MBARI's Midwater Ecology Low-Light Imaging System Development

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***Abstract*-This paper focuses on the technology for an imaging system that allows MBARI's midwater ecologists to detect both illuminated, nearly transparent organisms and stimulated bioluminescence. The system utilizes high intensity red LEDs and an ICCD camera with the ability to gate the detected light. This system uses less power than traditional underwater video systems and provides a higher contrast image for use in future automated counting systems.**

I. INTRODUCTION

MBARI's midwater ecology researchers desired a low-light camera for both illuminated and non-illuminated transects with sufficient sensitivity to detect stimulated bioluminescence and sufficient resolution to allow visual identification of animals. This capability will allow them to advance their research on the distribution and abundance, of mesopelagic zooplankton and micronecton that cannot be accurately surveyed using nets or acoustics.

The standard white light method of illuminating video transects provides excellent imagery and data on the distribution and abundance of delicate gelatinous organisms and has greatly improved researchers understanding of the importance of these animals in the midwater, benthopelagic and epibenthic ecosystem. However this method undoubtedly underestimates the abundance of fast moving crustacean, fish and squid that have photoreceptors and are capable of avoiding an oncoming light source before they are within range of the imaging system. Research on the photosensitivity of deep-see crustacean [10] [11] and fish [12] [13] [14] has shown that almost all of the species studied lack the visual pigments to see in the far red wavelengths. Therefore, a high resolution imaging system using far-red illumination will be the optimum method for quantitative assessments of these ecosystems.

The use of a low-light camera and LED illumination also results in a system with relatively low energy requirements which makes it ideal for remote operations where power may be a limiting factor. The gating features built into the system will also allow the researchers to see farther into the water column by virtually eliminating scattering due to suspended particles thus minimizing the affect that the presence of the vehicle has on the sample data. This feature may also allow the vehicle to operate on the bottom in low visibility conditions that would normally delay or preclude operations.

This paper focuses on the technology development of that system. It specifically relates the camera survey, camera controller development, illumination development and integration for such an imaging system. The resultant system allows MBARI scientists to record excellent video imagery of nearly transparent species such as siphonophores and medusae. The camera can also be used with a SPLAT system to quantitatively measure the occurrence of bioluminescent species such as ctenophores. [1]

II. CAMERA SELECTION

The camera required for the video system has an optimal combination of high resolution, low-light sensitivity and low video noise. Our exhaustive search of existing cameras, including models from Ball Aerospace, Defense Vision Systems, Stanford Photonics, ROS, Andor, Cooke and Dessert Star, resulted in the selection of an ITT ISG-880 Gen IV Ultra Blue ICCD camera with an extended spectral response that includes near IR. Selected specifications for this camera are shown in

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Table I. The high sensitivity of this camera allows the use of illumination sources that most species can't see, such as red and near IR. The Gen IV Ultra Blue intensifier also allows the system to detect the wavelengths of light emitted by most bioluminescent organisms [6].

TABLE I
SELECTED CAMERA SPECIFICATIONS

Specification	Quantity
System Resolution:	≥ 525 TVL/ph
	485 TVL/pw
System Optical Input Format	1"
MCP Intensifier Resolution:	64 ± 2 lpmm
MCP Optical Input Format	18mm
Lens Mount	C-mount
Min Faceplate Illumination	≤ $1\text{x}10^{-6}$ lux
MCP Gain Range	0 to 40,000
Gating Range	100ns to > 50us
Video Signal	RS-170
Spectral Response	~600nm to 900nm
Input Power	< 10W at $12V_{DC}$

II. ILLUMINATION

Illumination comes from commercially available high intensity red LEDs which were modified for use underwater [2]. Calculations based on (1), describing the attenuation of light that passes through an attenuating medium, and using the Min Faceplate Illumination in Table I, showed that these high-intensity LEDs were fully adequate to illuminate a scene.

$$\mathrm{E} = \mathrm{E}_o e^{-(\alpha+\beta)r} \quad (1)$$

where E is the resultant illumination in lux, E_o is the original illumination level at distance 0 (lux), α is the attenuation coefficient for the water at a given wavelength (cm^{-1}), β is the scattering coefficient for the water and suspended sediment at a given wavelength(cm^{-1}), and r is the distance the light travels in cm.

