

## **Field Trials of Stereoscopic Video with an Underwater Remotely Operated Vehicle**

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### **ABSTRACT**

We have developed a flicker-free stereoscopic video system which uses commercial television components. This system has been installed on an underwater remotely operated vehicle (ROV) which is used for service and inspection tasks at a gas production platform 130km off the North-West coast of Western Australia.

We report the results of field and laboratory time trials of remote manipulation tasks and also the general experience gained in the field operation of the system.

The use of conventional video for manipulation requires the use of special skills and trial and error to make up for the lack of depth perception. The underwater environment also makes conventional video hard to use because it reduces the effectiveness of other depth cues such as shadowing and perspective. Stereoscopic video overcomes these problems by providing the operator with an intuitive sense of the depth relationships of the work-site. Operators report that this reduces frustration and mental effort as well as giving them confidence in their actions.

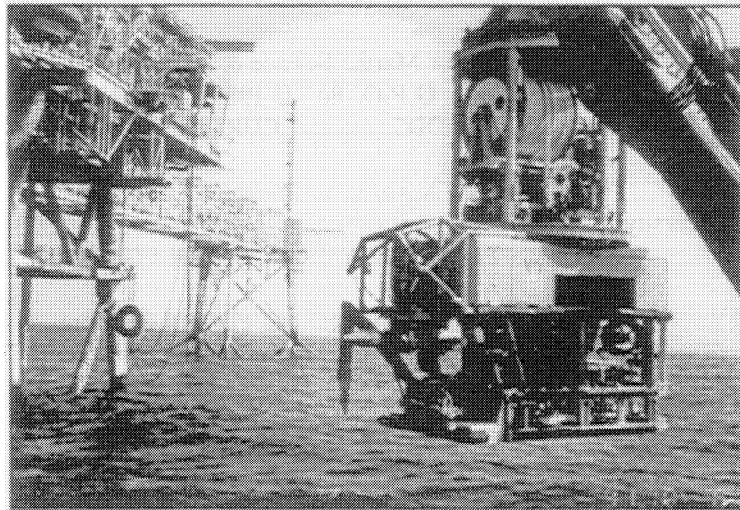
Some of the other advantages which we have observed include the increased ability to see through suspended matter (fine particles) in the water. The system is most useful in manipulative tasks but also useful for general 'flying' of the ROV making navigation through the platform easier.

Our results indicate that stereoscopic video will be a valuable tool in the operation of remotely operated vehicles in the underwater environment.

### **1. INTRODUCTION**

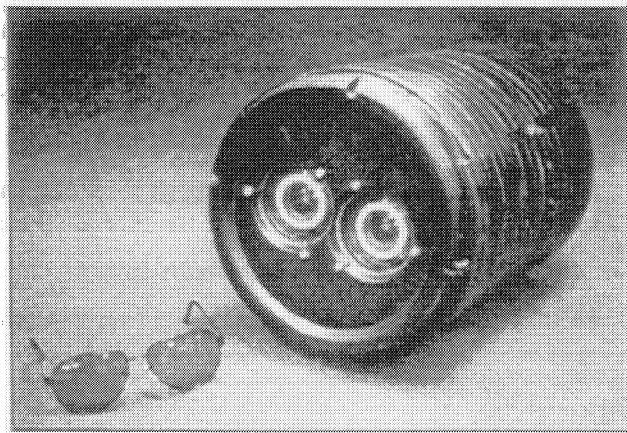
There is a world-wide trend towards the use of remotely controlled equipment to perform tasks which are too dangerous or difficult to be performed by humans. One area in which Remotely Operated Vehicles (ROVs) are commonly used is the offshore oil industry where Underwater ROVs are widely used to maintain, inspect and service the underwater structure of oil platforms. ROVs are usually only fitted with conventional video cameras whose images are displayed on television monitors in the control room. Unfortunately, conventional television only provides the operator with a two dimensional view of the remote scene and therefore does not reproduce stereoscopic vision, which is the most important visual cue by which humans perceive depth. As a result, some tasks can be extremely difficult to perform - particularly those which are performed with a manipulator arm.

Woodside Offshore Petroleum Pty. Ltd. operates three ROVs at the 'North Rankin A' gas production platform which is located 130km off the north-west coast of Western Australia (Figure 1). Their main ROV is a Perry Triton Inc. 'Triton' and is fitted with a Schilling manipulator arm. Woodside uses the ROV to perform a range of inspection and maintenance tasks in and around the platform which is located in approximately 125 metres of water. The ROV is unmanned and operated from a control room located in a support ship.



