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14. ABSTRACT

The paper provides an overview of a Hybrid Underwater Camera (HUC) system combining sonar with a range-gated laser camera system. The sonar is the BlueView P900-45, operating at 900kHz with a field of view of 45 degrees and ranging capability of 60m. The range-gated laser camera system is based on the third generation LUCIE (Laser Underwater Camera Image Enhancer) sensor originally developed by the Defence Research and Development Canada. LUCIE uses an eye-safe laser generating 1ns pulses at a wavelength of 532nm and at the rate of 25kHz. An intensified CCD camera operates with a gating mechanism synchronized with the laser pulse. The gate opens to let the camera capture photons from a given range of interest and can be set from a minimum delay of 5ns with increments of 200ps. The output of the sensor is a 30Hz video signal. Automatic ranging is achieved using a sonar altimeter. The BlueView sonar and LUCIE sensors are integrated with an underwater computer that controls the sensors parameters and displays the real-time data for the sonar and the laser camera. As an initial step for data integration, graphics overlays representing the laser camera field-of-view along with the gate position and width are overlaid on the sonar display. The HUC system can be manually handled by a diver and can also be controlled from a surface vessel through an umbilical cord. Recent test data obtained from the HUC system operated in a controlled underwater environment will be presented along with measured performance characteristics.

15. SUBJECT TERMS

sonar, laser range-gated camera, underwater imaging, turbidity

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Overview of a Hybrid Underwater Camera System

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ABSTRACT

The paper provides an overview of a Hybrid Underwater Camera (HUC) system combining sonar with a range-gated laser camera system. The sonar is the BlueView P900-45, operating at 900kHz with a field of view of 45 degrees and ranging capability of 60m. The range-gated laser camera system is based on the third generation LUCIE (Laser Underwater Camera Image Enhancer) sensor originally developed by the Defence Research and Development Canada. LUCIE uses an eye-safe laser generating 1ns pulses at a wavelength of 532nm and at the rate of 25kHz. An intensified CCD camera operates with a gating mechanism synchronized with the laser pulse. The gate opens to let the camera capture photons from a given range of interest and can be set from a minimum delay of 5ns with increments of 200ps. The output of the sensor is a 30Hz video signal. Automatic ranging is achieved using a sonar altimeter. The BlueView sonar and LUCIE sensors are integrated with an underwater computer that controls the sensors parameters and displays the real-time data for the sonar and the laser camera. As an initial step for data integration, graphics overlays representing the laser camera field-of-view along with the gate position and width are overlaid on the sonar display. The HUC system can be manually handled by a diver and can also be controlled from a surface vessel through an umbilical cord. Recent test data obtained from the HUC system operated in a controlled underwater environment will be presented along with measured performance characteristics.

Keywords: Sonar, Laser Range-gated camera, Underwater imaging, Turbidity.

1. INTRODUCTION

Diver visibility is one of the key R&D issues in underwater sensing. It relates to inspection, search and rescue, and identification in both civilian and military applications. Electro-Optical (EO) types of sensors are known to have higher fidelity in details, with better resolution and textural information of the object under examination. But this approach often suffers from limited range due to particle and turbulence scattering [1, 2]. The acoustical imaging often provides longer reach, trading resolution in the process. It would be ideal to incorporate the best of both worlds into one seamlessly integrated system, with shared field of view (FOV). This paper describes an innovative Hybrid Underwater Camera (HUC) system integrating a 2D BlueView sonar and an underwater range-gated laser camera sensor. The Laser Underwater Camera Image Enhancer (LUCIE) was originally developed by Defence Research and Development Canada organization and evolved over three developmental generations [3, 4]. Neptec Technologies Corp (NTC) acquired the commercialization rights of LUCIE III, the latest generation and most compact version. The BlueView sonar P900-45 is well-established 2D sonar and operates at 900kHz over a field of view of 45 degrees. The HUC is the first such system in existence and attempts to combine vision obtained from sonar with the extended water propagation benefits of a laser range-gated intensified camera.

The HUC system was assembled and tested in early 2014. The major components of the system will be described along with test data and performance evaluation.

