THE CURRENT STATUS OF UNDERWATER PHOTOGRAMMETRY

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ABSTRACT

In recent years photogrammetry has been applied to an increasing extent for underwater measurement purposes. This paper examines recent developments and brings the reader up to date with current equipment, techniques and applications. Possible future developments are outlined.

APPLICATIONS

Since the early 1970's there has been a growing interest in applying photogrammetric measurement techniques to objects in the underwater environment. Initial work concentrated on underwater mapping of the sea bed, location and mapping of shipwrecks and measurement of marine biological specimens (Pollio, 1971; Rosencratz, 1971; Torlegard and Lundalv, 1974).

In more recent years, the growth of the offshore oil and gas industry has created new applications. In September 1983, there were about 130 production platforms operating in the North Sea alone with over 5000 km of pipeline linking them together and with the land. These installations must undergo a regular inspection and maintenance programme to ensure that they meet safety requirements. Several systems have evolved to meet this demand for underwater inspection based on the use of divers, underwater video, still photography, NDT equipment and direct visual inspection. The results produced are largely of a qualitative nature.

In 1977, an underwater damage assessment survey was carried out by photogrammetry during the repair of the North Sea Heather platform. This work was discussed at the ISPRS Hamburg congress (Welsh et al, 1980) and demonstrated that photogrammetric techniques could produce accurate measurements of the size and shape of a damaged area of a platform leg. A great deal of interest was aroused by this work in both the offshore oil industry and photogrammetric circles. This in turn has led to photogrammetry gaining acceptance as a means of producing reliable dimensional information in the underwater environment and to underwater photogrammetry now being offered as a commercial service by several companies.

Underwater photogrammetry is an area of application of close range photogrammetry which has developed rapidly over the last four years. At the ISPRS Commission V symposium held in 1982, four papers were given on this subject (Adams, 1982; Baldwin and Newton, 1982; Fryer, 1982; Turner and Leatherdale, 1982) and further papers will be presented in Rio. This paper reviews progress during this period and examines the current status of underwater photogrammetry. Possible future developments are also given. The paper is based partly on replies to a questionnaire sent to known workers in this field and partly on the personal opinions of the author. Unfortunately none of those who supplied information have had the opportunity to see the paper before printing. Any errors or misinterpretations of the replies are, therefore, solely the responsibility of the author.

UNDERWATER INSPECTION

Any underwater inspection task requires the use of an underwater work system to take the necessary equipment to the site and to operate it there. Several work systems are available and the choice of system is dependent upon the cost factor, the nature of the task and the depth of water in which it is to be performed. The systems normally operate from a support ship.

Traditionally divers have been used for underwater inspection and maintenance tasks. Whilst there are advantages in using a diver for some tasks, the range of tasks that can be carried out is restricted owing to the limited amount of equipment that can be carried, decompression restrictions and the divers umbilical. Air diving is possible at depths down to 50 m. The breathing gas is air and is normally supplied through an umbilical from the surface but a free swimming scuba diver may be used in shallow water. The scuba diver is, however, limited to short periods at the work site by the amount of air that can be carried. For deeper and longer dives, saturation diving is employed. The breathing gas is a mixture of helium and oxygen and the divers are pressurised to the desired working depth in a living chamber for up to four weeks. At the end of that time decompression may take up to one week. The divers are transferred to and from the work site by a diving bell and an individual diver may work for up to six hours at the site. Divers may also use one atmosphere diving suits . These allow a diver to be taken to and from the work site without any decompression and inspection and maintenance tasks can be carried out on site using the manipulator arms of the diving suit. Whilst air diving remains the most cost effective method in shallow water saturation diving is very expensive and is in direct competition with other work systems. Diving using atmospheric suits is less expensive but the range of tasks that can be performed is limited.