**Figure 1:** The Triton ROV fitted with the Stereoscopic Video System at the North Rankin Platform.

In 1990, we embarked on a project to develop a stereoscopic video system for use with Underwater Remotely Operated Vehicles (ROVs) - in particular the 'Triton' ROV operated by Woodside Offshore Petroleum. The stereoscopic video system which was developed is shown in Figures 2 and 3.



**Figure 2:** The Underwater Stereoscopic Video Camera



**Figure 3:** The Stereoscopic Display

Figure 2 shows the stereoscopic video camera which is fitted to the ROV. It consists of two high-quality video cameras mounted in an underwater housing. The camera outputs a field-sequential PAL video signal (left and right images alternating at the 50Hz field rate). Figure 3 shows the display system which is installed in the ROV control room. The display system receives the video signal from the stereoscopic video camera, stores it in internal video memory and displays it on the monitor at twice the original rate such that left and right images are displayed alternately on the screen at a rate of 100Hz for PAL and 120Hz for NTSC.<sup>1</sup> The system displays a full-colour,

flicker-free three-dimensional image to the operator who wears a pair of special glasses which direct the correct image to each eye (left image to left eye and vice versa). The monitor is shown here fitted with a Tektronix (SGS410) Liquid Crystal Modulator and passive glasses. The system is also compatible with the active liquid crystal shutter glasses sold by StereoGraphics and Tektronix.

## 2. Performance Assessment

Once the stereoscopic video system was developed, we proceeded to assess the performance of the system and determine what advantages it offered to controlling ROVs. Assessment of the system included a range of laboratory time trial experiments and subsequently field trials of the system on the 'Triton' ROV. The time trials consisted of ROV personnel performing a task a number of times under various viewing conditions (2D and 3D). The time trials were assessed by measuring task times, subjectively observing operator performance and collecting operator feedback. In the field trial, the stereoscopic video system was also used in routine (day-to-day) operation of the ROV, for which only subjective assessments were possible.

The inclusion of subjective assessments in the evaluation of the entire system is considered to provide a more accurate appraisal than relying solely upon automatically recordable data.<sup>2,3</sup> The field environment is a complex environment and hence applying laboratory style constraints will not necessarily reveal true field performance.

## 3. Results

### 3.1 Laboratory Time Trials

The laboratory time trials were conducted at Curtin University using an Asea industrial robot. The robot was controlled using a three degree of freedom proportional control joystick. The task was a 'pick and place' task where the operator had to manoeuvre a hook to pick up and move a cylinder between a series of pegs. The same task was performed 10 times by each operator, generally alternating between 3D and 2D viewing. The last two tasks were performed by directly viewing the robot (without cameras) from a position just behind the video cameras. Six ROV personnel from Woodside participated in the trials. None of the subjects had used this particular robot before.

Figures 4 and 5 show the summarised results of these trials. Figure 4 shows the mean times for the laboratory time trial. The horizontal axis shows the task number for the sequence of ten tasks and the vertical axis shows the mean task time in minutes. Each data point on the graph represents the mean time of all tasks at that particular sequence number and a particular viewing condition (across all of the operators). For example, the first black diamond on the left (3D-1) is the mean time of all tasks that were performed first in the sequence of ten tasks and in 3D. The error bars represent plus and minus one standard deviation. Some of the data points have been discarded (eg. 2D-1, 3D-8) at task numbers where less than two operators performed that particular viewing condition.

It can be seen that the 3D mean time was consistently lower than that for 2D viewing. A learning curve is evident in the results indicating that the operators progressively get better in performing the task in both 3D and 2D. The times for direct viewing are the lowest of all the task times. However, the later 3D viewing times are very close to the direct viewing times.

Figure 5 shows a frequency distribution (histogram) of all the task times for the three viewing conditions used (irrespective of their sequence number). The horizontal axis is task time in minutes and the vertical axis shows normalised frequency. The sum of all the times of a particular viewing condition equal one. It can be seen from this graph that direct viewing provides the lowest task times and it also has the lowest variance. 3D viewing has the next peak of times followed by 2D viewing. Variance also progressively increases from direct viewing to 3D to 2D viewing. It can be seen from the curves that when using 2D viewing, it was possible to perform some of the tasks as quickly as with 3D viewing. However, 2D viewing also produced some of the longest task times.

