A REAL TIME PHOTOGRAMMETRY SYSTEM FOR UNDERWATER AND INDUSTRIAL APPLICATIONS

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ABSTRACT:

A market survey within the Offshore Oil and Gas Industry highlighted the operational deficiencies in providing a dimensional measurement service based on traditional photographic based photogrammetry. This has led to the development of a real- time photogrammetry system which can be used operationally in air or underwater.

The developed Non-Contact Measurement System (NCMS) is used by engineers and operational technicians to extract three-dimensional data for use in on-site decision making processes, or for reporting via CAD systems, to aid with construction, maintenance and repair.

The system allows a range of inputs, including a purpose designed digital stills camera incorporating a high resolution CCD, video cameras, scanned photographs and satellite images. Analysis is carried out using a PC based image processing system, with full stereo viewing, and software written as a Microsoft Windows application.

The paper introduces the development of the system, reports on its benefits and introduces the applications for such a product.

KEY WORDS:

Real-Time, Digital Photogrammetry, Digital Camera, Image Processing, Close-Range, CAD/CAM, Underwater.

1. INTRODUCTION

1.1 Historical

Camera Alive have used conventional photogrammetry as the basis for a measurement service provided to the Offshore Oil and Gas Industry since 1980. Its applications have been focussed on underwater activities where remote measurement of three- dimensional objects was necessary for such tasks as the repair or maintenance of steel tubulars, the monitoring of corrosion and the evaluation of weld defects or impact damage. Other applications, out of the water, have included the measurement of drilling derricks, the survey of structural components of the offshore platforms between the sea and the deck, measurements required to plan the installation of additional pipework and to fabricate clamps or other strengthening or repair pieces. [1-9] Figure 1 illustrates a typical result from the underwater survey of tubular steel structural members prior to the installation of a clamp.

Since the introduction of the service in the North Sea in 1980 photogrammetry has been used in almost every offshore producing region of the world.

Marketing and sales activity had defined the main three- dimensional measurement requirements of the Offshore Industry as:

- Fast Image Capture and Presentation of Results;
- Accuracy;
- Objectivity;
- Cost Effectiveness.

While conventional photogrammetry, based on the use of photographic cameras, was regarded as a useful tool for many applications, its use was being excluded from many potential applications because:

It was not able to deliver the measurements without a significant delay. Photographs had to be chemically processed to confirm that they contained the subject matter and were of good photographic quality. The photographs then had to be transported onshore for analysis. A further delay resulted in ascertaining the precise measurements required from the analysis, in liaison with the engineer. The result then had to be presented in draft form before being revised and finally presented. Often the results were not available in time to be beneficial within an ongoing operation. This restricted the use of photogrammetry to surveys which could be carried out in advance of the remedial or installation phase of the job.

The extraction of the data was not able to be controlled directly by the user of the data, which led to interpretation errors.

The cost of the service could only be justified when no other technique could be used to obtain the measurements, hence restricting the range of applications.

In 1989, at the instigation of five far sighted Oil and Gas Companies, a detailed analysis of their measurement requirements was made. This highlighted in particular the programmed exploration and production in water depths of greater than 300 metres. At these water depths the use of divers became prohibitively expensive and potentially damaging to their health. The alternative was an increase in the use and expansion in the range of applications of Remotely Operated Vehicles (ROVs), figure 2. If this was to be achieved it would be necessary to have available a remote dimensional measurement system that could meet the need for cost effective, accurate and objective dimensional data within short time scales, preferably in real time. The objectives for the development had been set.

1.2 Feasibility

A range of state of the art technological solutions to remote dimensional measurement problems were considered. These included laser and acoustic techniques. However, the requirement for any system to be integrated into an ROV which was always moving relative to the subject focussed the investigation on techniques that could acquire data on the whole subject instantaneously, rather than sequentially. For this reason a visual imaging technique was essential.

1.3 Development Objectives

The feasibility study concluded that, on the basis of the main requirements for speed, accuracy, objectivity and cost effectiveness, the development objectives should be set as follows:

The use of photogrammetry principles would meet the requirements of accuracy and objectivity, as well as that of using a visual imaging technique that would capture the whole scene instantaneously.

