

## COMMERCIAL UNDERWATER PHOTOGRAMMETRY - THE FIRST DECADE

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### INTRODUCTION

The first major commercial contract for underwater photogrammetry was completed in 1978 and reported to ISP at the Hamburg Congress by Welsh et al, 1980 (1). This task involved the urgent measurement of the damaged leg of a new oil production platform in the North Sea in order to prefabricate a repair plate, and was successfully accomplished by photogrammetry after other methods of measurement underwater had failed.

Ten years later it is appropriate to review the developments which established photogrammetry as a reliable, accurate and economical method of measurement underwater. The combination of stereoscopic underwater photography and photogrammetric analysis is now recognised and used operationally by all the major oil producers in the North Sea and is now being adopted in other offshore areas where permanent structures have to be maintained. Video cameras, currently used to navigate remotely operated vehicles (ROVs) and to control underwater operations from the surface, are also being used to obtain stereoscopic imagery with the promise of real-time videogrammetry for measurement where instant results are more important than resolution and accuracy. This may be the major achievement of the next decade.

Following that first contract, an association was formed in 1980 to bring together the three essential components for a successful operational service: expertise in diving and underwater photography provided by Camera Alive Limited of Aberdeen; underwater camera manufacture by Underwater and Marine Equipment Limited; and photogrammetric analysis by Hunting Surveys Limited. The early operational experience of the association has been described in Turner and Leatherdale 1982 (2) and Leatherdale and Turner 1983 (3). An alternative system, described by Baldwin and Newton 1982 (4), was operational for a short time, and a general review of the status of underwater photogrammetry was given by Newton 1984 (5) at the ISPRS Congress in Rio. Since that time the manufacture of UMEL cameras has been taken over by Camera Alive Marine Equipment Limited (CAMEL) and, following the closure of Hunting Surveys, the photogrammetric analysis has been transferred to Plowman Craven and Associates. In ten years photogrammetry has become well established as an economic and reliable method of inspection and measurement underwater amongst offshore oil and gas producers around the world and is attracting the attention of other disciplines involved in underwater operations.

Development in all aspects of underwater technology has been spectacular over this period, in response to the needs of offshore oil production extending into ever deeper and more difficult waters. The role of photogrammetry in this development has been identified by the Society of Underwater Technology and the Offshore Energy Technology Board who chose to present the first David Partridge Award for Underwater Technology to John Turner in 1988 in recognition of a major achievement in underwater technology.

#### ADVANTAGES AND EXPECTATIONS OF PHOTOGRAMMETRY

Photogrammetry is in its element underwater. It solves the very problem which is uppermost in the minds of offshore operators, engineers, marine biologists, oceanographers and underwater archaeologists - a means of reducing the horrendous cost and uncertainty of success in recording and measuring things underwater. Saturation divers may cost up to 3000 per hour in the North Sea, and remotely operated vehicles (ROVs) between 200 and 500 per hour.

Large quantities of photographs can be taken in a very short space of time, for subsequent analysis by experts in the comfort of a well equipped office. The reductions in operating costs are spectacular: structures which took days to inspect and measure by physical contact, can be photographed in a few hours. Against these savings in underwater operations, the cost of photogrammetric analysis is trivial.

There are other advantages. Photographs provide an unbiased and unselective archive of information at known times, independent of human memory and foresight, and can be re-interpreted in the future for entirely different purposes. Corrosion pitting or weld failures may only be noticed at an advanced and serious stage, but re-examination of earlier photographs may help to reveal their cause and rate of development. The results of photographic interpretation and measurement are very much more reliable, because they are undertaken by specialists in relatively unharrassed surroundings, and can be repeated, and subjected to second and third opinions.

The only weakness in the system is the dependence on obtaining satisfactory photography, which in the case of photogrammetric measurement means usable stereoscopic coverage. As ROV operators become more accustomed to taking photography for particular purposes their competence has improved but thorough briefing is still essential. There may also be obstructions in confined spaces which prevent the acquisition of the required pattern of photography. The maximum stand-off distance at which acceptable image quality can be obtained is generally about 2 metres even in clear water which inhibits the use of the technique for extensive seabed mapping.