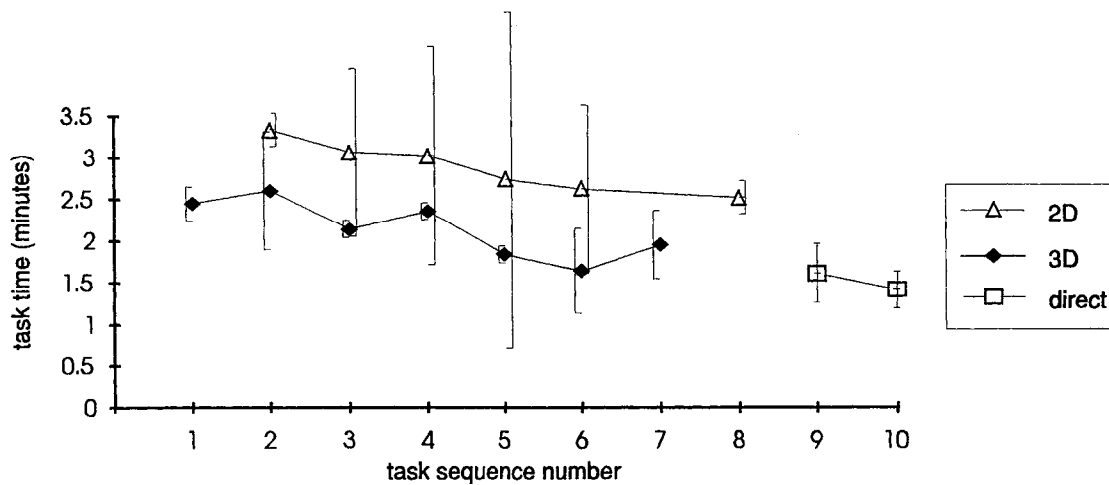


Figure 4: Mean task times for the laboratory task

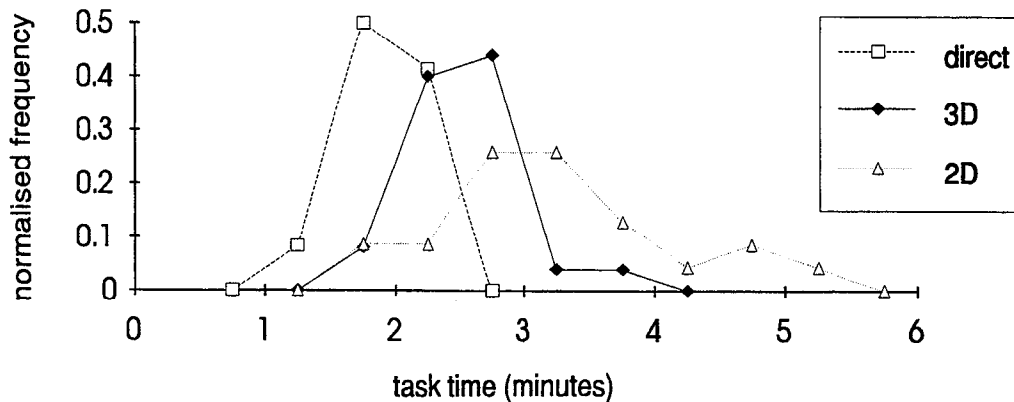


Figure 5: Frequency distribution of task times for the laboratory task

These results coincide with observations made during the trials that more errors tended to occur under 2D viewing as opposed to 3D viewing. Also, when an error did occur (such as dropping the cylinder), it was easier to recover in 3D than 2D. That is 3D performed a lot better than 2D with new tasks - in this case error recovery where the actual task deviated from the practiced task.

The overall mean task times for the three viewing conditions were 2D: 2.8 minutes, 3D: 2.13 minutes and direct: 1.52 minutes.

### 3.2 Field Time Trials

In October 1991, the stereoscopic video system underwent its first series of field trials. The field trials consisted of using the system during routine operation of the ROV and time trials to obtain some objective performance data.

The time trial task consisted of using the Schilling manipulator arm, fitted to the front of the ROV, to perform a 'pick and place' task using the apparatus shown in Figure 6. The apparatus consisted of a shackle and vertical cylinder attached to a large concrete weight and also a piece of rod with a handle. The task consisted of removing the rod from the vertical cylinder, placing it through the two eyes of the shackle, releasing the rod, touching the

cylinder, then removing the rod from the shackle and finally replacing the rod back in the cylinder. The ROV operators felt that this task was a fair representation of the wide scope of their work with the manipulator arm.