The alternative systems replace the diver with some form of underwater vehicle equipped with manipulator arms, sensors and positioning systems. Such vehicles are able to take over some of the tasks of the diver and reduce the risk to human life. They are particularly suited for use in the deep and hostile environment of the North Sea. Foremost among the underwater vehicles is the manned submersible . This is a one atmosphere, free swimming, mini-submarine capable of carrying a crew of two or three people. Today manned submersibles are able to dive for up to ten hours, can be positioned to an accuracy of ±3 m and have sophisticated equipment for performing a range of tasks. Consequently, whilst expensive to operate, they are competitive and are extensively used for offshore platform inspection and pipeline surveys. Some manned submersibles are equipped with diver lock-out facilities which allow a diver to be taken directly to the work site and be supplied with lighting and equipment whilst there. Problems with manned submersibles are the surface launch and retrieval routine which cannot be operated in rough seas and the poor manoeuvrability in confined spaces. In recent years, there has been an increasing emphasis on the development of unmanned remotely conrolled vehicles (ROV's). These vehicles are controlled from the surface through an umbilical but may be free swimming in the future. There are two kind of ROV's. Firstly the smaller eyeball type vehicles, equipped with video camera, still camera and thrusters, which are primarily used for visual inspection. Secondly, larger and more powerful vehicles equipped with manipulators and sensors like a manned submersible. ROV's are highly manoeuverable, able to enter restricted spaces and can operate for long periods without risk to human life.

All the aforementioned work systems have been employed to obtain underwater photography for photogrammetric purposes. Scuba diving has been used on the Great Barrier reef in Australia by Fryer (1982) and in South Africa by Welham (1982). In the North Sea, Leatherdale and Turner (1982) report the use of saturation diving and Baldwin and Newton (1982) the use of manned submersibles. Bakhuizen (1983) has used an ROV.

UNDERWATER CAMERAS

Table 1 lists the characteristics of several commercialy available underwater cameras using the 35 mm and 70 mm format. All the cameras are housed in a water tight and pressure resistant housing. Most are fitted with wide angle lenses to cover a good field of view and accommodate long lengths of film so that many photographs can be taken before the camera has to be removed from the water for reloading. Many also feature internal rechargeable power units, automatic film advance and internal data chamber.

The 35 mm cameras are generally light, small in size and simple to operate. Many of them are fitted with one of the range of Nikkor water corrected lenses and employ a focal plane shutter. These cameras are best suited for use in shallow water with a free swimming diver to transport the camera and in situations where cost is critical. Frequently the controls are external so that the diver can change the camera settings.

For work carried out in connection with the offshore oil industry and in deeper waters, the cost of the cameras is small compared to that of the work system. Consequently the best possible cameras are employed in an attempt to obtain good quality photographs first time. 70 mm cameras with their increased film area and better image quality are preferred unless size and weight are critical. A number of these cameras are derived from the standard Hasselblad cameras and are fitted with a Zeiss lens, between lens shutter and domed front port. A glass reseau plate is often fitted to monitor film flatness and deformation.

Photosea Systems Inc. is the only company to currently manufacture underwater stereocameras. In the Photosea 2000 the two lenses are mounted in a single housing at a separation of 63.5 mm. A single length of 35 mm film is used which allows up to 100 stereopairs to be taken. The camera is compact and appears ideal for use with small ROV's.

All underwater cameras are basically non-metric and it is necessary to calibrate them if they are to be used for photogrammetric purposes. The usual method of calibration is to photograph a three dimensional test object of known dimensions from the stand-off distance at which the camera will be used. This is performed either onshore in a shallow water tank or on-the-job offshore at the underwater work site. On-the-job calibration is favoured by most workers (eg Adams, Baldwin, Boyd, Fryer and Gres) and has the advantage of including local variables so that the differences from one site to another can be allowed for during the photogrammetric analysis. On-the-job calibration presents some difficulties in deep waters due to the need to deploy and photograph at the work site a test object which may sustain damage. If damage is suspected the test object must be redimensioned from new metric photography taken on board the support ship or onshore. In shallow water Fryer and Welham have used a diver held system which includes a frame attached to the cameras and always in the field of