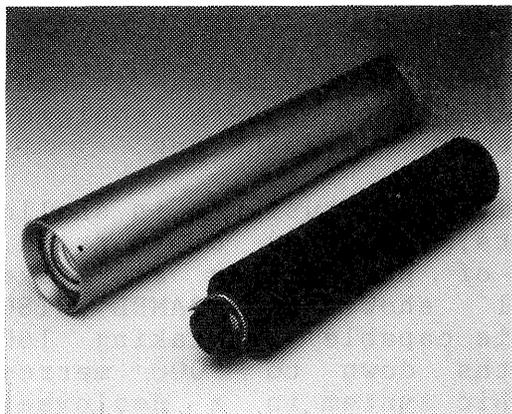
Divers and ROV operators, generally not specialist users, can concentrate on acquiring suitable photography and no longer have to get involved in the interpretation and measurement. Users can analyse the evidence for themselves. Having removed the divers as a source of confusion, the users now want to be able to take measurements themselves without having to specify their requirements in advance to photogrammetric specialists. In this respect photogrammetrists have been conspicuously unsuccessful in simplifying their expertise and equipment to make it accessible to experts in other disciplines. For photogrammetry to become an every-day tool for underwater measurement and recording, it must be made available to the end users as black box technology. The photogrammetric specialist who does not happen to be a pipeline engineer or marine biologist is getting in the way and degrading the extraction of information. The challenge for photogrammetrists is to produce a simple and reliable system for interpretation and measurement which is portable and truly user friendly. Such a system has been designed and described by Baldwin 1984 (6) but is still seeking financial backing. The need exists and users are more concerned about modest cost and ease of operation by non-photogrammetrists than with accuracy and refinement.

#### USER NEEDS

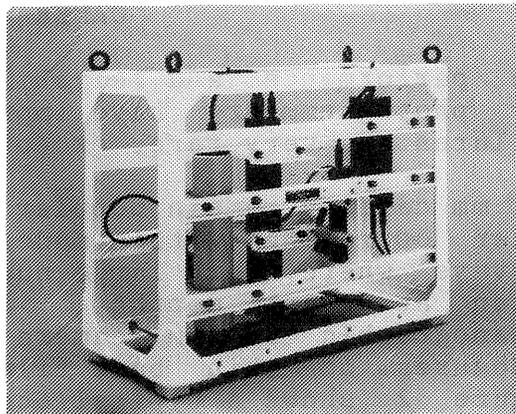
User needs are often remarkably simple and undemanding and it is a mistake for photogrammetrists to strive to extract the maximum amount of information and the highest attainable accuracy from the available photography. It is also counter-productive to specify unnecessarily complex patterns of photography which are unlikely to be achieved. If the system fails to produce rapid and reliable results, it becomes a very expensive disaster. It is also essential to understand users' needs and to present the results as digital or graphic information which is both convenient and meaningful to them.

Most measurements may be obtained from individual photomodels but some critical dimensions or angles involve complex patterns of photomodels. Some measurements require judgement and interpretation, even imagination, as well as factual observation. The depth of corrosion pits or the wastage of annodes must be related to the original surface before corrosion started, which can only be estimated. The observed surface of a damaged platform member has to be related to the probable axis of the member before the damage occurred.