2. HUC SYSTEM OVERVIEW

This section presents the HUC overall system. Its two major components are the sonar and range-gated camera. Figure 1(a) presents a high-level HUC system diagram and Figure 1(b) shows a representation of the system once integrated. The main system components are described in the following subsections.

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2.1 Laser Range-Gated Camera

The general principle of laser range-gated camera is illustrated on Figure 2(a). A laser emitting a short pulse of light is synchronized with an intensified camera. A gating mechanism blocks the light arriving at the camera and will only open to capture the reflected light pulse corresponding to a pre-determined range of interest. This prevents the capture of backscattered light by the camera that does not carry any information from the range of interest and therefore contributes to increased noise and loss of contrast. In previous trials, LUCIE has demonstrated imaging capabilities in excess of 3 times the range of visible camera with lights. Experimental data is shown in Figure 2(b), where LUCIE is compared to a standard TV camera with 500W lights, and also the underwater intensified SIT camera, for open ocean water conditions. At night or in deep shadows where a diver would have to carry lights, the increase in range from the use of a range-gated camera in similar conditions will be improved by a factor of 3 to 5 [4].

Figure 3(a) shows a representation of the LUCIE system and Figure 3(b) identifies the main system components. LUCIE uses a 600mW average power 532nm pulsed laser that can generate up to 25,000 pulses per second. The pulse duration is 1ns. The instrument is Class 1 eye-safe and can be operated without any danger to nearby divers. A gated Gen III intensified camera is synchronized with the laser pulse emission. The gate delay setting can vary from a minimum of 3ns and up to a maximum of 512 ns (i.e. a target range of almost 60 meters), in increments of 200ps. The camera is also equipped with 6:1 motorized zoom lens. A precision miniature attitude, heading reference system (AHRS) provides attitude and heading data. The gate is initially set using a 600kHz sonar altimeter. The sonar determines the range to an object/area of interest which in turns determines the gate setting to capture images coming from that object. LUCIE can also operate in 4 distinct polarization modes: linear horizontal and vertical and circular clockwise and counter clockwise. The sensor is powered with a Lithium-Iron battery pack that can provide up to 90 minutes of operation. The sensor interfaces with an underwater computer through a USB link.

2.2 BlueView Sonar

The P900-45 sonar made by BlueView is a 2D sonar that operates with 256 beams over a 45° field of view. The size of each beam is 1° horizontal by 20° vertical and they are spaced by 0.18°. The sonar optimal range is within 60m and it has a theoretical range resolution of 2.5cm.

2.3 SharkMarine Navigator Underwater Computer

The LUCIE camera and P900 sonar are integrated with the SharkMarine "Navigator" underwater computer platform. The Navigator has its own battery and can be operational for up to six hours. The user's interface is done through two thumb controls, emulating the functions of a mouse, along with a 6.7 inch diagonal 1024 by 768 pixels display. The computer runs the P900 sonar and LUCIE sensor control applications. In addition to the sonar and LUCIE independent data displays, the outline of the LUCIE field-of-view along with the gate position and width can be overlaid on the sonar data, providing added situational awareness for the operator.

2.4 Integrated System

The P900 sonar and LUCIE range-gated camera are mechanically integrated with the Navigator; the sonar communicates through an Ethernet link and the camera through a USB link. Figure 1(b) shows a representation of the fully integrated HUC system. As part of the HUC system, the Navigator display is also transmitted to a monocular display installed on a diver's helmet. An Ethernet link also connects the Navigator to a surface vessel computer that can be used to control the sensors and display the collected data. This configuration is especially useful for situations where the HUC system is installed on a remotely operated vehicle (ROV) and controlled from a surface vessel.