MANUFACTURER	MODEL	LENS	FORMAT (mm x mm) FIELD OF VIEW	FILM SIZE MAXM. FRAMES PER LOAD	FRONT PORT	SPECIAL FEATURES		MIN. RANGE (m)	MAXM. OPERATING DEPTH (m)	WEIGHT IN WATER (kg)
						RESEAU	DATA CHAMBER			
BENTHOS	Several	Nikkor water corrected 28 mm f 3.5	24 x 36 $35^0 \times 50^0$	35 mm 1600	Plane	No	Yes	0.6	11000	18 – 48
COMEX	Cercomex	38 mm f 5.6	60 x 90 $50^0 \times 75^0$	70 mm 25	Domed	Yes	Yes	0.6	200	?
HASSELBLAD	–	Zeiss 50 mm f4 Distagon 60 mm f3.5 Distagon 80 mm f2.8 Planar	60 x 60 75^0 diagonal 66^0 diagonal 52^0 diagonal	70 mm 200 200 200	Domed acrylic	No	No	0.4 0.5 0.6	200	0.6
LYNX	70	Schneider 47mm Super Angulon	60 x 60 ?	70 mm 200	Ivanoff corrector	Yes	No	?	600	?
NEPTUNE	35C	Olympus 28 mm	24 x 36 ?	35 mm 50	Ivanoff corrector	Yes	No	0.3	600	?
	UPS 81	Zeiss 60 mm f3.5 Distagon	60 x 60 ?	70 mm 200	?	Yes	No	0.9	600	?
NIKON	Nikonus III	Nikkor water corrected 15 mm f 2.8 28 mm f3.5 35 mm f2.8 80 mm f4	24 x 36 94^0 diagonal 59^0 diagonal 46^0 diagonal 22^0 diagonal	35 mm 36 36 36 36	None	No	No	0.3 0.6 0.8 1.0	60	<1
PHOTOSEA	1000	Nikkor water corrected 28 mm f3.5	24 x 36 $35^0 \times 50^0$	35 mm 250	Plane	No	Yes	0.6	600	1.1
	2000	28 mm f3.5 (two)	$35^0 \times 50^0$	250 single 200 stereo		Yes	Yes	0.6	6000	0.9
	NDT 3000	?	?	120 stereo		Yes	Yes	0.15 (fixed)	?	1.5
	70	70 mm f3.9	60 x 60 $40^0 \times 40^0$	70 mm 450	Plane	Optional	Yes	0.6	6000	1.8
UMEL	DHC 70	Zeiss 38mm f4.5 Biogon	60 x 60 $72^0 \times 72^0$	70 mm 200	Domed acrylic	Optional	Optional	0.35	600	1.4
	Several	Nikkor 35 mm f2.8 Pentax 35m f3.5 Zeiss 35 mm f2.4	24 x 36 46^0 diagonal	35 mm 500	Domed acrylic	No	Optional	0.3	8000	5

TABLE 1 MAIN CHARACTERISTICS OF SOME UNDERWATER CAMERAS

view, for calibration purposes. On-shore calibration is easier to organise and is carried out at less frequent intervals. It does, however, assume that the camera is stable and that conditions in the shallow water tank are similar to those offshore.

UNDERWATER PHOTOGRAPHY

The photographic phase should result in a set of photographs taken such that each object point to be measured appears on at least two photographs. Both 'single and twin camera set ups' are employed. Twin cameras are normally rigidly mounted together on a base bar at a separation which results in a B/D ratio of about 1/5. Convergence angles of up to 20° are often used to increase the area of stereoscopic overlap. Alternatively an underwater stereocamera may be employed or a beam splitter on a single camera to produce half frame stereopairs on 35 mm film.

Colour is generally preferred to monochrome as the photographic emulsion on account of its superior interpretative qualities. Colour reversal film is more popular than colour negative and a selection of suitable films with moderate to high speeds is commercially available.

For most applications artificial lighting is needed. A variety of electronic flash units is available with power ratings varying from 65 to 300 ws^{-1}. These operate with either internal rechargeable batteries or a 24 v power supply. Stand off distances are limited and at depths greater than 50 m in the North Sea, a maximum stand off distance of 5 m is the usual limit at which lighting can be provided due to light absorption and scattering.

There appears to be little difficulty in taking photographs of adequate quality underwater but there are frequently problems in getting them to cover the correct portions of the object and provide satisfactory stereo-cover . This is a particular problem when using divers. Ideally the diver should be a photographer with an understanding of the necessary requirements of photography for photogrammetric purposes. This is rarely the case and, to assist in getting photographs which cover the required area, some workers have attached frames and probes to their cameras to indicate the overlap area and necessary stand-off distance. When using manned submersibles and ROV's, a video camera may be mounted alongside the still cameras to serve as a viewfinder. The view is presented on a monitor screen and can, if desired, be examined by a person with a knowledge of the photogrammetric requirements before the picture is taken. In any underwater photogrammetric operation many more photographs are taken than are analysed in an attempt to obtain suitable coverage.