The speed of image capture requirement necessitated replacing the photographic cameras with electronic imaging devices, with a corresponding change in the analysis equipment to handle these electronic images.

The duration of the measurement process could be reduced by automating many of the set-up and measurement routines. The use of analysis equipment designed to handle electronic images would enable this process.

The cost benefit would be achieved by replacing the expensive optical / mechanical analysis system with a PC based image processing system, as well as designing the user interface so that it could be operated directly by the engineer who required the information, rather than by a skilled technician.

2 THE DEVELOPMENT

The development of the system progressed along the lines indicated by the feasibility study, with the main work areas defined as follows:

- Imaging Devices;
- Transmission Systems;
- Image Processing System;
- Stereo Viewing System;
- Photogrammetric Software;
- User Interface Software.

The concepts have been recorded by Turner, Yule and Zanre [10].

Test marketing of the component technologies as they were developed indicated that the success of the system would depend on the imaging devices, which would limit the accuracy, convenience and cost of the system, and the user interface software which would determine who could use the system and so the size of the market.

2.1 Imaging Devices

The use of electronic visual imaging devices gives an immediate advantage over photographic devices: the image is available for analysis immediately after data capture without chemical or other processing. This comes with a disadvantage in that image resolution is generally lower. However, the market requirement placed the priority on speed rather than accuracy.

Electronic visual imaging devices come in many forms. Scanned forms are only suitable when the camera and the subject are stationary. They can be used to transfer the image data from a photograph, for example, into an electronic form. The forms that are immediately of interest within any real time photogrammetry system are video and digital stills cameras. Both can input into the Non-Contact Measurement System.

2.1.1 Video Cameras

Video cameras have the following benefits:

- They have good time resolution, with the video framing rate 25 or 30 frames (50 or 60 fields) per second, depending on the International Standard. This is useful when tracking a moving target or when viewing from a moving platform, to allow the image to be captured at the precise moment when the subject content is correct.
- They are inexpensive, and so provide an immediate cost benefit.
- They can provide colour images, which allow better interpretation of some subjects.
- They can provide intensified images, and so can be used in conditions of low ambient illumination without artificial lighting.
- They are easy to install as they use commonly available transmission systems.
- They can be used for real time stereo video.

They do however, have the following disadvantages:

- They have a poor space resolution, commonly about 400 horizontal lines.
- They have a low grey scale resolution of 64 levels.
- They are analogue devices with their overall performance dependent on the value of electronic components which can change with time and temperature. Their images are hence not exactly reproducible, which makes it difficult to calibrate the cameras precisely. The images can also be affected in transmission and by external interference making calibration of the system, rather than just the cameras, important.

The main applications for video input are:

- When a cost effective system is required that is not expected to give extremely high precision measurements.
- When there is a requirement for stereo viewing in real time.
- For the supervisory control of robotic manipulators, where time resolution is more important that spatial resolution.

2.1.2 Digital Cameras

Video cameras were not the choice when more precise measurements were required. In this case digital stills cameras were specified. The most important aspect of this choice is that the camera is truly digital, so that the quality of the image is unchanged from camera, through transmission, storage and processing. With full error correction routines, any transmission interference can be eliminated with the image in a digital form.

To correctly specify such a camera it is important to understand the difference between an analogue image and a true digital image.

