THE APPLICATION OF STEREOSCOPIC VIDEO TO UNDERWATER REMOTELY OPERATED VEHICLES

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ABSTRACT

A Stereoscopic Video System for use with Underwater Remotely Operated Vehicles (ROVs) has been developed by Curtin University's Centre for Marine Science and Technology. The system provides ROV operators with a fully three-dimensional (stereoscopic) view of the ROVs surroundings. This increased perception of depth offers several advantages to both the piloting of ROVs and also to the operation of an ROV manipulator arm.

The stereoscopic video system consists of an underwater stereoscopic video camera which fits on the ROV and a stereoscopic display which is installed in the ship-based ROV control room. The system was developed in close cooperation with Woodside Offshore Petroleum who have used the system on their Triton ROV. Three ROVs are currently operated at Woodside's oil fields on Western Australia's North West Shelf.

Field use of the system on the Triton ROV has revealed many advantages of stereoscopic video. One of the areas where advantages are particularly evident is in the operation of the manipulator arm. Operators have reported that it is perceptually easier to perform manipulator tasks. This is because the spatial relationship of objects can be immediately identified, making object placement and alignment easier. The system also provides a better understanding of the work site and a perceived improvement in image quality and therefore improved visibility.

INTRODUCTION

Underwater Remotely Operated Vehicles (ROVs) are being increasingly used in the offshore oil and gas industry. ROVs can be used to perform a wide range of inspection and manipulation tasks. The ROV's actions are monitored by the use of video cameras mounted to the vehicle and television monitors installed in the ROV control room. Unfortunately, a conventional ROVs video system and manipulator arm combination are no replacement for the fidelity and the dexterity of human eyes and hands - one main reason for this is the lack of depth perception.

DEPTH PERCEPTION

A person perceives depth in the world around us using several different visual cues. Several of these cues are: perspective, shading, shadowing, familiar size and interposition. The strongest cue by which a person perceives depth is the principal of stereoscopic or binocular vision.

A person's stereoscopic vision is a direct result of the fact that the two human eyes each obtain a slightly different perspective view of the world. The difference between the left eye view and the right eye view is called a perspective difference. The brain processes the slight differences between these two views and thereby the person is able to perceive the world in depth.

Unfortunately, conventional television does not reproduce the effect of stereoscopic vision to the observer. A normal video camera only captures a single view and at the display, both eyes see the same single image. As a result only a two-dimensional or flat image is seen. A stereoscopic video system is designed to reproduce full depth perception to the viewer. The stereoscopic camera acquires a left and right perspective image and the display presents the left images to the observer's left eye and the right image to the observer's right eye. The operator then sees a fully three-dimensional image which dramatically improves the perception of depth, perspective and distance.

In the underwater environment many of the other depth cues mentioned earlier are reduced or eliminated because of the unusual lighting, suspended matter in the water or simply because the environment is totally unfamiliar and doesn't provide the usual references we are used to in our usual terrestrial world - eg. a bigger column may not be closer to the camera than a narrow column. As a result, the depth cue of stereoscopic vision can be even more valuable in the underwater environment.

STEREOSCOPIC VIDEO

Stereoscopic video is the process by which video technology is used to capture and display three dimensional images. At the Centre for Marine Science and Technology at Curtin University, we have developed a stereoscopic video system for use with underwater ROVs. The system consists of a compact underwater stereoscopic video camera which is mounted on the ROV and a stereoscopic display which is installed in the ROV control room.

The camera

The compact underwater stereoscopic video camera (Figure 1) consists of two video cameras mounted side-by-side in an underwater housing. The camera's size is

110mm ϕ x 240mm which is approximately the same size as conventional underwater video cameras. The camera is fitted with 7mm auto-iris fixed focal length and fixed focus lenses. The camera in installed on the ROV in the same manner as conventional underwater video cameras. Only one of the ROVs existing video channels is needed to transfer the stereoscopic video signal to the surface based control room for display on the stereoscopic display.

An important feature of the video camera is that it only outputs a single video signal and therefore only requires a single video channel between the ROV and the surface. The camera combines the two perspective (left and right) views into a single video signal using a process called multiplexing. A PAL video signal (as used in Australia and Europe) displays 50 discrete images per second. The camera stores left and right images onto alternate images of the video signal so that 25 images per second are from the left camera and the other 25 images per second are from the right camera - in a left, right alternating sequence. This signal can also be recorded with a video recorder for later playback in full 3D.

One of the other features of the camera is that it can be switched to operate as a standard 2D video camera if needed. This can be useful if the video signal is to be recorded for later display on a non-3D display.

