}$
#(1) $\alpha_1=0$ & $\alpha_2=0$	21	32.653	129.985
#(2) $\alpha_1=e_1x^2$ & $\alpha_2=e_2y^2$	19	30.14	86.324
#(3) $\alpha_1=e_1x^4$ & $\alpha_2=e_2y^4$	19	30.14	28.596

Therefore, we accept version #(3) of the mathematical model based on equations (1) & (2) with $\alpha_1 = e_1x^4$ & $\alpha_2 = e_2y^4$. Equations (3) and (4) in a polynomial form describing the distortions due to the ultrasonic system are solved and statistically tested using Fisher F-Test, to check the significance of the polynomial terms. It is known in advance that adding more terms to a polynomial will improve the agreement with the observations as long as these terms are linearly independent. However, the improved accuracy should be justified against the increased computational requirements. Accordingly at a certain significance level (α), we can test the null hypothesis

H_0: Effect of added term = 0,

by computing the variance ratio (F), equation (8) and comparing it with the F distribution value, $F_{1,DF,\alpha}$. If the variance ratio is insignificant, we may conclude that the effect of this parameter is also insignificant, (Hamilton 1964).

$$\text{Variance Ratio (F)} = DF. \frac{(V^TPV)_B - (V^TPV)_A}{(V^TPV)_A} \qquad \text{...........(8)}$$

where:

$(V^TPV)_B$ is the sum of squared residuals before adding the parameter.

$(V^TPV)_A$ is the sum of squared residuals after adding the parameter.

Results of this test showed that in the X-polynomial the terms (A_2y, A_3xy, A_4x^2, A_5y^2, A_6x^3, A_7y^4) are insignificant. In the Y-polynomial the terms (B_3xy, B_4y^2, B_5x^2, B_6y^3, B_7x^4) are insignificant. Accordingly equations (3) & (4) could be reduced to equations (9) & (10) without statistically changing the results at a significance level $\alpha = 0.05$.

$$X = A_o + A_1x + A_6xy^2 + A_7x^4 \qquad \text{............(9)}$$

$$Y = B_o + B_1y + B_2x + B_6yx^2 + B_7y^4 \qquad \text{............(10)}$$

Results of fitting the image coordinates (x,y) to the 25 object coordinates (X,Y) of the 100 mm test object of photo II using equations (9) and (10) gave residuals in X and Y that are normally distributed (Figure 6).

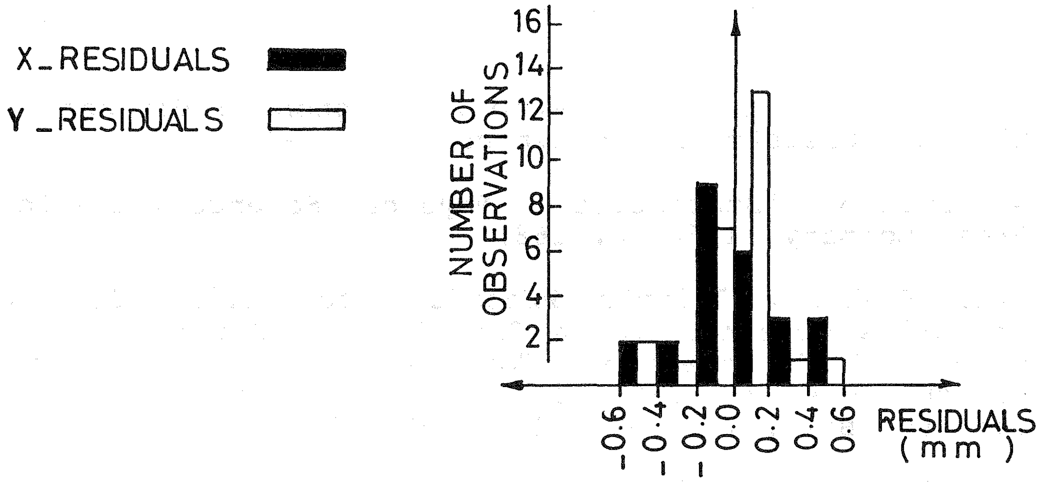


FIG (6) HISTOGRAMS OF (X & Y) RESIDUALS AT THE (25) TEST OBJECT POINTS

The root mean square errors in both directions were;RMSE(X) = 0.2757 mm and RMSE (Y) = 0.2480 mm.

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REFERENCES

[1] American Society of Photogrammetry and Remote Sensing, **"Manual of Photogrammetry"** 3rd edition, 1966.

[2] I.Y. Abdelaziz & H.M. Karara, **"Photogrammetric Potentials of Non-metric Cameras"**, Publications of the University of Illinois, Vol. 36, 1974.

[3] J. Hobbins and F. Winsberg, **"Ultrasonography in Obstetrics and Gynecdogy"**, 1977.

[4] K.W. Wong, **"Geometric Calibration of Television Systems For Photogrammetric Applications"**, Publications of the University of Illinois, Vol. 16, 1968.

[5] K.W. Wong, **"Geometric Analysis of the RBV Television System"**, Publications of the University of Illinois, Vol. 42, 1974.

[6] R. Bernstine and H. Thompson, **"Diagnostic Ultrasound in Clinical Obstetrics and Gynecology"**, 1978.

[7] W. Hamilton, **"Statistics in Physical Science"**, The Roland Press Company, 1964, p. 168.

[8] Z.A. Wishahy, **"Simple Procedure to Refine Ultrasonic Imageries Obtained by an Oscilloscope Camera"**, Archives of the XV International Congress of Photogrammetry and Remote Sensing, Vol. XXV, A5, Commission V, Rio De Janeiro, Brazil, June 1984, pp.771-778.

[9] Z.A. Wishahy, **"Refinements of Photographs Obtained From Ultrasonic Instruments By an Oscilloscope Camera"**, Unpublished Ph.D Dissertation, Department of Civil Engineering, Cairo University, 1985, p. 160.