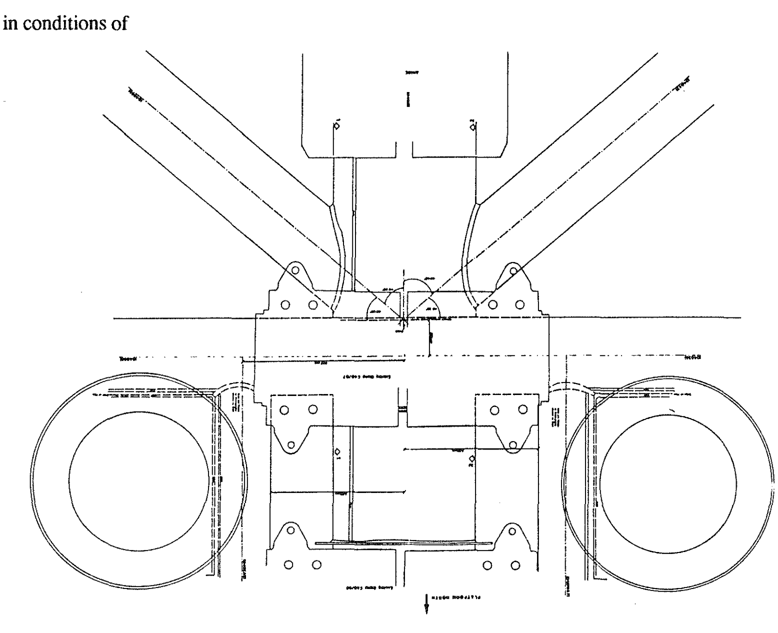
An analogue image consists of a stream of voltage amplitudes which represent the grey levels or colours of each line of the image, together with synchronising pulses which indicate the start of each line of the image. Such a data stream is illustrated in figure 3.

A digital image is made up of individual bytes of data, each a number of bits deep. Each byte of data can be equated to a point on the image. The greater the number of bytes the greater the resolution of the image. The greater the number of bits, the more accurately the intensity of the illumination can be recorded, and hence reproduced. Such a data stream is illustrated in figure 4.

While it is possible to "grab" the image from a video camera to convert it to a digital form, it is not possible by this process to identify the individual imaging element (pixel) on the charge coupled device (CCD) of the video camera that produced the byte within the grabbed image. (The problem is made much worse with tubed cameras to the extent that they are only used as a last resort within the Non-Contact Measurement System.)

The importance of this to the photogrammetry process is that it is difficult to accurately calibrate an electronic camera that captures or processes or trans-

Figure 1. A typical application of conventional photogrammetry within the Offshore Oil and Gas Industry. The drawing shows the result of a survey of tubular steel structural members prior to the installation of a clamp.



mits images in an analogue form. This will have a corresponding adverse effect on the tolerance that must be placed on each measurement taken.

A number of "digital" cameras were evaluated prior to making the decision to develop a digital camera to meet the precise requirements of the Non-Contact Measurement System. Most of these cameras were discovered not to be true digital cameras as they involved one or more analogue stages within the image capture and transmission path. Any analogue stage looses the integrity of the image data and so precludes the identification of the individual pixel from the CCD which was responsible for forming each individual part of the image, as well as reducing image quality in general.

In addition to normal photogrammetric calibration parameters, it is important to be able to calibrate the performance of the CCD in terms of the dark current (the residual image pattern in the CCD prior to exposing it to the subject) and the relative sensitivity of the individual pixels. Both calibration factors become crucial when automating the relative orientation and measurement process, which rely on image matching techniques.

Some digital cameras were of the slow scan form, from which the image cannot be extracted from the imaging device quickly. To preserve image integrity, which could be damaged by a continued dark current build-up over a short period of time, these cameras are normally cooled in liquid nitrogen and so are not suitable for operational use.

Other digital cameras did not allow a buffer memory adjacent to the camera head, so not allowing an image to be captured and then transmitted over a slow transmission system.

The digital cameras developed for the Non-Contact Measurement System have the following benefits:

- The high resolution CCD (1242 x 1152 pixels) gives at least four times the area resolution of video cameras, so allowing measurements of higher accuracy or larger areas to be covered in one image to achieve the same accuracy.
- A high grey scale resolution of 256 levels, which allows better interpretation of the subject.
- The data form of a digital image means that image quality is not degraded in the transmission system.
- Full digital control of the formation of the image which makes the calibration of the camera and the automation of measurement tasks more reliable.
- High quality lenses are readily available, so increasing the quality of the images, and hence the accuracy of the measurements, correspondingly.

The main applications for digital input are when high spatial resolution is required. The performance of the digital camera can be adequately compared to a 35mm monochrome photographic film image.

However, they also have disadvantages:

- They are monochrome devices.
- They require digital transmission systems which, due to the larger amounts of data produced by the larger and higher quality image, tend to be slower.
- They are more expensive than video cameras.