The attenuation coefficient for water, used in (1), can be read from a chart like that shown in Fig. 1 [5].

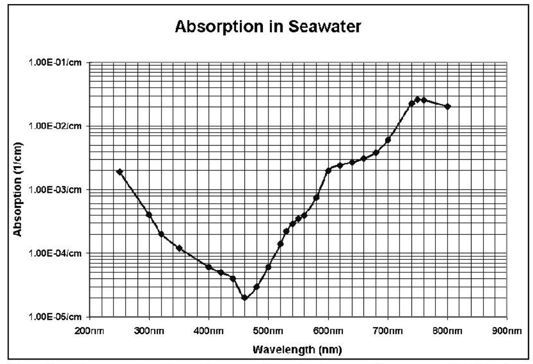

Fig. 1. A graph showing optical absorption coefficients for light in seawater [9].

Past history has shown that white and green/blue wavelengths are readily observed by the midwater's inhabitants, so red illumination was chosen to create an unobtrusive observation system [8]. Although the red wavelength is absorbed rapidly in seawater, the resultant contrast also provides a stark difference between the subject and the murky background, increasing the signal-to-noise ratio. Consider three objects in water (Table II), a target object set at 150cm and suspended particles at 100cm and 200cm from a lens. Using (1) and the corresponding absorption coefficients for light at 635nm (red) and 460nm (green), the green light returned from the particle is much closer in intensity to the target object than red light. Hence, the red light provides a much higher contrast return which results in a higher signal-to-noise ratio. This higher contrast solution provides an image that is an advantage for automated image processing solutions [7]. Examples of these high-contrast images are shown in Figs. 6 & 7.

TABLE II
COMPARISON OF RED AND GREEN RETURN

		Returned Illumination	
Object	Distance	Red	Green
Particle	100cm	62%	97%
Target	150cm	49%	95%
Particle	200cm	39%	94%

The inherent signal-to-noise advantage of using red illumination. Although the overall return is lower, particles behind a target provide a much lower signal return. Other methods, like light/camera separation or gating, must be used to deal with particles between the camera and the target.

Further efforts to increase the image quality include setting the lights far apart from the camera, shown in Fig. 2., to minimize backscatter from particles between the camera and target object.

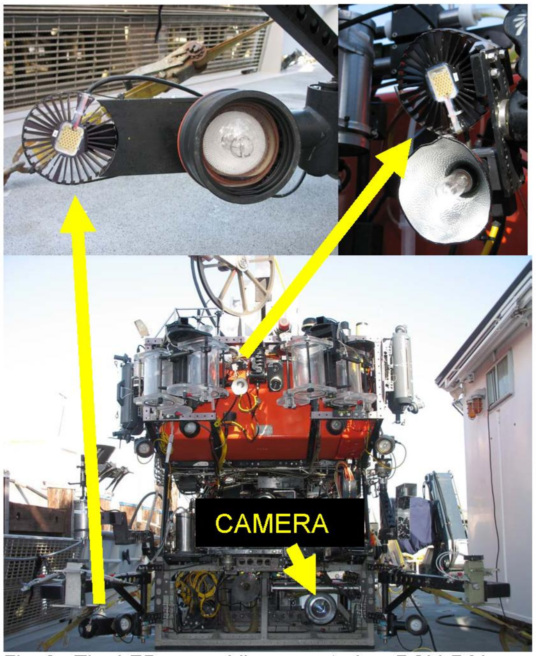

Fig. 2. The LED assemblies mounted on ROV *R/V Ventana* next to the standard gas lights used for the other onboard cameras.

III. Optics & System Resolution

The project goals dictated a target distance of 1.5m in front of the lens with a diagonal FOV of 74°. Since the camera has a 1" format CCD, we would need an 8.5mm lens to meet the FOV requirement. The scientists also desired a zoom lens, which would need to be motorized. In the end, we chose a Rainbow CCTV G10X16M zoom lens with motorized zoom, focus and iris. The specifications for this lens are shown in Table III. Regrettably the lens did not meet the FOV goal, as there were no 1" format motorized zoom lenses that met the requirements, but the motorized nature of the lens made up for the lack of FOV.