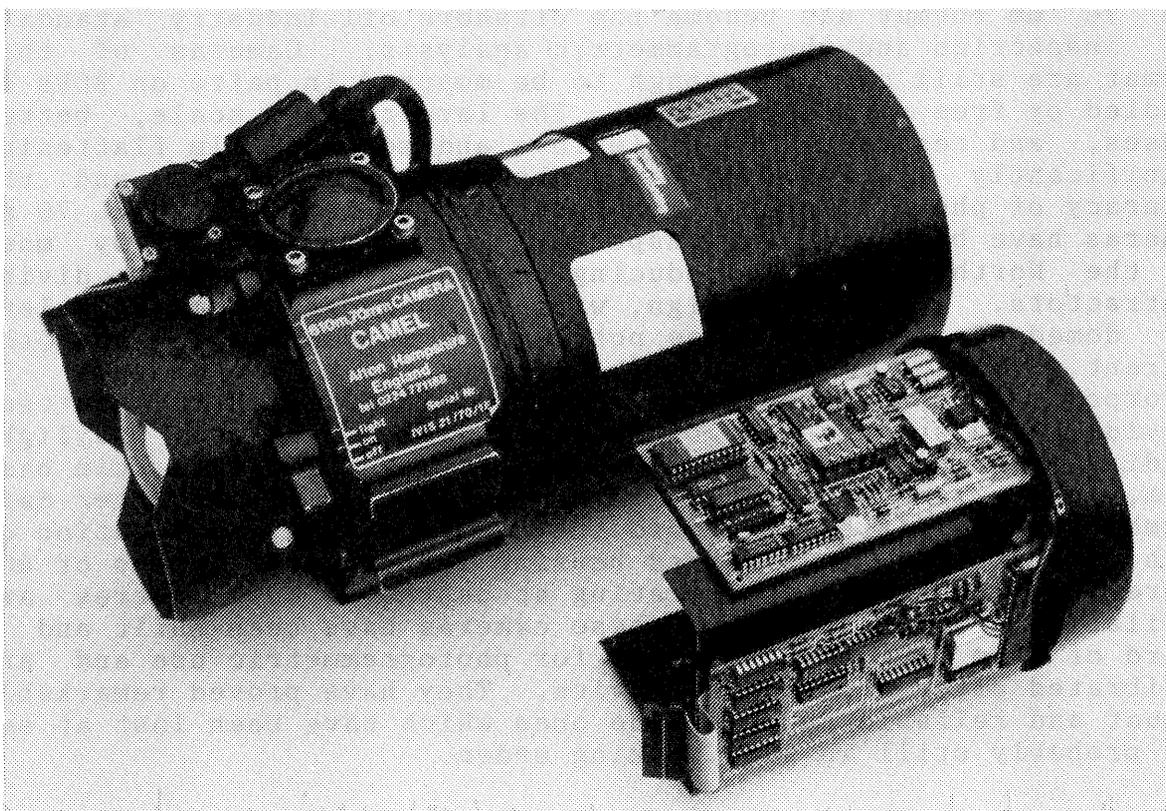
It is understandable that users would prefer to make such measurements and judgements for themselves.



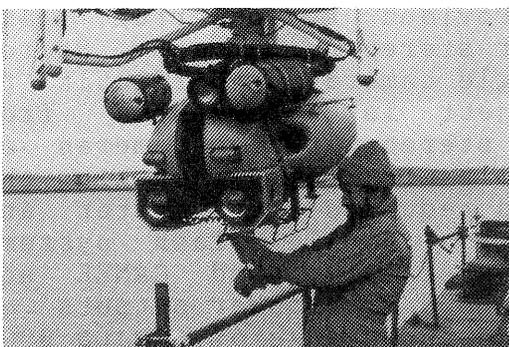
**FIGURE 1.** CAMEL CI800 camera, 800 exposures, 9000 metres water depth.



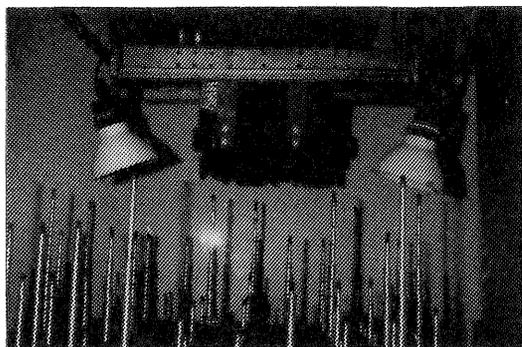
**FIGURE 2.** Typical CAMEL oceanographic photographic system.



**FIGURE 3.** CAMEL CI7070 70mm photogrammetric camera with Ivis 48 character data display.



**FIGURE 4.** A pair of CI7070 cameras mounted on a small ROV.



**FIGURE 5.** The CAMERA calibration system.

## CAMERA DEVELOPMENTS

The performance and reliability of underwater cameras suitable for photogrammetry have improved to the point where equipment failures are very rare, except under extreme mishandling.

35 mm cameras remain popular with diving enthusiasts in shallow water operating within modest budgets, and for oceanographic surveys where very large quantities of photographs are taken often at great depths. Figure 1 shows the CAMEL CI800 oceanographic 35 mm camera which is capable of taking 1600 exposures on thin base film at depths down to 9000 metres. Figure 2 shows a typical oceanographic system in a deployment frame. Neither of these applications is primarily concerned with photogrammetric measurement.