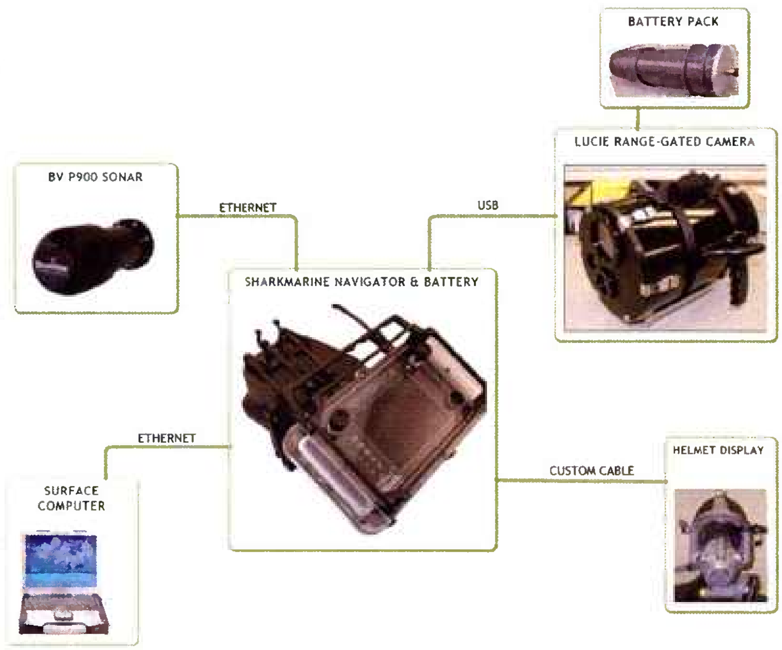


Figure 1. (a) HUC system diagram representation.

(b) Representation of the integrated HUC

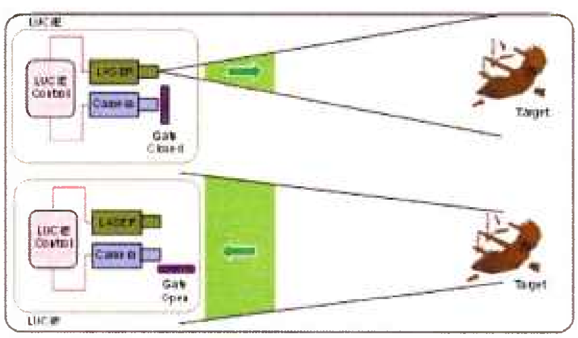
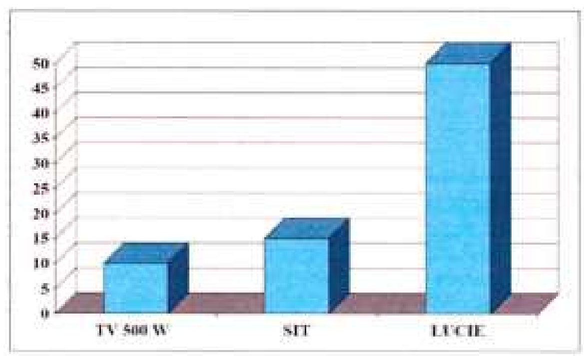


Figure 2. (a) Operating principle of laser range-gated camera.



(b) Comparative water penetration capability.

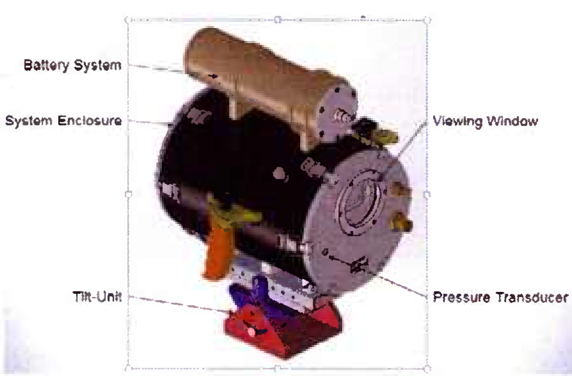
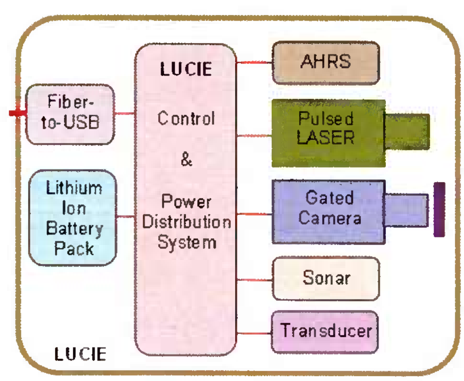


Figure 3. (a) Representation of the LUCIE range-gated camera.