TABLE III
LENS SPECIFICATIONS

Specification	Quantity
Focal length:	16-160mm
Iris:	F2.2 – close
Mount:	C-mount
Angular FOV:	43.6° x 33.4° at 16mm
	4.6° x 3.4° at 160mm

The optical block design, which involves a hemispherical lens and corrective diopter that corrects for light diffraction in seawater was provided by Insite Pacific Inc., formerly Insite Tritech.

The zoom lens is powered and controlled by the VLIC board discussed later in this paper. It provides the user with the ability to adjust the lens' focus and zoom as well as override the autoiris function, built into the lens, and adjust the iris.

The system resolution is a function of the scene illumination, camera/intensifier, lens, signal losses over cabling, video recorder, storage media and playback device (if used), and monitor. The system was suspended in MBARI's saltwater test tank and the resolution chart specified in IEEE Standard 208-1995 was placed 1.5m from the face of the camera [3]. The video was observed on a Sony PVM-1354Q monitor with an advertised resolution of over 600 TVL. Using this equipment we measured 300 TVL/ph and 400 TVL/pw from the system. We have observed lower system resolution, typically around 200-250TVL/ph, after recording and playback on Hi-8 media and after conversion to MPEG. Ultimately direct recording to a digital format will increase the system resolution and eliminate the conversion losses generally associated with analog transfer and storage media.

IV. Video Lighting & Interface Card (VLIC)

MBARI built a custom circuit card, called the video lighting and interface card (VLIC), to control and monitor the system. The VLIC provides an interface to

- control and monitor the ITT low-light camera
- adjust the motorized zoom lens
- monitor environmental conditions inside the pressure casing
- enable/disable and adjust the intensity of the lights
- provide high-speed timing signals to the camera and light source for gated applications

The user communicates with the VLIC via Ethernet on the ROV using a standard telnet interface. This Ethernet connection, which is made possible by an off-board Lantronix XPort RS-232 serial to Ethernet converter, allows the user to easily run the system from anywhere on the ship that has a video monitor and a computer. We used an Ethernet interface because it eliminates ground loops and noise generated by the ROV. A LabVIEW application has been written to allow the operator to more easily operate the system, although the application relies on a simple underlying ASCII menu structure.

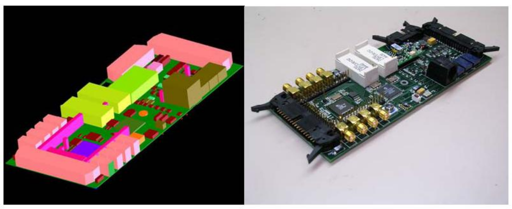

Fig. 3. The solid model of and finished video lighting and interface card (VLIC).

V. System Integration

Solid models of the various system components, including the VLIC shown in Fig. 3, were created in Solidworks for basic integration. After Insite Pacific finished the optical integration, technicians at MBARI completed the final internal wiring. The assembled camera is shown in Fig. 4 prior to being inserted in the pressure case.

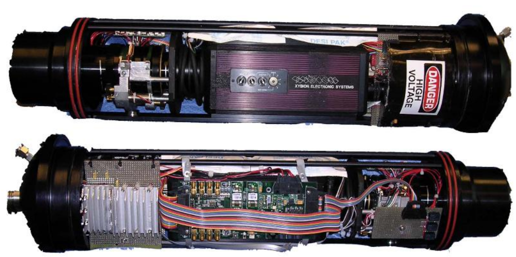

Fig. 4. The integrated camera, lens, VLIC and supporting electronics in their housing mounting bracket.

The cable assembly between the pressure casing, the LEDs and the ROV was built using oil-filled tubing and a junction can to accommodate the prototype nature of the camera. The mass and flexibility of this cable assembly caused several failures of the coaxial video cable at the connectors initially. In the end, a service loop was added to each coaxial cable junction and the entire wire assembly was strain relieved going into each pressure-balanced oil-filled, PBOF, connector. Ultimately the oil-filled cable assembly will be replaced with an SO based cable assembly.