The provision of control for scaling and orientation of the spatial model is more difficult and time consuming in the underwater environment than in air. Several workers (eg Welham, Leatherdale and Turner, Fryer) use control positioned in every photograph. This control may take the form of a frame, in some cases physically attached to the cameras, or scale bars positioned by diver or manipulator arm in the field of view. The systems developed by Baldwin and Newton and Boyd use completely uncontrolled photographs.

In the underwater environment, data acquisition by photography is quicker than by visual inspection and direct measurement. This results in savings in time and cost. Further the photographs record large amounts of data in a permanent form and consequently measurements can be checked, additional ones made and sets of photographs compared at any time.

PHOTOGRAMMETRIC ANALYSIS

Any method of photogrammetric analysis should produce results of an acceptable and consistent level of accuracy and retain simplicity of operation and versatility in application. The selection of any particular method is controlled by environmental and operational considerations.

The underwater environment is one of uncertain and variable properties which are radically different from those of the terrestrial environment. Refractive index changes in water resulting from variations in density, salinity, pressure and temperature cannot be controlled. As a result, a camera calibration carried out in a shallow water tank onshore may not apply at depth in the underwater environment. In addition there may well be significant changes in camera behaviour from one underwater site to another. Ideally, therefore, the method of analysis should include on-the-job camera calibration. Further it is difficult to provide photo control underwater and the dependence of any method of analysis on control should be considered. For close-up diver inspection work, a frame attached to the cameras can be used for calibration and scaling purposes. It is also relatively easy for the diver to attach scale bars to the object prior to photography. When using an underwater vehicle, however, it is preferable to take photographs as the vehicle passes the object. Scale bars can only be attached to the object after stopping the vehicle which adds considerably to the dive time.

Operational considerations largely result from the desired location of the photogrammetric analysis facility. If possible, analysis is best done onshore in a suitably equipped photogrammetric laboratory. In such case there are few constraints on equipment and the in-house computer can process the measurements. Staff with the necessary expertise must, however, be available. In some cases, particularly if results are needed quickly, the analysis will have to be done offshore on a support ship or production platform. The available equipment is then restricted to that which is relatively portable and capable of operation in this environment. Staff to undertake the analysis will also have to be positioned offshore.

Table 2 lists some methods of analysis which have been used with underwater photographs. Analogue methods which normally involve the use of a plotting machine, are associated with metric photography. Consequently they are generally unsuitable for underwater photographs and there are few instances where they have been employed. Welsh et al (1980) report that Fairey Surveys Ltd used an analogue method in their work on the Heather platform repair. Relative orientation was performed on a Wild A8 and the measurements made on each model were corrected for the effects of refraction and lens distortion prior to final scaling.

Analytical methods of analysis are free from many of the limitations of analogue methods. They are more flexible, can handle non-metric photography and allow the identification and compensation of systematic errors in the photography. As a result, analytical methods are widely used with underwater photographs. Photo measurement is performed with either a stereocomparator or an analytical plotter. Applications to date have tended to use instruments developed for aerial photogrammetry and already in-house at the measuring centre (eg Zeiss Stecometer, Matra Traster). However, con-

	METHOD	CALIBRATION	SCALE CONTROL	CAMERA	MEASURING INSTRUMENT	STAND OFF DISTANCE (m)	DEPTH (m)	ACCURACY (mm)	SOURCE
ANALOGUE	Analogue Relative Orientation & Scaling	On shore, Test tank	Known distances in most photos	Benthos	Wild A8	1.0	100	7	Welsh *et al*, 1980
ANALYTICAL	Analytical Relative Orientation & Scaling	On shore, Test tank	Known distances in each photo	UMEL DHC 70	Zeiss Stecometer	1.6	?	Few	Leatherdale & Turner, 1983
					HTI Minicomparator	1.5	?	5	Bakhuizen, 1983
			Known distances in some photos	Benthos 35 mm	Zeiss Stecometer	1.0	100	3–5	Welsh *et al*, 1980
				UMEL DHC 70	Zeiss Stecometer	1.6	?	Few	Leatherdale & Turner, 1983
			Known camera separation	UMEL DHC 70	Zeiss Stecometer	1.6	?	Few	Leatherdale & Turner, 1983
				Cercomex	HTI Minicomparator	1.5	?	5	Bakhuizen, 1983
					Matra Traster	1.0	<200	0.2	Puybouffant
		On the job	Known distances in each photo	Nikonus III with beam splitter	Qasco SD4	1.0	3	5	Fryer, 1982
				UMEL DHC 70	Matra Traster	0.65–1.65	100	5	Gres, 1980
			Known distances in some photos	Nikonus III	Qasco SD4	1.5–3.5	10	3.5	Fryer, 1982
	Projective Transformation & Intersection	On the job	Not required	Benthos 370–2	Zeiss Steko 1818	2.0	Test tank	5	Baldwin & Newton, 1982
				UMEL DHC 70	Zeiss Steko 1818 Ross SFS–3	1.6	>140	2.5	Baldwin & Newton, 1982
				Neptune 35C	Zeiss Steko 1818	0.4	Test tank	<1	Boyd, 1983
				Neptune UPS 81	Zeiss Steko 1818	1.2	Test tank	<5	Boyd, 1983
			Known control points in each photo	Nikonus III	Zeiss Steko 1818	1.3	Test tank	0.8	Adams, 1982 Welham, 1983
				Nikonus III with beam splitter	XY digitiser with electronic parallax bar	1.0	Test tank	1	Adams, 1982 Welham, 1983