The 70 mm format has become the offshore oil industry standard for inspection and photogrammetric analysis. Cameras of this format are still compact enough to be mounted in pairs on ROVs or handled by free swimming divers. The larger image scale, better lenses, and reseau plates to improve and monitor film flattening significantly increase both the photographic quality and the accuracy of photogrammetric measurement. Since 1980, UMEI 70 mm cameras have been used for inspection and photogrammetry by most of the North Sea oil producing companies and their diving contractors. The basic design, with Zeiss Biogon 38 mm f4.5 lens and domed front port, has not changed fundamentally but the current version, the CAMEL CI7070 shown in Figure 3, incorporates many improvements. Prontor electro-magnetic shutters provide flash synchronisation between pairs of cameras. Daylight loading magazines take up to 70 exposures, or 200 with thin base film, and a sensor detects film jams. An IVIS 48 character data chamber can be fitted to record the number, time and location of each exposure. The standard housing is rated for depths of 600 metres but housings for operating at depths of 6000 metres are available. Over sixty of these cameras have been built and a third of them have reseau plates for photogrammetric use and are calibrated after each major service. They have proved remarkably robust and reliable and even the ones which have been lost at sea are probably still in good working order.

## LIGHTING

Artificial illumination has to be provided by powerful flash units and is particularly critical for stereo photography. Stereo pairs taken sequentially with a single camera are difficult to observe satisfactorily if the object is illuminated from different directions. Simultaneous stereo with two cameras is preferred to achieve consistent illumination and to obtain the required stereoscopic overlap. This requires both master and slave cameras to be synchronised with a single flash system. Previous flash systems were not satisfactory and CAMEL now manufacture a range of units of their own with power outputs of up to 1000 joules and housings with depth ratings of 600 to 9000 metres. Another persistent cause of system failures has virtually been eliminated.

## FILM

Early work was done with black and white negative film but colour reversal, Kodak Ektachrome at 64 or 200 ISO, is now used almost exclusively because of the substantial improvement in interpretation.

## UNDERWATER OPERATIONS

Operations are planned to minimise the time spent underwater and simplify the procedures in every possible way. Pairs of cameras mounted on all kinds of ROVs are used to obtain stereo photography as illustrated in Figure 4. A video camera mounted beside the photographic cameras enables the operator at the surface to manoeuvre the ROV into the required positions to take photographs. Fender bars or manipulator arms may be used to achieve the required stand-off distance and to carry scale bars positioned within the camera field of view to provide portable control. Otherwise the manipulators are used to clip magnetic scale bars onto the object itself.

Only exceptionally are divers with single cameras needed to gain access in restricted spaces.

## CALIBRATION AND CONTROL

Camera calibration and residual water refraction distortion are determined simultaneously by photographing a three dimensional object in a water tank as shown in Figure 5. Cameras are re-calibrated in this way after major overhauls, but all routine servicing can be done without disturbing the alignment of the lens and port. Although this method has been rejected by the more scientifically minded, Newton 1984 (5), Baldwin 1984 (6), and Welham 1984 (7), it has been shown to produce entirely acceptable results given appropriate control, and is attractive to the users because prime diving time can be devoted exclusively to photographing the objects to be inspected and permits quite small ROVs to be used which could not carry the cumbersome calibration frames required for on-site calibration. There is also no need for the operation to be supervised by photogrammetrists.

Experience with the more rigorous solutions has been noted and corrections can now be applied to the calibrated focal length for average salinity on site.

Control is supplied by scale bars or frames placed around the object. For simple tasks involving individual photomodels, two or more scale bars are attached to the object by magnets or tied to a manipulator arm or crash bar in front of the ROV and within the stereoscopic coverage of the photographs. For multiple photomodel tasks, control can be provided by scale bars in every model; by attaching a measured frame designed to enclose the whole object; or by using the fixed orientation parameters of a rigid two-camera system determined from the controlled models to provide control for the models without control. The last solution

is the one adopted for routine inspection programmes involving thousands of stereo-pairs of photographs, from which few if any stereomodels will be required for photogrammetric analysis. Provided some stereo-pairs in each mission contained control bars, any of the photomodels can be used for photogrammetric measurement whenever required. Besides saving time and cost in underwater operations, this system is extremely simple and therefore likely to succeed even without specialist supervision.