The camera also contains special image alignment optics to provide a converged stereoscopic view in such a way that image distortions are reduced (Woods, 1993). Image alignment is a very important principle in the use of stereoscopic video and close attention has been made to this aspect in the design of this camera.

The display

In the ROV control room, the stereoscopic video signal from the stereoscopic video camera is fed into the stereoscopic display (Figure 2). The display system consists of a stereoscopic converter unit and a video monitor. The stereoscopic converter receives the 3D video signal from the stereoscopic video camera and outputs it to the video monitor at twice the original rate. This means that the video signal from the camera (at 50 images per second - 50Hz) is displayed on the screen at a rate of 100 images per second (100Hz). The higher display rate means that the stereoscopic images will be seen without flicker - if a normal 50Hz display is used, significant flicker would be evident.

The observer wears a special pair of polarised 3D glasses which allow the observer's left eye to only see the left images and the observer's right eye to only see the right images. The observer will see the underwater images in full-colour flicker-free 3D.

It should be noted that the system is also compatible with the NTSC video standard (as used in North America) for which the base 60Hz image rate is displayed at 120Hz.

Figure 1: The compact underwater stereoscopic video camera.

FIELD USE

The Stereoscopic Video System has been developed in close cooperation with Woodside Offshore Petroleum. The system has been used in the field by Woodside on a Perry Tritech Inc. "Triton" ROV. The ROV is operated around Woodside's North Rankin and Goodwyn gas production platforms. These platforms are located 140km off the coast of Karratha in Western Australia's North West Shelf region (Figure 3). The Triton ROV is fitted with a Schilling manipulator arm which is used to perform a wide range of manipulative tasks. The stereoscopic video system has been used in a wide range of operational conditions and a range of field experiments have also been performed to assess the performance of the stereoscopic video system on the ROV (Woods et al, 1994).

BENEFITS OF STEREOSCOPIC VIDEO

Stereoscopic Video offers many benefits to the operation of ROVs - the most obvious being the increase in depth perception. Our research has observed the following benefits of stereoscopic video when used on underwater ROVs:

- Object placement and alignment are easier, particularly when using the manipulator arm. When using conventional video, the operator needs to learn a range of special skills to overcome the lack of depth information (eg. touch and feel, trial and error). These special skills would not normally be needed in real world viewing. When operating in 3D, these special skills are not required because stereoscopic video intuitively provides the operator with depth information the same way that he or she experiences depth in the real world.
- 3D can allow the operator to see through suspended matter (fine particles) in the water.
  If the particles are small, the suspended matter acts as noise in the image and acts to mask or mute the background image. In a quite remarkable process, the brain is able to correlate the images from the two eyes to remove noise to see the true signal or background image. This results in a perceived improvement in image quality and therefore improved visibility. The

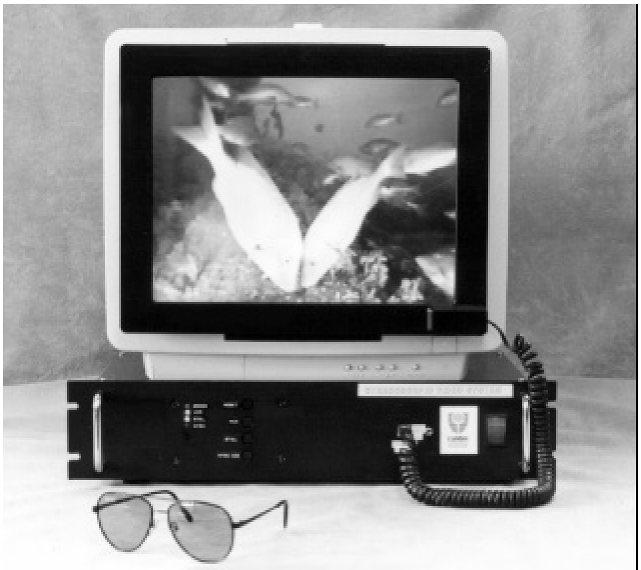

Figure 2: The stereoscopic display

perceived improvement in signal to noise ratio has been measured at about 3dB (Pastoor and Schenke, 1989). Even though the system does not physically improve the image quality, the process of viewing the images in stereo makes the images look like they are of a higher quality.

If the particles are large, that part of the background image which a particle obscures for one eye can probably be seen by the other eye. In effect the observer can see around the particles.

- 3D viewing provides the operator with a better knowledge of the work-site layout - WHERE things are - and it also helps the operator identify unfamiliar or complex scenes - WHAT things are. In the underwater environment marine growth can cover parts of the production platform structure. This marine growth can make it very hard to distinguish the arrangement and shape of members of the structure. Stereoscopic video can make this arrangement quite obvious.

