The development of a compact underwater stereoscopic video camera

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ABSTRACT

This paper describes the development of a compact underwater stereoscopic video camera. The camera was specifically developed for use on Underwater Remotely Operated Vehicles (ROVs) which are operated extensively in the offshore oil and gas industry. The camera has been used at the oil and gas fields operated by Woodside Offshore Petroleum off the north-west coast of Western Australia. The camera is 11cm in diameter, 24cm long and weighs just under four kilograms. The camera housing contains a pair of miniature video cameras and an internal 3D multiplexer which generates the single video output signal (in the field- sequential 3D video format). Since the camera outputs a single video signal (although in 3D), it can be easily interfaced with an underwater ROV's existing video system. The 3D video signal is transmitted to the surface by a single video channel where it is viewed on a stereoscopic display installed in the ship-based control room. The camera provides several improvements over the first underwater stereoscopic video camera developed by the Centre in 1991. One of the notable improvements is the camera's reduced size, which offers a number of operational benefits. The optics of the camera have also been improved by using parallel camera axes to eliminate keystone distortion and depth plane curvature.

Keywords: stereoscopic, video, camera, underwater, teleoperation, ROV, three-dimensional.

1. INTRODUCTION

Underwater Remotely Operated Vehicles (ROVs) are commonly used in the offshore oil and gas industry. They are often employed in preference to using divers and perform a range of inspection, manipulation and maintenance tasks on the underwater structures of production platforms, subsea well heads and underwater pipelines. ROVs are usually fitted with several conventional (monoscopic or 2D) video cameras whose images are displayed on television monitors in the ship based ROV control room. Woodside Offshore Petroleum operates three ROVs at their two gas production platforms located off the north-west coast of Western Australia.

2. DESIGN BACKGROUND

In 1991, Curtin University's Centre for Marine Science and Technology developed a stereoscopic video system for use with underwater ROVs [1,2] - in particular the 'Triton' ROV operated by Woodside Offshore Petroleum (Figure 1). The system consists of an underwater stereoscopic video camera which is installed on the ROV and a stereoscopic display which is installed in the ROV control room (see Figures 2 and 3). The underwater stereoscopic video camera acquires the left and right perspective images needed to produce a stereoscopic image. The camera

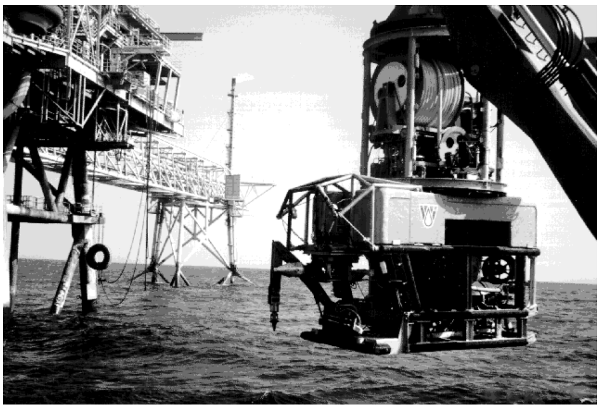

Figure 1: The Triton ROV fitted with the Stereoscopic Video System at Woodside's North Rankin 'A' platform.

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outputs a single 3D video signal which is transmitted to the surface by a single video channel. In the ROV control room, the operators wear light-weight polarised 3D glasses to view the stereoscopic display which provides a real-time, full-colour, flicker-free, stereoscopic image. The system was found to offer many benefits in the operation of the ‘Triton’ ROV [2].