By hand (in air) it was possible to complete the task in approximately four and a half seconds whereas the fastest time possible underwater with the manipulator arm was one and a half minutes.

The task was performed by four different operators under three different viewing conditions: (2Da) 2D using the ROVs standard video camera, 3D using the 3D video camera and (2Db) 2D using one of the images from the 3D video camera. It was only possible to perform a relatively low number of tasks because of the limited time available. Viewing condition 2Da was performed 6 times, 3D was performed 11 times and 2Db was performed 4 times.

An unfortunate difference between the 3D video camera and the 2D video camera was that they used different lenses and therefore had different fields of view. The 2D camera had a horizontal field of view of approximately 60 degrees whereas the 3D camera had a much wider field of view of approximately 90 degrees. This meant that there was a significant difference in the image quality between the 2D and 3D cameras. The image from the 2D camera appeared closer to the operator and therefore had more image detail than the image from the 3D camera. It should also be noted that the 3D and 2Db viewing conditions have half the vertical resolution of the 2Da viewing condition because of the field-sequential method used to encode the 3D video signal.

The three viewing conditions could therefore be considered as follows: 2D from the 2D camera (2Da) had good image quality but a lack of depth information, 3D from the 3D camera had low image quality but had good depth information and 2D from the 3D camera (2Db) had both a lack of depth information and low image quality (because of the wider field of view and also the halving in vertical resolution).

The mean for the three viewing conditions (across all the tasks performed) were 2Da: 2.3 minutes, 3D: 2.6 minutes, 2Db: 6.8 minutes. It should be noted that a direct comparison cannot be made between the 2Da and 3D viewing conditions because of the different camera fields of view used (60° for 2Da and 90° for 3D). What these results do indicate is the ability of 3D viewing to improve the usability of poor quality images. As one would expect, there was a large difference between 2D viewing with the high resolution image (lower field of view) (2Da) and 2D viewing with a low resolution image (2Db) (because of the wider field of view and halved vertical resolution). The results show that the 3D viewing of two low resolution images (equivalent to two 2Db images) produced task times almost as good as 2Da viewing for this particular task.

Ideally, this trial should have been performed with the same field of view lenses on both 2D and 3D cameras. This will be the subject of future studies. Based on the results of the laboratory trials, we anticipate that improved task performance will also be evident in the field.

It was not possible to assess learning effects in this trial because the test apparatus moved between tasks and therefore the task geometry kept on changing.

### 3.3 Subjective Assessments

Although the field time trial results by themselves do not provide any conclusive results on the advantages of using the stereoscopic video system in the field, subjective assessments did reveal benefits in the use of the stereoscopic video system.



**Figure 6:** The field trial test apparatus.

In several of the manipulator trial experiments, the operators could be seen to use a lot of trial and error when operating in 2D. When using 3D, the operators generally had more confidence in deciding where the manipulator had to be placed and at what orientation it had to be to complete the task.

All of the operators preferred the Tektronix Liquid Crystal Modulator and passive glasses to the StereoGraphics CrystalEyes Liquid Crystal Shutter Glasses. Although the CrystalEyes provided slightly lower ghosting, the passive glasses were much more comfortable to wear and they also allowed other non-3D monitors to be viewed without flicker interference problems. Looking at other monitors in the control room while wearing the CrystalEyes glasses was very annoying because of the flicker produced by the interference between the update frequency of the monitors and the switching frequency of the glasses.

All of the ROV operators who used the system during the field trials believed that the stereoscopic video system would be of advantage to ROV operations. They believed that it would be most useful with the manipulator arm, but also for general 'flying' of the ROV.

## **4. Discussion**

### **4.1 Benefits**

The general benefits of using stereoscopic video for teleoperation have been widely documented.<sup>3,4</sup> Most of these benefits are due to the increase in depth perception via stereoscopic vision. Depth is also perceived by a number of monoscopic cues such as perspective, relative size, shading and shadowing. However, in the underwater environment many of these cues are missing or reduced. The underwater environment is not structured like our usual environment where walls are vertical and floors are horizontal, a larger fish is not necessarily closer than a smaller fish, shading and shadows can be muted by murky water and lighting is not necessarily from above like the sun or lights in a room. These factors make the depth cue of stereoscopic vision even more important underwater than in normal everyday viewing.