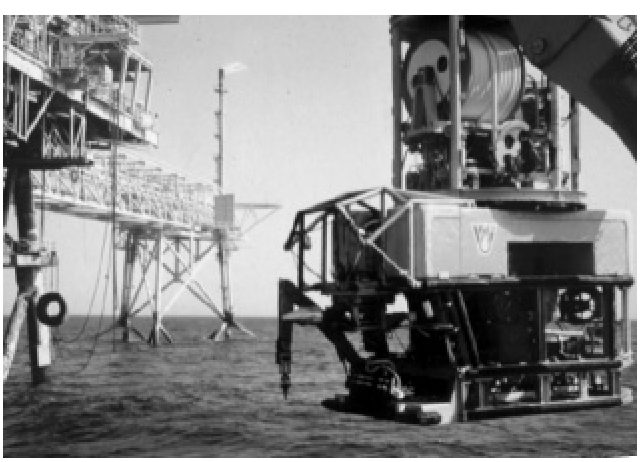

Figure 3: The Triton ROV fitted with the stereoscopic video system at the North Rankin Platform

- Several ROV operators have reported that they found working with 3D less frustrating and less mentally tiring. Frustration is most likely reduced because the operators use less trial and error. Mental fatigue is reduced probably because the operators spend less effort concentrating on the scene trying to understand it.

Our experience to date indicates that the use of stereoscopic video (3D viewing) will improve task performance and reduce task time when compared with conventional video (2D viewing). The amount of improvement will depend upon a range of factors, including how depth-dependent the particular task is. Tasks which involve the use of a manipulator arm will generally be highly depth dependant and it is in this area that most improvements are generally experienced.

DRAWBACKS

There are some drawbacks associated with the use of stereoscopic video. The most obvious drawback is the increased cost of the equipment. The stereoscopic camera and stereoscopic display are specialised equipment and need to be specially procured. The stereoscopic video system we have developed is, however, compatible with all of the existing video equipment of the ROV and ship based control room (umbilical cable, video routing and video recorders). The amount of specialised equipment is therefore kept to a minimum.

There are some image distortions associated with stereoscopic video. These distortions will depend upon the camera and display configurations used (Woods et al, 1993). The compact underwater stereoscopic video camera has been designed to eliminate a number of distortions which can be present - such as keystone distortion and depth plane curvature (Woods et al, 1993). Non-linearity of distance is however still present. This can be noticed when an ROV is approaching a stationary object at a constant velocity. Non-linearity of distance causes the speed of approach to appear to increase as the ROV comes close to the object. This is a problem with absolute depth perception as opposed to that of relative depth perception which is what is used when for example controlling the manipulator arm. The operator should be made aware of this effect to reduce the likelihood of any problems.

A rather strange effect which has been noticed is that if the observer moves from side to side while looking at the stereoscopic display, the image will appear to `follow' the observer. In one particular example, 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, however, if the operator is made aware of this effect, any possible problems should be reduced.

Objects which are too close to the stereoscopic camera may appear blurred or as double images. This is similar to what happens when you look at something which is too close to your own eyes. If something is positioned very close to the stereoscopic camera, the stereoscopic display attempts to reproduce the image very close to the observer's eyes and similarly this be difficult to view. This effect can be overcome by closing one eye or by switching the display to 2D when things come too close to the stereoscopic camera.

Eye strain is something that we have been very careful to monitor and document in the field use of the stereoscopic video system. Many people may be aware of the eye fatigue and headache problems associated with the 3D movies of the 1950s era. Much of the problems were due to the bad alignment of the stereoscopic images. The stereoscopy and 3D of today has evolved to a much more sophisticated level. Needless to say, eye fatigue and headaches can still be a problem if good quality control and stereoscopic alignment are not maintained. In our field trials of the stereoscopic video system, operators reported that they did not experience any headaches they would associate with using the system. Some people have reported eye fatigue especially when the system is badly aligned, however, we believe that eye fatigue can be reduced if good alignment is maintained and appropriate camera parameters are chosen.

CONCLUSION

Our research and studies show that stereoscopic video offers many benefits to the operation of ROVs. The benefits appear to far outweigh the disadvantages.

Operators have reported that the stereoscopic video system is of most use when performing manipulator tasks - a task which requires high accuracy and is highly (3D) depth dependant. Experience has shown that stereoscopic video is also useful when flying and navigating the ROV.

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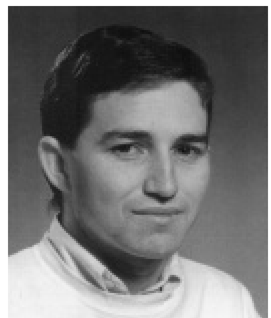

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