Figure 2: The original underwater stereoscopic video camera

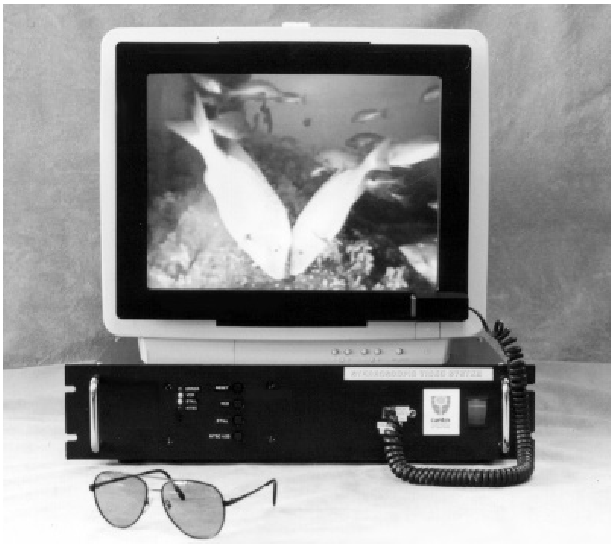

Figure 3: The stereoscopic display

While the system provided many advantages, one main disadvantage of the system was the large size of the underwater stereoscopic video camera - both in terms of volume and mass. The camera weighed an impressive 22kg and had external dimensions of 22.5cmf x 33cm. This was approximately 8 times the volume of the conventional (2D) cameras used on the `Triton’ ROV. Although the large size did not affect the quality of the stereoscopic images generated by the camera, it did cause problems in the operational use of the camera on the front of the ‘Triton’ ROV. The main camera on the ‘Triton’ is usually fitted on a pan and tilt unit to allow the camera to be directed to any desired viewing direction. The large size of the stereoscopic camera meant that it required a considerably larger operational volume on the front of the vehicle. As the pan and tilt unit moves the camera to the desired viewing direction, the camera must not collide with any other apparatus on the front of the ROV. This placed limitations on what other equipment could be fitted to the front of the ROV - suction arms, an second manipulator arm, other video cameras, docking apparatus, etc. This meant that the camera could not be left on the vehicle at all times due to the over-riding need to fit these other pieces of equipment to the ROV at various times.

There is also a considerable disincentive to continually remove and re-fit the stereoscopic video camera. It can take 15 minutes to bring the ROV from operational use in the water to a secured position on the deck of the ship. It may then take another 20 minutes to fit the camera and change any other equipment and finally another 15 minutes to re-launch the ROV and position it to its previous location. It is unlikely that the ROV operators could afford to spend 50 minutes to change over a video camera.

The large mass and moments of the camera also imposed excessive torque requirements on the pan and tilt mechanism. Therefore requiring a more powerful pan and tilt mechanism or leading to rapid wear on the existing mechanism.

The design imperative was therefore to develop a much smaller underwater stereoscopic video camera - A camera which could be left on the vehicle at all times and could function either as a conventional (2D) video camera or as a stereoscopic video camera.

3. THE NEW CAMERA

Development was recently completed on the new compact underwater stereoscopic video camera (see Figure 4). The new camera is considerably smaller than the original camera, with external dimensions of 11cmf x 24cm. The new camera is also considerably lighter than the original camera weighing just less than four kilograms. The primary source of the size reduction is the use of a pair of miniature video cameras - the Sony XC999. The cameras are genlocked and a 3D multiplexer within the underwater housing combines the video signal from the two cameras to generate a field-sequential 3D video signal. The light sensitivity of the camera is 4.5 lux with real-time update.

The new camera is again a single housing design - as opposed to the use of two separate camera housings mounted together. Although this means that the stereoscopic video camera must be specially manufactured, a single housing design means that the camera can be much smaller, camera alignment is much easier to control and maintain and expensive underwater cabling is minimised. With separate cameras there is more opportunity for camera misalignment to occur and size differences may also exist between the images from the two cameras. The internal 3D multiplexer also removes the need to install extra electronics within the electronics bottles of the ROV. The single housing design also means that the camera can be treated and installed just like any of the other cameras - A single conventional cable connects to the camera housing and outputs only a single video signal.

Figure 4: The new compact underwater stereoscopic video camera

In addition to the reduced size of the camera, several other operational improvements were implemented - the camera can be easily switched between 2D and 3D modes and the parallel camera configuration was implemented to reduce image distortions. If the operators desire a 2D video signal, they do not need to remove the camera or switch to another camera. Another benefit of the 2D/3D mode switch is that if for any reason one of the cameras fails to work (possibly due to sediment adhering to one of the camera lenses), the stereoscopic camera can still be used in 2D mode with the other camera in the housing. There is no immediate need to bring the camera to the surface for maintenance - so called "twin engine reliability" [3].

The parallel camera configuration involves the mounting of the camera lenses with parallel optical axes. Convergence is achieved by offsetting the Camera CCDs (imaging sensors) relative to the lens. This configuration avoids the problems of keystone distortion and depth plane curvature [4].

Figure 5 illustrates the difference between using the parallel camera configuration and the toed-in camera configuration for the parameters of the new camera (t=45mm, f=7mm, C=800mm, Wc=6.4mm, Ws=296mm, V=800mm, e=65mm). Figures 5(a) and (b) illustrate how object space is displayed to the observer on the stereoscopic display. Each grid represents a 100mm square in object space. It can be seen that there is significant curvature of the depth planes in the toed-in camera configuration, however, there is no depth plane curvature in the parallel camera configuration. Figures 5(c) and (d) illustrate the image which will be displayed on the stereoscopic display if a grid is placed at the convergence distance of the cameras. Figure 5(d) shows the a moderate amount of keystone distortion would be present if the toed-in camera configuration were used - if displayed on a 16" display monitor, approximately 3mm of vertical parallax would be present in the corners of the screen. In contrast, the parallel camera configuration does not exhibit any keystone distortion (Figure 5(c)). Further information about these diagrams in contained in Reference 4.