#### PREPARATION

Both photographic inspection and photogrammetric measurement can be non-destructive, which is a prime consideration for marine biology, oceanography and sedimentology, but engineers usually require marine growth to be removed from structures before photography. This can largely be done by ROVs using scrapers, hydraulic brushes and high pressure water jetting, sometimes with abrasives such as a sand slurry added to the water. While soft and mobile marine growth make it difficult to select fixed minor control points for transfer between photomodels, hard growth such as mussels and tube worm can provide useful identifiable points. Serious problems arise with new structures of uniform texture and areas of damage which have been ground and polished and these may require magnetic targets and greasepaint graffiti to be added before photography to provide sufficient features and texture for stereoscopic measurement.

#### PHOTOGRAMMETRIC ANALYSIS

From the beginning, a Zeiss Stecometer stereocomparator was used for observation, and orientation programmes developed by K M Keir at Hunting Surveys needed only minor modification to handle underwater applications. The lack of a real time three dimensional model was a disadvantage only overcome by the immense experience of H M Hall who has observed and adjusted hundreds of thousands of photomodels for both aerial triangulation and short range applications and was responsible for all the underwater photogrammetry undertaken between 1977 and 1987.

Features could only be plotted from discrete points and profiles were interpolated. Surface modelling and isometric views were generated on an Intergraph system whenever more complex analysis was required.

When Hunting Surveys closed down in 1987, Plowman Craven and Associates took over the photogrammetric analysis using a Digicart analytical plotter and McDonnell Douglas GDS graphics system. The analytical plotter is much more effective for plotting features and profiles, and perspective views can be plotted from all angles using the GDS system as shown in Figures 6 and 7.

A complete system with CAMEL underwater cameras and calibration software has been licensed to GHD of Melbourne, Australia since 1985.

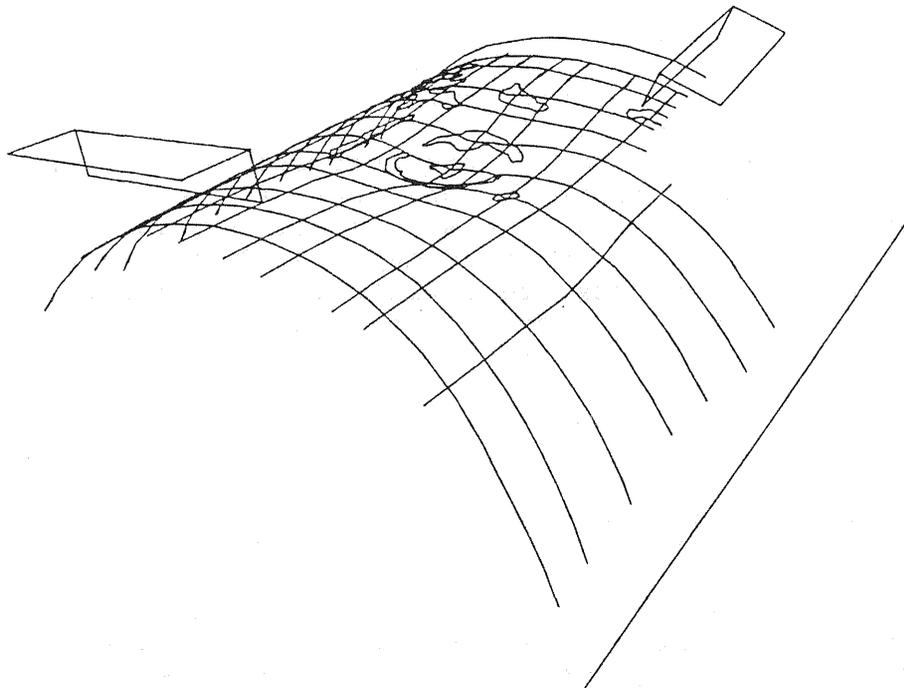


FIGURE 6. Perspective drawing of dented pipe with outline of corrosion pipes. Scale bars are also shown.