(b) LUCIE sub-systems

3. HUC TESTS

3.1 LUCIE Qualitative Evaluation

Figure 4 shows a front view of the LUCIE sensor; the laser pulses are emitted through the window at the bottom while the upper larger window captures the laser light returns. The very small window on the left side corresponds to the LUCIE sonar that is used to measure the distance to a target of interest. The distance information is then used to set the gate accordingly. The right side of Figure 4 shows a preliminary test performed in a low visibility outdoor pool. A latticed chair is used as target, shown in the top portion of the figure. The bottom left image shows an attempt to image the chair with high quality underwater camera through the water column, showing the contrast limit. The middle bottom image shows a LUCIE image of the chair with a gate time setting selected to view the frame of chair. The right bottom image shows a LUCIE image obtained with the gate time setting selected to view the lattice of the chair.

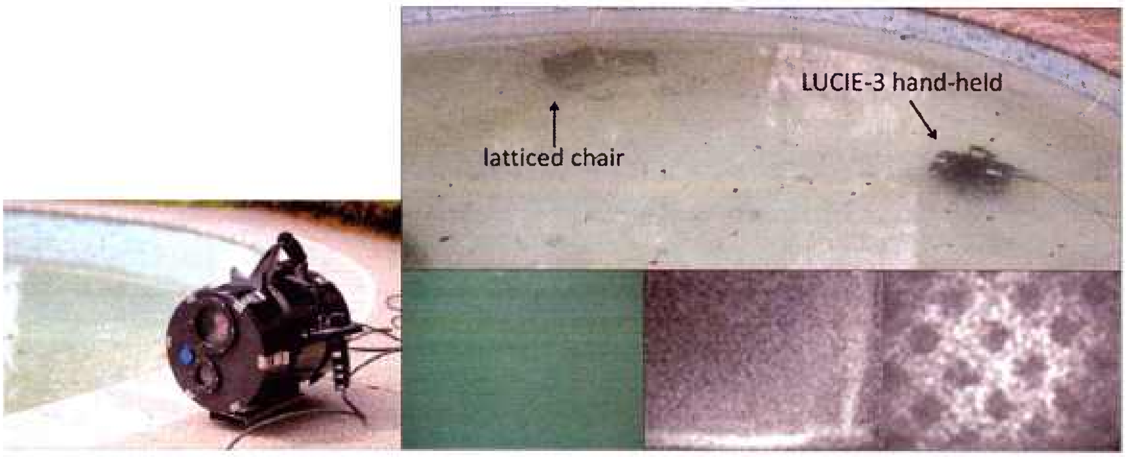


Figure 4. Left picture shows the LUCIE sensor front view.

3.2 HUC Controlled Tests

The HUC system was also tested in a controlled environment at the Ocean, Coastal and River Engineering facility of the National Research Council Canada (NRCC). The facility is equipped with a large scale wave flume, shown on Figure 5(a), measuring 318 feet in length, 6.5 feet in width with a maximum depth of 8 feet. Pumps are used to generate a current in the flume. The water holds particulate matter that is being stirred up by the current; turbidity can be controlled by adjusting the water current intensity.

Figure 5(b) shows the test setup. The HUC system is installed on cinder blocks at the bottom of the flume and secured with straps to prevent it from being toppled by the current. A target board, shown in Figure 6(a), is attached to a gantry and can be moved at precise distances away from the HUC. A turbidity meter (Analite 160) is also installed near the HUC and measures the turbidity level once per minute. Figure 6(b) shows the LUCIE range-gated system submerged in the flume and illuminating the target board.

Besides testing the major functions of the HUC system, one of the primary test objectives is to measure the number of beam attenuation lengths that LUCIE can reach to image a given target. This measurement requires an independent estimate of the water attenuation coefficient. Secchi disks were used for that purpose. The Secchi disk distance, Z_{sd}, is defined as the distance at which the disk disappears. Hou has provided an elaborate derivation on how Z_{sd} can be related to the photopic attenuation coefficient 'c_p' and the details can be found in [5]. Diver visibility depends on the photopic beam attenuation coefficient, which is the attenuation of the natural light spectrum convolved with the spectral responsivity of the human eye. In summary, for the case where Z_{sd} is measured horizontally (the visibility range in the horizontal direction), 'c_p' can be expressed as:

$$c_p \cong \frac{4.8}{z_{sd}} \quad (1)$$

In practice, it is common to measure the beam attenuation coefficient 'c' at a particular wavelength. Zaneveld has shown that the photopic beam attenuation coefficient 'c_p' is well approximated by the monochromatic beam attenuation 'c' measured at 532nm, near the peak of the human eye sensitivity [6].