2.2 Transmission Systems

When the cameras are being used remotely from the analysis system the image data must be transmitted from the cameras to the system. In some cases within the offshore environment, the camera is separated from the analysis system by 1200 metres or more of electrical umbilical which is used to power and control the ROV, as well as to bring back the images and other data.

Conventional ROV transmission systems are suitable for the use of video input into the Non-Contact Measurement System, but slow down digital input to the extent that it can take up to one minute to transmit a single image. Modern fibre optic systems are necessary to allow full digital images to be transmitted in real time.

2.3 Image Processing System

The processing of the images captured from the video or digital cameras is carried out within the PC mounted image processing system. This is a modular system based on the Texas Instruments TMS 34020 graphics chip. The image processing system is mounted in the bus of the host computer, and is controlled from the host computer. However, the image capture, processing and display functions are controlled over a high bandwidth local bus, hence by passing the PC bus. The PC based image processing system, together with the stereo viewing system, is illustrated in figure 5.

The use of the modular system brings the benefit of being able to tailor the system to the precise requirements of the user. A different capture board is used for video and for the digital camera. Dedicated image processing functions are carried out on other boards. Stereo viewing of real time video requires an add- in board. However, the base system is identical. Video and digital boards may be installed concurrently, allowing versatility in the use of the system.

The system brings the following additional benefits:

- The use of a PC means that the software has been written as a Microsoft Windows application and hence provides the benefits of working with this popular graphics user interface.
- The system can be based on an office or industrial computer chassis and hence can be tailored to withstand the rigours of offshore working without penalising desktop users.
- The system has a lower capital cost than dedicated workstation based image processing systems that are often no faster for the tasks that are required to be carried out.
- The system is easily transportable.
- The PC environment allows images to be stored on magnetic or optical disks, or to be sent over standard telephone or radio transmission systems, with no image quality reduction. Images can be transferred to be viewed on a standard VGA compatible computer screen with a slight reduction in quality.
- The PC environment allows easy access to other software packages, such as word processing, graphics and CAD such that the measurement data extracted is immediately usable for reports, drawings and for further processing.

2.4 Stereo Viewing System

A design requirement was that the Non-Contact Measurement System should be able to be used by engineers, without specialised knowledge and training. This placed a special emphasis on the design and use of the stereo viewing system.

Test marketing indicated that the stereo viewing system should allow multi-access to allow the extraction of data to be discussed, and to facilitate introductory training.

Conventional optical stereo viewing systems were rejected.

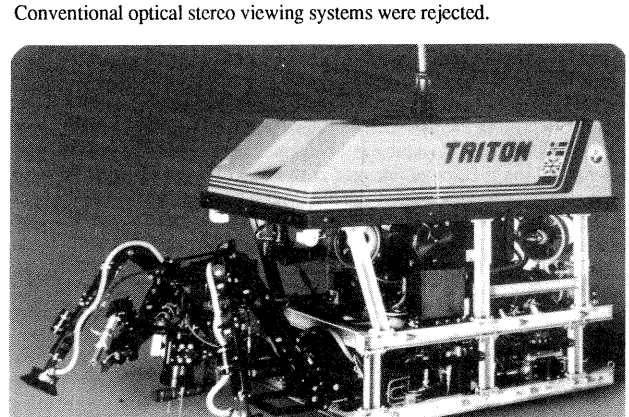


Figure 2. A typical Offshore Remotely Operated Vehicle (ROV) which will have to carry out the work of divers in deep water.

The system chosen is based on liquid crystal shutter technology. A high quality graphics monitor, with a colour resolution of 1280 x 1024 x 8 bits, has been fitted with a liquid crystal screen which can be circularly polarised in synchronisation to the rate at which the image processing system displays the alternate left and right hand images on the screen, usually at a frequency of 100 or 120 Hz to avoid user fatigue. The user has only to wear circularly polarised glasses or clip-ons to view high resolution stereo images.

For the measurement process, the Non-Contact Measurement System reduces the display to monochrome 1024 x 512 pixel x 8 bit resolution.

The benefits of the viewing system can be summarised as follows:

- The viewing system can be set-up and operated without a high level of skill or experience.
- The viewing system allows multi-user access.

2.5 Photogrammetric Software

The system is used in a user selectable mode. This may be as a monocomparator, stereocomparator or full digital plotter.