Our study has observed the following benefits of using stereoscopic video on the Triton ROV.

- Object placement and alignment were easier. In both the laboratory and field trials, the operators noted that when operating in 3D they did not require the use of a range of special skills which they would normally use when operating in 2D. 2D viewing requires the operators to develop a range of special skills which they would not normally use in real world viewing. These skills include the use of shading and shadows, touch, and a lot of trial and error. In contrast, 3D viewing intuitively provides the operator with depth information, the same way he or she experiences depth in the real world.
- 3D allows the operator to see through sediment (fine particles) floating in the water. In 2D, this degrades the quality of the image, whereas in 3D, the brain is able to remove visual noise (suspended matter) from the stereoscopic image to see the true signal or background image.
- 3D provides the operator with a better knowledge of the work-site layout (WHERE things are) and also helps the operator identify unfamiliar or complex scenes (WHAT things are).

This was evident when the ROV was working around the platform structure which was covered in marine growth. In 2D the marine growth made it hard to distinguish the arrangement of members of the structure, whereas in 3D this arrangement was quite obvious. Unusual node arrangements were visible and sacrificial anodes were very prominent.

Operators also reported that navigation through the platform was easier because the arrangement of the platform structure could be seen more easily. This would presumably be a valuable advantage for inexperienced operators who are unfamiliar with the structure of the platform.

- Several of the operators also reported that they found operating with 3D less frustrating and less mentally tiring when using the manipulator arm. Frustration was reduced most likely because the operators used less trial and error. Mental fatigue was reduced probably because the operators spent less effort concentrating on the scene, trying to understand it (since the 3D system provides the operator with more information).

## 4.2 Drawbacks

The most obvious drawback is the increased cost of the stereoscopic video equipment. The stereoscopic camera and stereoscopic display are specialised equipment and therefore need to be specially procured.

There are also some image distortions associated with stereoscopic video. These distortions will depend upon the camera and display configurations used.<sup>5</sup> It was noticed by the operators that when approaching a stationary object at a constant velocity, the speed of approach would appear to increase as the ROV approached the object. This is a known effect of stereoscopic video and in this instance was also due to the wide angled lenses being used on the stereoscopic video camera. This effect can be reduced by the appropriate choice of camera parameters. We also expect that if the operator is made aware of this effect, problems will be reduced.

An unusual effect that some of the operators noticed was that if they moved their head from side to side while viewing the stereoscopic display, the image appeared to 'follow' them. In one particular situation, the operator had parked the ROV against part of the platform structure. When the operator moved his head, the image appeared to move and as a result the operator thought the ROV had moved when in fact it had not. This effect may or may not have any detrimental effects, but we expect that any problems will be reduced if the operator is made aware of the distortion.

Some of the operators reported that they sometimes had difficulty viewing the stereoscopic display when things came very close to the stereoscopic camera - the image appeared blurred or as double images. This is similar to the situation that occurs if one tries to look at something which is very close to the eyes. If something is placed too close to the stereoscopic camera, the stereoscopic display will attempt to reproduce the image very close to the observer's eyes and hence it will be difficult to view. This effect can be reduced by the appropriate choice of camera parameters (dependent upon the usual operating distance) or overcome simply by closing one eye or switching the display to 2D.

Eye strain is something we have been very careful to monitor and document in the field trials of the stereoscopic video system. Many people may be familiar with the eye fatigue and headache problems associated with the 3D movies of the 1950s. Many of the problems associated with these movies were due to the red/blue technique used to achieve 3D and also bad alignment of the 3D images. The 3D technology of today has evolved to a much more sophisticated level, however, eye fatigue and headaches can be a problem if good quality control and stereoscopic alignment are not maintained. In the field trials of the stereoscopic video system, the operators reported that they did not experience any headaches they would associate with using the system. Some of the operators experienced eye fatigue during initial use of the system, but this disappeared with subsequent use. We believe that eye fatigue can be reduced if good alignment of the stereoscopic images is maintained and appropriate camera parameters are chosen.

## 5. Conclusion

We believe that the benefits of using stereoscopic video for the operation of underwater remotely operated vehicles far outweigh the disadvantages. Our results to date indicate that stereoscopic video will be a valuable tool in the operation of ROVs in the underwater environment.

## 6. Acknowledgments

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