Most of the LUCIE imaging measurements were obtained with Z_{sd} of the order of 4.1m. However, because of continuous on-going current in the flume, the turbidity can vary slightly from one set of measurements to the next. In order to get a more precise estimate of the beam attenuation coefficient at the time of a given image acquisition, several measurements of Z_{sd} were acquired at different turbidity levels and used to calibrate the turbidity meter, which provides its measurement in NTU units. The turbidity sensor will give a rough measurement of beam attenuation but will not provide a measurement of the absorption coefficient, which is an important factor in determining image quality. Figure 7 shows the results of such calibration, valid over the range of experienced turbidities and expressed as:

$$c = 0.87 * Turbidity\ value\ (NTU) + 0.2 \quad (2)$$

Figure 8 shows the results of the target imaging obtained at distances of 3m, 5m and 6m relative to the HUC, respectively. Table 1 shows for every distance setting, the measured values of the attenuation coefficient c, and the corresponding beam attenuation lengths (AL). At 6m, the target gross chequer board details can still be seen and this corresponds to an attenuation length of 6.8.

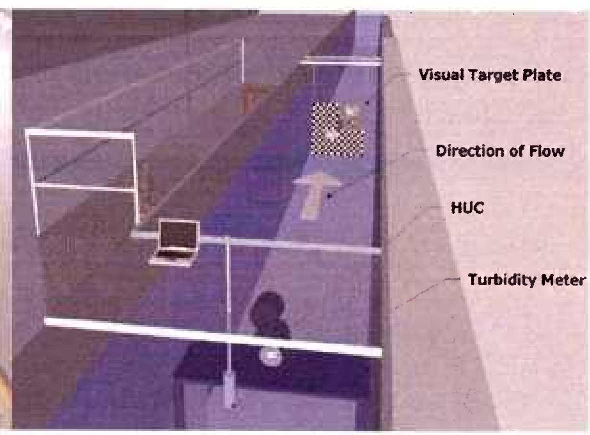


Figure 5. (a) NRCC large scale flume. (b) Test setup

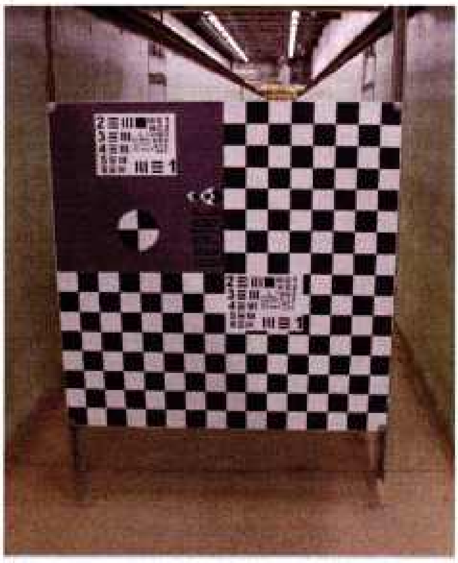
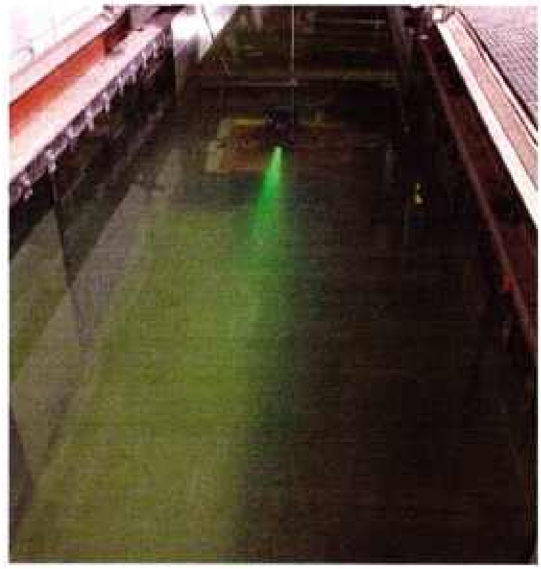


Figure 6. (a) Target board used for the tests.