The system runs on 110VAC and uses about 2A when the LEDs are on. For comparison, the traditional HID lighting alone on the ROV uses a minimum of 1200W. The ROV monitors the 110VAC for ground faults to ensure that the 110VAC doesn't damage the system or endanger the ROV operators. The system uses standard voltage converters, from Vicor, that convert the 110VAC to the various DC voltages needed throughout the system.

The entire system is rated to a depth of 1850m and the components of the system have been pressure tested in an oil-filled tank to an equivalent pressure at that depth. The first at-sea dive went down to 1000m and several at-sea dives have been that deep since then.

VI. Gating Features

The system's controller, the VLIC, contains a timing element that can provide eight relatively independent timing pulses with resolution down to 4ns and is pre-configured for use with a Q-switched laser for range-gated illumination solutions. The controller also provides a timing pulse for the intensifier gating on the camera.

The camera also has independent manual gating controls that can be adjusted from <100ns to 20msec. This manual adjustment is set by a series of knobs on the side of the camera and must be pre-set before deploying the camera.

Similar to the Laser Optronix AquaLynx, when this system is interfaced with a pulsed laser, the system will be able to view 2m

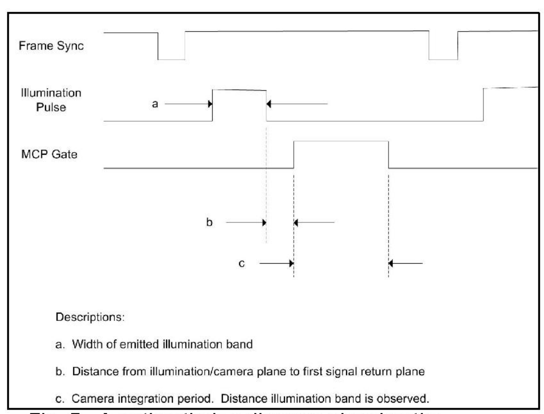

Fig. 5. A gating timing diagram showing the relation between the firing pulses of the video sync, MCP intensifier and illumination.

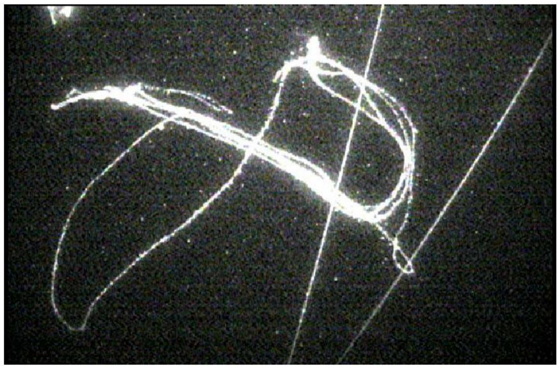

Fig. 6. A siphonophore illuminated with red LEDs. The strait lines are red lasers mounted on Ventana's HD video camera used to determine the size of objects or animals.

slots of water out to 100m theoretically. Gating essentially eliminates the scattering caused by particles between the lens and target by ignoring the light return from those particles. It is also used to freeze the motion of the self-illuminated objects in the scene such as bioluminescent plankton.

VII. User Interface

The user interface is based on an RS-232 ASCII menu that is accessed by the user through a standard telnet session initiated from the ship. The simple ASCII menu structure provides control over the lens, lighting and camera. Overlying the ASCII menu interface is a LabVIEW 7 based interface that simplifies interactions with the system. The user can adjust the camera's sensitivity, which adjusts the maximum intensification gate level. The user can also manually adjust the focus, zoom and iris of the lens, or set the iris to automatic adjustment.

VIII. Conclusions & Results

This extremely sensitive camera provides a low-noise image and can be adjusted across a wide range of sensitivities to provide an optimal image for both illuminated and non-illuminated scenes. It has been mounted on MBARI's ROV *R/V Ventana* and has acquired a number of video sequences that has allowed the researchers to identify approaching animals prior to stimulation and subsequent bioluminescent display. Examples of the images captured by this system are shown in Figs. 6 &7.

Fig. 7. An illuminated larvacean house beyond the SPLAT screen. [1]

Scientists will continue to use the system to study these unique organisms and publish their results in the future.

IX. Acknowledgements

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