CORROSION MEASUREMENT ON UNDERWATER STRUCTURES

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ABSTRACT

Accurate measurement of corrosion is required for underwater structures, to determine the structural safety and plan for repair and maintenance. This type of measurement is regularly carried out using photogrammetric techniques using stereopairs of 70 mm cameras mounted in special underwater cases. This paper discusses tests carried out on a 35 mm stereo camera to evaluate its performance when operated by a remote controlled submarine.

Lens characteristics were determined by photographing a target array as well as the "Plumb Line" system, and problems such as lighting and interior orientation are discussed.

1.0   INTRODUCTION

The "PHOTOSEA NDT4000 Combination Television Close-Up Stereo Inspection Camera" comprises a solid state television camera, and a stereo 35 mm camera and flash unit within a waterproof housing which is designed to be mounted on a submarine manipulator.

According to the manufacturers specifications, the camera has two lens systems each of 28 mm focal length mounted 62 millimeters apart on a single body, and it is fitted with a reseau grid. Both photographs of a stereopair appear on the same piece of film. The camera focus has been fixed at 255 mm, and the housing portholes are designed to correct for distortions arising from the air/water interface.

Stereopairs were taken of a target array as well as plumb lines to determine lens distortion.
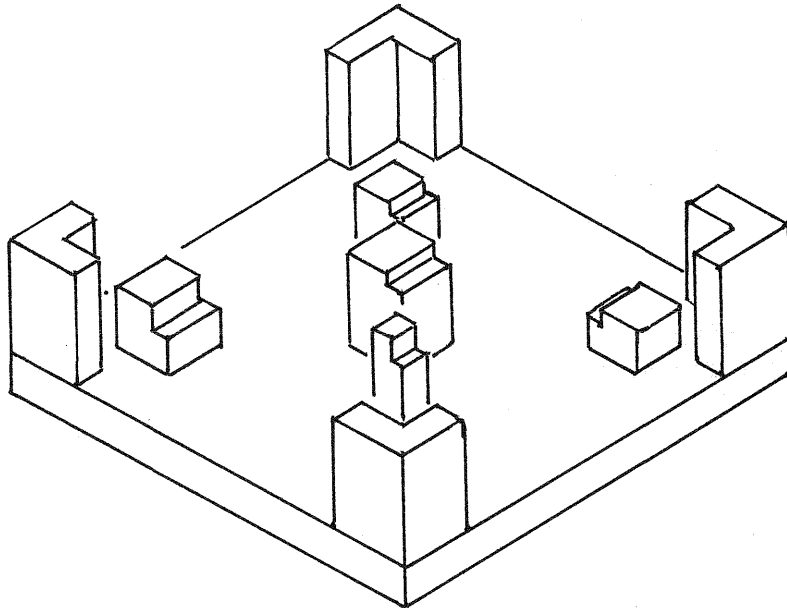
FIGURE 1: Target Array

2.0 EXAMINATION OF THE IMAGE AREA

A stereopair was mounted in a mono-comparator with a one micron resolution, the photos were aligned so that the frame edges were nearly parallel to the comparator axis system, and measurements made to determine the spacing between the two cameras.

These indicate that the reseau grid is at 10 mm spacing, and that the the two camera systems are 63.000 mm apart at the backplane. This is exactly one millimetre greater than specied by the manufacturer.

3.0 FOCAL LENGTH AND DISTANCE UNDERWATER

The refractive index of water is very close to 1.34, and does not vary greatly with salinity, or depth. For underwater work, the nominal focal length has to be corrected for this refractive effect.

In addition, the focal length has to be adjusted for the focussed distance, since the nominal focal length is for objects at infinity. The standard lens formula $1/f = 1/s + 1/S$ is used for this calculation, where f is the focal length at infinity, s is the object distance, and S is the focal length for the object distance s.

Object Distance	S (Air)	S (Underwater)
254 mm	31.469	42.168

Three measurements were then taken at each of 8 points to determine the standard deviation of pointing for these photographs and this was found to be 8 microns.