In order to allow the camera to be configured in the parallel camera configuration, it was necessary to mount each lens and CCD in an accurately adjustable jig. The level of adjustment provided by this arrangement significantly simplifies the task of obtaining accurate stereoscopic camera alignment. Once the camera internals are mounted within the underwater housing it is not possible to adjust the alignment. However, all degrees of freedom are locked using locking screws to prevent the camera going out of alignment while it is in service.

Other details of the camera are that the inter-lens separation is 45mm and it uses 7mm focal length auto-iris fixed-focus lenses (on a 1/2" CCD). The value of convergence currently used for the 'Triton' ROV is 800mm, however, this value is user adjustable at the time of alignment. The relatively close separation of the two camera lenses (as compared to normal human eye separation - 65mm) is often commented upon. Apart from the fact that the reduced camera separation allows a reduced camera size, the reduced separation also reduces the depth range of images displayed on the stereoscopic monitor. To avoid making stereoscopic images too difficult to view, it is necessary to limit the amount of image parallax displayed on the screen (reduce the depth range). This is due to a property of stereoscopic displays called the accommodation vergence conflict [4]. The chosen lens separation value of 45mm does produce some image distortion (depth non-linearity) (see Figure 5(a)) however this is a necessary compromise to produce stereoscopic images which are not too difficult to view [4].

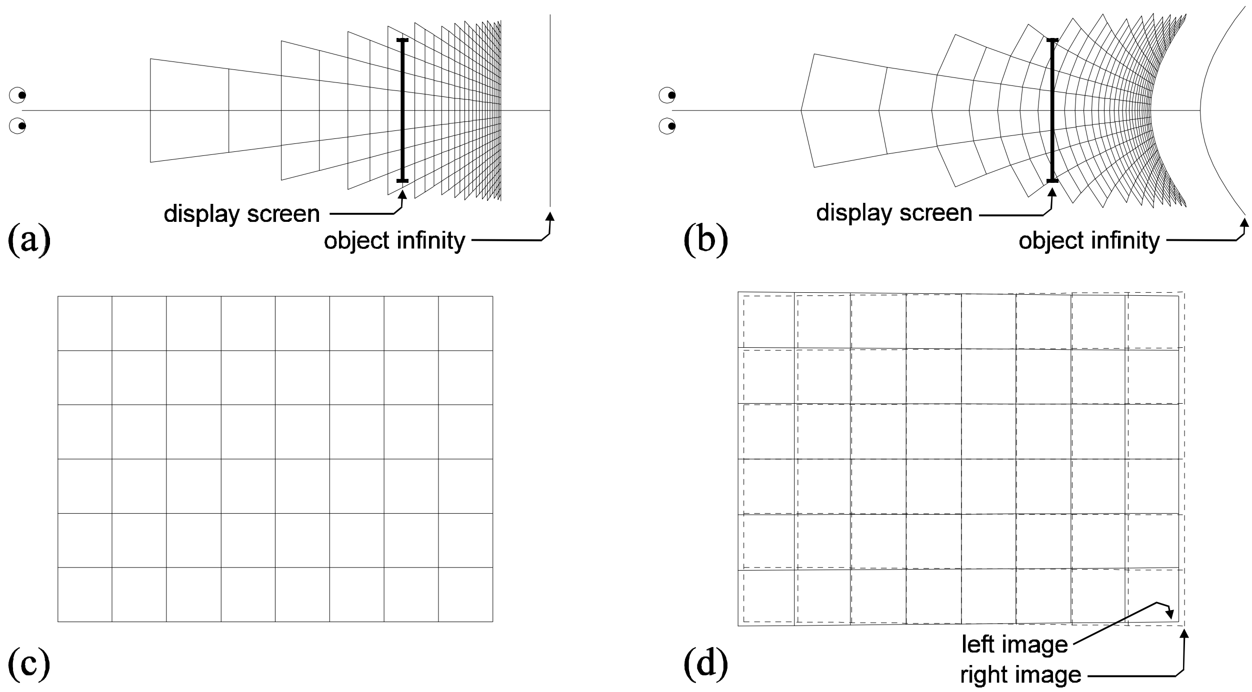

Figure 5: Illustration of the difference between the parallel camera configuration and the toed-in (converged) camera configuration. (a) 3Dmap of parallel cameras and (b) toed-in cameras. (c) keystone distortion of parallel cameras and (d) toed-in cameras.

4. CONCLUSION

In operational use, the camera has performed well. The reduction in the camera's size certainly simplifies its use. Task performance field trials are yet to be performed on the camera, however, from subjective assessments, task performance improvements are anticipated.

5. ACKNOWLEDGMENTS

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