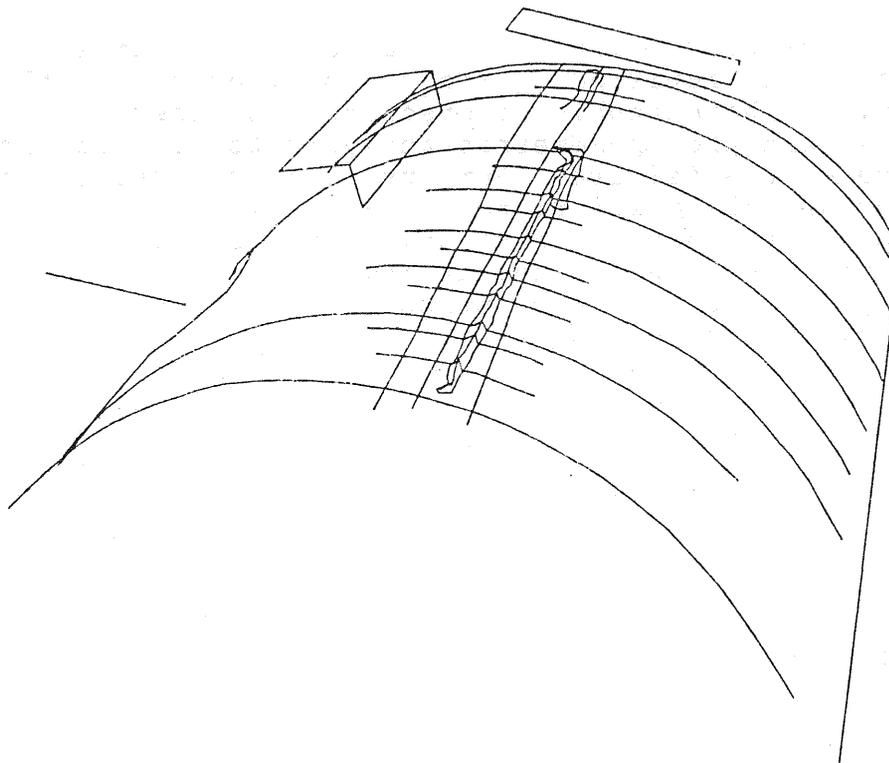


FIGURE 7. Perspective drawing of damaged pipe.

Detailed photogrammetric analysis of critical areas of damage, corrosion or replacement will continue to be sent to specialists, but user demand for a simple portable system for stereoscopic interpretation and approximate measurement which they can use themselves cannot be ignored. Although quite a number of the new generation of PC-based photogrammetric systems has been investigated and tested, none has so far met the required standard of user friendliness, robust portability and low cost, which would justify our recommending them to our clients for occasional use by engineers without photogrammetric training. Hopefully improved systems will be presented at Kyoto.

## APPLICATIONS

Over ten years we have been asked to photograph and sometimes to measure the seabed, natural features in the sea, and all kinds of man-made structures, and CAMEL cameras have been used by our clients to take prodigious quantities of photographs, most of which we never see. Most of the photogrammetric analysis has been related to the measurement of damage, corrosion, wastage of sacrificial anodes, weld fractures, replacement and redesign of sections of oil production platforms and pipelines. Measuring scour and sediment around structures has also been required.

Corrosion in sea water is a continual process which eventually weakens steel structures despite cathodic protection and must be monitored meticulously. Selected areas of pitting are photographed regularly and the depth and size of individual pits are measured to calculate the rate of corrosion. Similarly the sacrificial anodes are measured periodically to check that the wastage rate conforms to expectations.

Stress causes weld failures in platform structures which must be detected and repaired quickly to prevent further damage. Systematic photographic inspection is used to locate weld fractures and photogrammetric analysis to measure and identify the cause of the failure. Serious cases may require clamps to be fitted around the platform nodes. Some of the more complex multi-model photogrammetric tasks have involved circular patterns of photographs around each tubular member to calculate the ovality, angle and offset of each member in order to design clamps to strengthen fractured joints.

Damage caused by storms, collisions and falling objects require immediate attention and repair to prevent serious loss of production. The first stage is to obtain inspection photography to assess the nature of the problem, followed by specific coverage to measure the areas of damage in order to construct repair plates or replacement parts. Isometric views, with or without scale exaggeration in selected directions, have been found to be particularly valuable to engineers assessing the seriousness of the damage and in designing repairs.

Many of the oil and gas production platforms in the North Sea are more than ten years old and require modification to adapt them to changing operating procedures. The original design drawings are often inadequate to design and prefabricate replacement parts and photogrammetry is used for this purpose.

#### SUMMARY

A commercial service for underwater photography and photogrammetric analysis has been developed to meet the needs of the oil and gas production industry, first in the North Sea and later in other offshore fields. Now that this service exists it is attracting the attention of other engineers, oceanographers, marine biologists, archaeologists and other scientists operating underwater. In the next ten years, much more widespread use of underwater photogrammetry can be expected if portable user friendly systems become available and videogrammetry can be developed into a real-time measurement system.

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