The first two of these modes exist mainly for the benefit of users with photogrammetric experience, and allow the acquisition of data for input into external software such as bundle adjustment or lens calibration programs. In most cases however the system will operate in digital plotter model, as this allows on-line stereo viewing and the ability to take measurements at will.

The standard phases of inner and relative orientation are performed (inner orientation being trivial with digital images). There is then the choice of scaling the model with a known distance or performing an absolute orientation with control points. As the setup phase is potentially the most difficult operation for inexperienced users great effort has been taken to hide as much of the process as possible from the user.

The system operates on a single screen which displays both the user interface and the stereo model simultaneously. Commands are input using a three button trackball or mouse.

2.6 User Interface Software

One of the most critical development objectives has been to design the user interface of the Non-Contact Measuring System such that it could be used by the engineer who required the data, rather than by a specialised technician. This has resulted in:

Software that has been written as a Microsoft Windows application. The graphic user interface will be familiar to all who have used the Microsoft Windows environment and the complete system is controllable through a "mouse driven cursor" by pointing and clicking. Typical menus and dialogue boxes are shown in figure 6.

The de-skilling of the photogrammetric set-up and operating commands such that the choice of commands is logical and easy to interpret without extensive training or detailed photogrammetric knowledge.

The dimensional data extraction process has been designed from the requirements perspective of an engineer rather than a map maker. In general the engineer is concerned with specific parts of the image rather than the whole.

Marketing has shown that measurement requirements are likely to be points, dimensions, angles, profiles and diameters, rather than surface models. For the construction of CAD drawings a polygon function, which can be used to describe all the features of one part of the subject and keep that data as a discrete entity when transferred into the CAD system, is essential. However, the features required by the map maker are still to be found within the user interface system.

To allow the engineer to build-up the measurements selectively from the image, a three-dimensional graphics overlay is integral to the user interface system. This allows all the measurements taken, be they discrete measurements, surface models or any other option, to be overlaid in three-dimensions on the stereo image. Editing of the overlay allows individual measurement "nodes" to be deleted or repositioned; additional nodes to be inserted; entities deleted; and groups of entities toggled on and off.

The CAD transfer utility saves the graphics overlay as a three- dimensional CAD file in the DXF format, such that it can be transferred to such CAD packages as AutoCAD and Intergraph Microstation for further processing or presentation.

2.7 Performance

In operation the system has been able to meet its design objectives and is used by engineers for the extraction of the data that they require. With video input the system can achieve typical pro-rata measurement accuracies of +/- 2mm, and the digital system +/- 0.5mm, within a subject field of view of one metre square. The better calibration and ease of interpretation of the images from the digital camera makes sub-pixel measurements possible.

3 APPLICATIONS

The applications of the system can be categorised as follows:

- Metrology Applications;
- Robotics Applications.

3.1 Metrology Applications

The metrology applications of the system largely follow the applications of the conventional photographic based system.

However, the range of applications has been increased to include those tasks in which the dimensional data is required immediately. This extends the applications to construction related tasks.

One side effect of the availability of the system is that tasks that had been carried out by other techniques, such as the sizing of the marine growth fouling on the underwater structures, can now been carried out more conveniently and cost effectively with the Non-Contact Measurement System.

The metrology applications can be summarised as including practically any dimensional measurement requirement underwater or in air.

3.2 Robotics Applications

One of the most interesting applications for the system is in the supervisory control of robotic manipulators that are used on ROVs to substitute for the manipulative capability of divers.

In most cases an underwater manipulator is under the direct control of an operator on the surface. As he moves a master control into the desired configurations, this movement is mimicked by the underwater manipulator. The positioning of the manipulator is normally carried out solely with mono video monitoring. Unless the ROV can be positioned such that it is stationary, which it cannot commonly be, the operation has to be carried out with uncompensated relative movement between the manipulator and the subject. This process is termed tele- manipulation.

The construction of these manipulators means that they can be positioned under software control reproducibly, but not accurately. Their in-built optical and electronic sensors are still unable to compensate for the tolerances in the mechanical construction of the joints and hydraulic actuators.