A plumb line calibration was then performed on the MPS with the following results:

Job: SOMSUB.DAT   (15-FEB-88   09:55)
Number of horizontal lines = 13;   Vertical lines = 12

LENS DISTORTION   (for 07 record)
Radial Distortion   R   Term :   .3663E-03
                                     R3 Term :   .3824E-04
                                     R5 Term :   -.1503E-06
                                     R7 Term :   -.9411E-15

Assymetric Distortion   X   Term :   -.4723E-04
                                     Y   Term :   -.1266E-03

NOTES: Lens distortion has been balanced at a point 20 mm
         Original Focal Length: 42.168; Adjusted Value: 42.154

BALANCED DISTORTION DATA

X	Y	R	Radial Distort.	One Sigma	Decentering Distort.	One Sigma
3.5	3.5	5.0	-.006	.001	.003	.000
7.1	7.1	10.0	-.027	.004	.014	.000
10.6	10.6	15.0	-.020	.009	.030	.000
14.1	14.1	20.0	.168	.015	.054	.001

There was great difficulty in measuring the lens distortion because the
images of the edges of the lines were not sharp, due to the effect of the
lighting on the wires which were circular in section.   This was more
noticeable both at the ends of the wires and in the middle section.

The distortion curve changes rapidly when the radial distance passes 15
mm, and therefore it is critical to get accurate data at the edge points
of the photograph.

Four more sets of observations were then taken in order to try and
correctly determine the actual lens distortion, and in some sets
observations along the straight edges of the test block were included to
try and improve the precision of the results.   The curves for these sets
were plotted, and even though they show a similar trend, they are
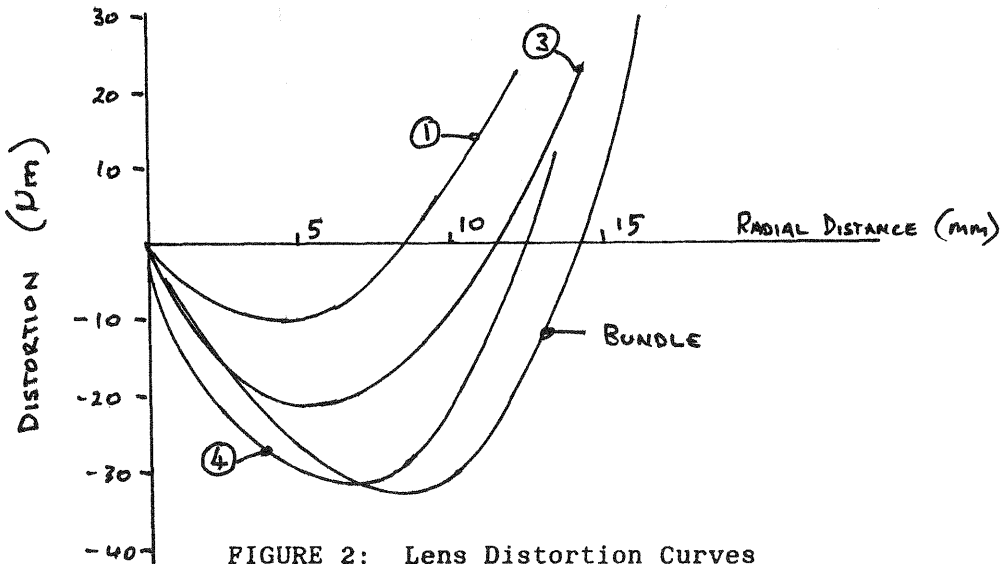obviously not consistent enough to be reliable.

FIGURE 2:   Lens Distortion Curves

4.0   ABSOLUTE ORIENTATION

Using the most likely set of lens distortion values from the plumb line observations, an absolute orientation was carried out on one of the stereopairs, with the following results:

ORIENTATION RESULTS

Left Camera				Right Camera		
OMEGA:	0 29 22			OMEGA:	0 06 56	
PHI :	359 42 17			PHI :	359 50 27	
KAPPA:	223 24 19			KAPPA:	223 20 09	
Xo :	100.32			Xo :	55.58	
Yo :	95.16			Yo :	52.91	
Zo :	285.55			Zo :	285.84	