TABLE 2 CURRENT METHODS OF ANALYSIS FOR UNDERWATER PHOTOGRAPHY

siderable interest is being shown in the smaller, portable and less expensive instruments (eg Ross SFS 3, HTI Mark II, Qasco SD4) for use in an offshore measurement system. Analytical relative orientation with scaling by scale bars in each photo is the method most widely adopted at present with underwater photography. Systems using a known camera separation are easier to apply in the underwater environment but are potentially less accurate as there is no way of knowing whether the cameras have been disturbed. The inclusion of scale bars in just some photographs is a good compromise solution. A projective transformation method avoids the need for scale control in individual photographs. However, it is necessary to photograph a calibration frame at the work site prior to photography of the object so that the transformation parameters can be derived. The coordinates of object points are then determined by intersection using these parameters. This method currently produces the best results but it is not always easy to apply.

ACCURACY

It has proved virtually impossible to standardise the accuracy figures quoted for the various systems. Different cameras, stand-off distances and ways of presenting the results preclude direct comparison. Consequently the accuracy figures in Table 2 are only a guide.

In general, it is safe to say that, at the present time, underwater objects can be coordinated by photogrammetry to an accuracy of about ±5 mm from a stand-off distance of 1.5 m using an analytical method of analysis. This accuracy is acceptable at this stage and should improve with time as new equipment and techniques are explored. In comparison, direct measurements made in water are likely to be less reliable and affected by subjective interpretation.

APPLICATIONS

By far the largest group of applications of underwater photogrammetry, in the last four years, have been in connection with the offshore oil and gas industry in the North Sea. Here no platform can be operated without a Certificate of Fitness issued by a certifying authority such as Lloyds. A survey to obtain a certificate must be performed immediately upon completion of the platform and this must be renewed every five years. Consequently the operating companies undertake regular inspection and maintenance programmes to demonstrate to the authorities that their platforms are in good order. Photogrammetry is currently applied in several aspects of these programmes. Typical applications include the assessment of damage, the monitoring of corrosion and wastage of protective anodes, the dimensioning of weld defects, the checking of as-built drawings and the monitoring of the build up of marine growth. The papers by Baldwin (1984), Boyd (1983), Gres (1980), Leatherdale and Turner (1983) and Welsh et al (1980) give further details of these applications. Pipelines must, also, be regularly inspected for damage or defects. By attaching cameras to an underwater vehicle, several kilometres of pipeline can be surveyed in a day. Any damage can then be assessed and measured.

Away from Europe and the offshore oil industry, other applications have developed, Fryer has mapped and monitored the growth rate of coral colonies in the Great Barrier reef of Australia and monitored pollution and its effects on marine life in environmentally sensitive areas eg near sewerage outlets. In South Africa, Welham has used the techniques to monitor barnacle growth rates. The mapping of underwater archaeological sites has, also, been carried out by Puybouffant.

THE FUTURE

Underwater photogrammetry is still in its infancy and the future will bring changes in equipment and operating techniques as development proceeds.