In order for the control of these manipulators to be automated, a closed-loop supervisory control system is required to inform the manipulator of where it actually is, rather than where it thinks it is.

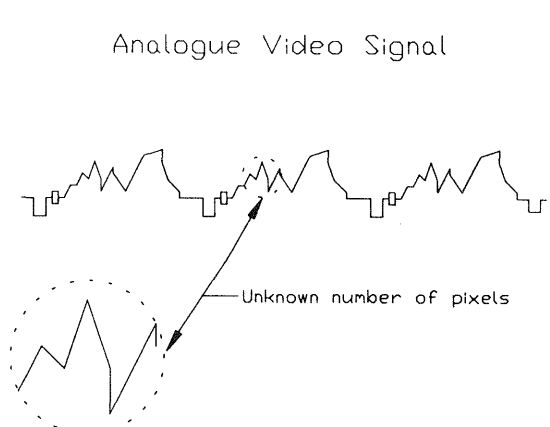


Figure 3. The data stream from a video image.

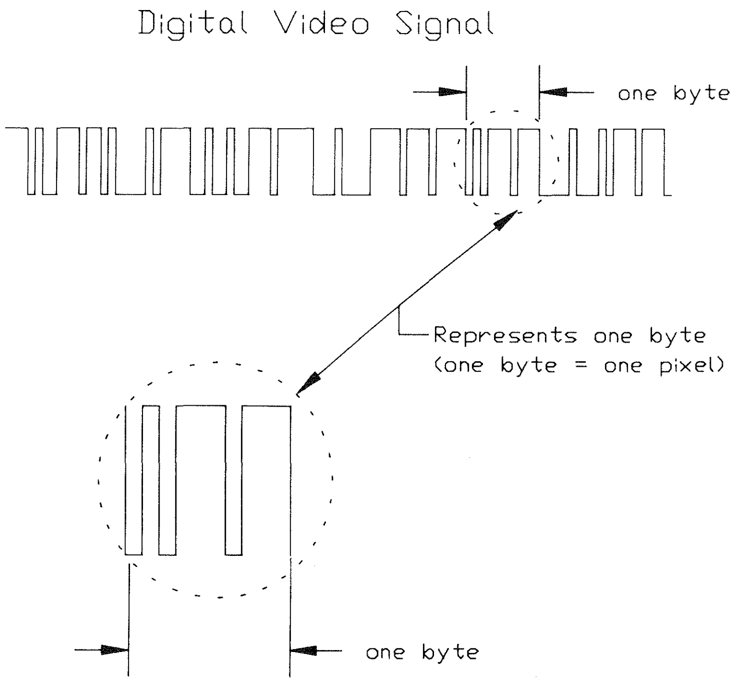


Figure 4. The data stream from a digital image.

Figure 5. The stereo viewing and control screen from the PC based image processing system, showing the Microsoft Windows control menu and the graphic overlay