(b) LUCIE submerged in the flume imaging the test board

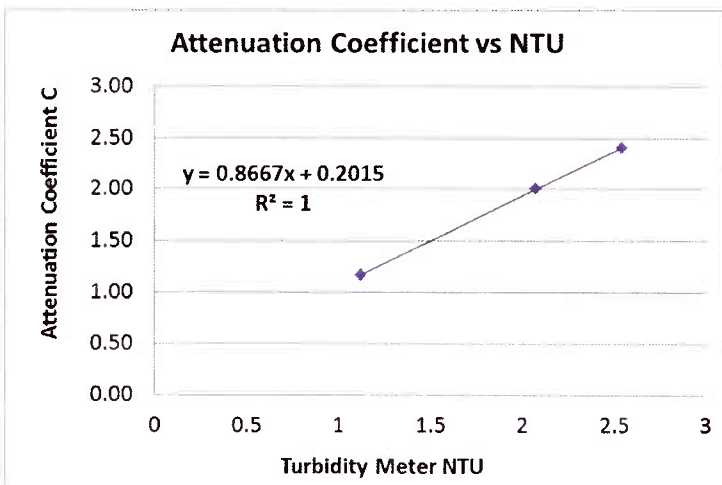


Figure 7. Calibration of the turbidity meter

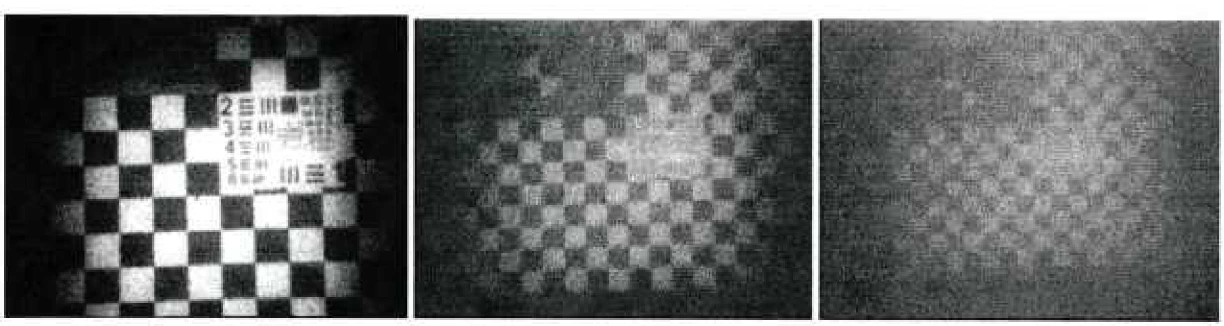


Figure 8. Starting from the left: Images of the target board obtained at 3m, 5m and 6m relative distance from the range-gated camera, respectively.

Distance to target	Turbidity Value	Attenuation coefficient 'c'	Beam Attenuation Length
3 m	1.15 NTU	1.19 m^{-1}	3.6
5 m	1.09 NTU	1.15 m^{-1}	5.7
6 m	1.08 NTU	1.14 m^{-1}	6.8

Table 1. Experimental results showing the beam attenuation lengths obtained at distances of 3m, 5m and 6m between the range-gated camera and the target board.

4. CONCLUSION

A Hybrid Underwater Camera (HUC) system which combines sonar with a range-gated laser camera has been developed. Tests carried at the large scale flume have indicated that the HUC range-gated camera can reach at least 6.8 beam attenuation lengths for the case of a high contrast target. This result is in line with prior tests performed in the Halifax harbor with levels of turbidity comparable to the current tests [4]. The calibration of the turbidity sensor to beam attenuation units was useful to characterize more precisely the optical performance of the sensor. The methodology will be examined in more details in upcoming field tests. A system performance estimation simulation tool is also under development for the HUC, and more extensive tests are planned for the HUC in a large river environment for the Spring 2014. At the time of preparing this paper, additional test data are not yet available.

5. ACKNOWLEDGMENTS

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