The trend away from the use of divers to underwater vehicles for work in deeper waters is expected to continue. This is being brought about by the difficulty and high cost of direct measurement in the underwater environment. Of the underwater vehicles, the manned submersible will continue to flourish owing to its suitability for this type of work particularly in connection with structural surveys and complicated underwater tasks. New developments in ROV's particularly of the small, less expensive type are constantly emerging but how far these will replace the manned submersible remains to be seen. The outcome of this trend will be to make the acquisition of photography not only cheaper but safer.

Currently all underwater cameras are basically non-metric. Will the future see the introduction of a metric camera in an underwater housing? It is doubtful whether the use, and hence the design, of such a camera is worthwhile owing to the uncertain and variable properties of the underwater environment. The recently introduced Cercomex camera may, however, be a first step in this direction. The future will certainly see the introduction of more compact camera set ups for use with small ROV's.

Video cameras are widely used for the guidance of underwater vehicles and some systems employ multiple cameras to provide an awareness of depth. Research is underway to investigate whether a measurement capability can be introduced into a stereo video system. If this proves feasible then, depending on the precision of the system, it may be possible to use it in preference to conventional photography for certain applications.

On the analysis side, more work is needed to investigate the influence of the underwater environment on camera behaviour and to assess whether the differences between an on-shore shallow water tank and offshore deep water calibration are significant. Other methods of analysis should be investigated, in particular the Bundle method.

Expertise is currently needed in a wide range of disciplines to undertake underwater photogrammetry. The photogrammetrist is only a part of the system and must associate with experts in underwater photography, vehicle operation and equipment manufacture to form a viable system. These systems are then offered as a commercial service to the oil companies and others involved with underwater measurement. The future of underwater photogrammetry will be more assured if the oil and service companies are able to operate the systems themselves. Future effort should, therefore, be directed towards producing systems, which though reliable and accurate, are relatively simple and easy to use by non-photogrammetric technicians.

CONCLUSIONS

There has been a great deal of activity and interest in underwater photogrammetry during the last four years. This has shown that photogrammetry can produce acceptable results when used in the difficult underwater environment. Interest in the technique is expected to grow in the forseeable future and it will find an increasing range of applications throughout the world. In particular, it should become an important tool in underwater inspection and maintenance work as the quest for oil and gas continues in this hostile environment.

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REFERENCES

ADAMS, L.P., 1982. Underwater analytical photogrammetry using non-metric cameras. International Archives of Photogrammetry, 24(V/1) : 12-22.

BAKHUIZEN, W.H.A., 1983. Development of a subsea photogrammetric system. Proceedings of 'Subsea Challenge' conference, Amsterdam.

BALDWIN, R.A., 1984. An underwater photogrammetric measurement system for structural inspection. (In press).

BALDWIN, R.A. and NEWTON, I., 1982. A proposed system for underwater photogrammetry from a manned submersible camera platform. International Archives of Photogrammetry, 24(V/1) : 39-52.

BOYD, C.R., 1983. Photogrammetry under water. Energy Business Centre Reference Book : 109-110.

FRYER, J.G., 1982. Underwater 35 mm photogrammetric applications in Australia. International Archives of Photogrammetry. 24(V/1) : 167-174.

GRES, J.P., 1980. Photogrammetry scans flare. Offshore, 40(10) : 108-112.

LEATHERDALE, J.D. and TURNER, D.J., 1983. Underwater photogrammetry in the North Sea. Photogrammetric Record, 11(62) : 151-167.

POLLIO, J., 1971. Underwater mapping with photography and sonar. Photogrammetric Engineering, 37(9) : 955-968.

ROSENCRATZ, D.M., 1971. Underwater photography systems. Photogrammetric Engineering, 37(9) : 969-972.

TORLEGARD, A.K.I. and LUNDALV, T.L., 1974. Underwater analytical systems. Photogrammetric Engineering, 40(3) : 287-293.

TURNER, J. and LEATHERDALE, J.D., 1982. Underwater photogrammetry for inspection and maintenance of North Sea oil platforms. International Archives of Photogrammetry, 24 (V/2) : 507-515.

WELHAM, L.G., 1982. Underwater stereometrology for scientists and engineers using non-metric cameras. University of Cape Town. M.Sc.(Eng) thesis (Unpublished). 249 pages.

WELSH, N., LEADBETTER, I.K., CHEFFINS, O.W. and HALL, H.M., 1980. Photogrammetric procedures for a North Sea oil rig leg repair. International Archives of Photogrammetry, 23(B5), 474-483.