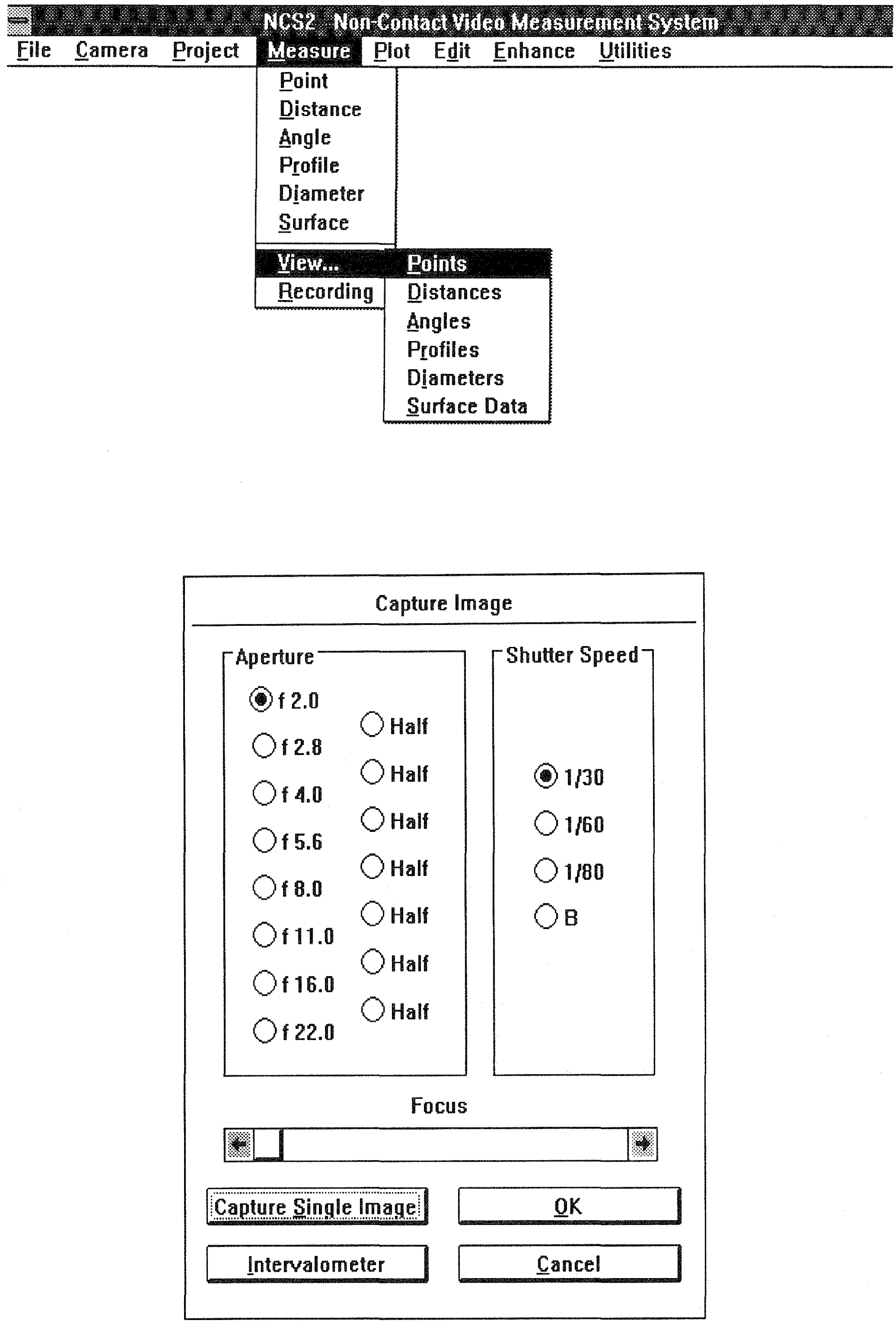


Figure 6. Above is the main menu from the measurement system with the measurement option selected. Below is the dialogue box from the digital stills camera image capture option.

In practice, the Non-Contact Measurement System is being applied to this problem in a manner which illustrates its versatility. This is detailed by Turner, Yule and Zanre in a paper entitled "ROV Vision - A Step Towards Automation"[11] and summarised below.

Using digital camera input, the Non-Contact Measurement System is able to capture the "environment" in which the manipulator will be working, and to convert this to a graphic form which can be entered into the manipulator control system.

Using video camera input which increases time resolution, the Non-Contact Measurement System is able to monitor fixed targets on the subject and so compute the movement of the cameras, and hence the ROV, relative to the subject. This data can be used to compensate for ROV motion.

Using video camera input an operator is able to view the movement of the manipulator relative to the subject in stereo, and so gain feedback that was not possible when using a single camera.

Using video camera input to a dedicated board within the image processing system, the movement of targets on the manipulator relative to targets on the subject may be monitored. This allows the relative position of the manipulator to the subject to be monitored and fed back to the manipulator control system.

4 CONCLUSION

An operational real time photogrammetry system, the Non-Contact Measurement System, has been developed which meets the clearly documented requirements of the Offshore Oil and Gas Industry.

The system has been designed to operate in a hostile environment and to be operated by the engineers whowho require the dimensional data.

The system is being applied to solve both metrology and robotic related measurement problems.

The next challenge is to apply the technology developed in one of the most hostile and demanding markets in the world to other markets, to challenge the concept that photogrammetry is a technique for photogrammetrists and to bring remote non-contact measurement to the masses.

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