RESIDUALS AT THE PLATES

NAME	XL	DX	YL	DY	XR	DX	YR	DY
63	-1.804	-7	-2.301	-13	-12.194	-10	-2.436	-30
68	-0.067	26	-0.460	-10	-9.729	8	-0.594	11
64	-3.600	-34	-0.601	19	-13.989	-57	-0.740	1
57	6.019	14	-2.792	-23	-4.808	19	-2.913	-27
59	5.407	31	-2.475	6	-4.270	7	-2.598	-3
46	12.288	18	-0.198	8	1.203	-18	-0.319	23
48	10.755	-15	-0.159	4	1.069	-4	-0.281	3
70	7.507	7	9.862	-6	-2.553	17	9.700	0
73	5.138	-16	7.275	1	-4.552	3	7.123	-1
74	2.910	-5	9.378	-11	-6.773	25	9.219	-14
52	3.688	-19	-10.906	24	-6.707	13	-11.019	37

RESIDUALS ON CONTROL POINTS

Name	XG(mm)	V(mm)	YG(mm)	V(mm)	ZG(mm)	V(mm)
63	100.00	-0.06	115.00	0.12	30.00	0.08
68	100.00	-0.12	100.00	-0.13	10.00	0.52
64	115.00	0.16	115.00	0.05	30.00	0.59
57	65.00	-0.18	85.00	0.04	40.00	-0.12
59	65.00	-0.06	85.00	-0.12	10.00	0.69
46	50.00	0.16	50.00	0.02	30.00	0.82
48	50.00	0.03	50.00	0.00	45.00	-0.34
70	110.00	-0.36	20.00	-0.10	10.00	-0.28
73	110.00	0.10	40.00	-0.04	20.00	-0.59
74	130.00	0.06	40.00	-0.10	10.00	-0.90
52	40.00	0.02	130.00	0.05	30.00	-0.82

The accuracy of the results was clearly unsatisfactory due mainly to the lack of correct lens distortion information.

5.0 BUNDLE ADJUSTMENT

To overcome the uncertainty in determining the lens distortion, and to find out the actual focal length used for this job as well as the actual camera base, a bundle adjustment was carried out using five models each observed from a different direction as indicated below. The adjustment was a "free" adjustment in that the control, focal length, and lens distortion parameters were free to move.

The results are as follows:

FINAL ADJUSTED OBJECT SPACE CO-ORDINATES AND RESIDUALS IN MILLIMETRES

NO	X	Y	Z	VX	VY	VZ	NO	X	Y	Z	VX	VY	VZ
7	-0.4	24.8	9.1	-.2	-.2	.4	7	-0.4	24.8	9.1	-.2	-.2	.4
7	-0.4	24.8	9.1	-.2	-.2	.4	8	9.2	25.0	9.8	-.8	.0	-.2
9	9.4	9.5	9.7	-.6	-.4	-.3	10	24.6	9.5	10.0	-.4	-.5	-.0
11	24.6	1.2	11.7	-.2	-.5	-.0	17	1.6	124.8	50.1	-.3	.0	.7
23	149.2	149.2	48.5	.6	-.2	.8	24	149.6	125.6	49.1	.1	-.0	.6
25	140.5	125.4	50.3	.5	.4	.3	26	140.6	139.5	50.1	.1	-.0	.6
27	125.1	139.6	50.2	.1	-.4	.2	28	125.2	149.3	50.3	.1	.0	.3
30	140.3	125.4	9.9	-.2	.0	.1	32	125.1	140.4	10.0	-.2	-.0	.2
33	125.1	150.0	9.3	-.1	.1	.0	40	125.4	0.4	10.4	.0	.0	.2
41	125.4	9.5	10.1	.4	-.5	.1	42	140.4	9.6	9.9	.0	.0	.4
43	140.5	25.1	9.8	.4	.1	-.2	44	150.1	25.0	9.7	.1	-.1	.3
45	40.3	50.1	44.9	.3	.1	-.1	46	50.1	50.2	45.0	.1	.2	-.0
47	40.1	50.0	10.4	.1	-.0	-.1	48	50.0	49.9	9.9	.0	-.1	-.1
49	50.4	40.0	10.8	-.2	.1	-.4	50	40.6	39.9	9.6	-.2	.1	.5
51	20.3	129.8	30.2	.3	-.2	.2	52	40.1	129.8	30.1	.1	-.2	.1
54	39.8	129.9	9.8	-.2	-.1	-.2	55	39.9	110.2	9.4	.1	-.1	-.1
56	19.7	110.1	11.3	.3	-.0	-.2	57	65.2	85.1	39.8	.2	.1	-.2
58	84.9	85.1	39.7	-.1	.1	-.3	59	65.0	85.1	10.1	.1	-.1	-.0
61	86.0	65.6	11.8	-.3	.2	-.7	62	64.5	65.4	11.1	.4	.0	-.4
63	99.8	114.9	29.7	-.2	-.1	-.3	64	114.4	114.9	29.7	-.1	.1	.1
65	100.0	115.0	10.0	-.2	-.0	-.0	66	114.6	115.0	10.1	-.4	-.0	.1
67	115.4	100.4	11.6	-.5	.0	-.7	68	99.8	100.2	10.0	.1	-.1	-.3
69	130.1	20.0	19.5	.0	.1	.3	70	110.2	20.2	19.7	-.1	.1	.1
72	110.7	19.7	9.1	-.0	.0	.3	73	109.9	40.2	10.0	-.1	.1	.0
74	129.9	40.2	10.1	-.1	.2	.0	00	50.2	43.3	45.0	.1	-.0	-.2
01	40.3	43.3	45.2	.1	-.1	-.0	02	40.3	40.2	43.1	.0	-.1	-.0
04	109.9	40.2	18.7	-.1	.2	-.0	05	110.0	37.2	18.5	-.1	.2	.0
06	109.9	37.2	20.1	-.1	.2	.0	08	129.9	37.3	18.7	-.0	.1	.1
09	129.8	40.2	18.7	-.0	.2	.1	10	85.0	68.2	39.7	-.3	.4	.7
11	114.6	100.1	23.8	-.1	.1	-.0	12	99.8	103.1	29.8	-.0	-.0	-.2
14	85.0	65.3	35.8	.0	.1	-.3	15	65.2	65.3	35.8	.1	.1	-.3
16	65.2	68.3	39.8	.2	.1	-.3	17	40.0	113.0	29.9	.2	-.1	-.1
19	40.0	110.1	22.0	.2	-.1	.0	20	20.2	110.1	22.2	.2	.0	-.0
23	39.9	112.9	21.7	.2	.0	-.2	24	114.4	103.1	29.8	-.1	.0	-.1
25	115.3	103.3	25.3	-.3	.0	-.6	27	85.6	68.5	36.7	-.0	.2	-.4
28	65.0	68.3	36.2	.2	.0	-.3	29	49.6	42.9	42.4	.3	.1	.3

RMS RESIDUALS FROM GIVEN VALUES: MX = 0.25;   MY = 0.17;   MZ = 0.36

Focal Length Correction		0.237E+00	0.395E-01	5.99
Lens Distortion	R**3 Term	0.493E-04	0.126E-04	3.91
	R**5 Term	0.305E-07	0.746E-07	0.41**
	R**7 Term	0.256E-10	0.132E-09	0.19**
	P1 Term	0.631E-05	0.109E-04	0.58**
	P2 Term	0.152E-04	0.108E-04	1.41**

* - RATIO IS LESS THAN FISHER STATISTIC VALUE OF 1.96

MEAN VARIANCE OF 210. XYZ CO-ORDS = 0.024

MEAN STD. ERROR = 0.16

MEAN STD ERRORS OF THE 70 X, Y, Z CO-ORDS: 0.13; 0.12; 0.20

Note that points such as 7 (which has a bubble on it), and 23 (which is out of focus) have large errors, while the majority lie inside the error range of about 1/3rd of a millimetre.

Only the R cubed term for lens distortion is significant, and the mean standard error in position is .204 millimetres

6.0   SUMMARY

The test observations indicate that an accuracy of about a quarter of a millimetre can be obtained from this camera arrangement and the MPS-2 analytical stereoplotter when the lens distortion has been accurately determined.   The plumb line system is usually the preferred method for determining lens distortion, and would have been successful if fine ruled lines on a flat sheet had been used instead of the wires photographed for this exercise.   The bundle adjustment is normally only used to provide an independent check on the plumb line results.

If some of the more doubtful points were reobserved, and the adjustment recomputed, it is likely that the results may be improved significantly, however the figures given are a good indicator as to the accuracy which can be achieved using this camera and the MPS in production work.