Bioluminescence Risk Detection Aid

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LONG-TERM GOALS

The long-term goal of this project is to develop a bioluminescence risk detection aid (BRDA) for underwater vehicle navigation and mission planning. The purpose of the bioluminescence risk detection aid is to provide real-time information as to the probability of above water visual detection of platform-induced (e.g. an Autonomous Underwater Vehicle, SEAL Delivery Vehicle, or diver) bioluminescence, based on local environmental data, *in-situ* measurements, and simple radiative transfer models. This work directly addresses ONR topic # N08-193. Our envisioned bioluminescence risk detection aid will include 1) a suite of simple, compact, low power sensors to measure the intensity of vehicle-stimulated bioluminescence, water attenuation properties, ambient light, and depth, 2) a data acquisition and processing system to integrate measurement streams and apply a simple radiative transfer algorithm to determine bioluminescence detection risk, and 3) a simple, user interface to display real-time threat risk.

OBJECTIVES

The primary objective for the Phase II is to: 1) Develop a prototype Bioluminescence Risk Detection Aid (BRDA) and navigation aid that measures the necessary parameters to provide an accurate prediction of the risk of being detected due to vehicle-stimulated bioluminescence, 2) conduct a series of field experiments to evaluate the optimal measurement suite and demonstrate the feasibility of the proposed system to predict the level of detection risk, 3) evaluate the performance of the prototype on an SEAL Delivery Vehicle (SDV), 4) provide a hand-held navigation aid and/or a user interface module that is compatible with SDV navigation systems.

APPROACH

Our Phase-II efforts focus on sensor development, user interface development, constraining model uncertainty, and continued evaluation of the system under various field conditions. All of this will be conducted with advice solicited from the Navy, especially Naval Special Warfare, Group 3 (NSWG3) regarding real operating conditions and the desired degree of complexity of the navigation display. The key toward achieving successful implementation of this risk detection aid by the Navy is to design a

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system that is easy to integrate, processes data in real-time, and provides a simple, reliable, and accurate threat indication display of the level of risk associated with stimulated bioluminescence.

To provide an accurate response, four key measurements are required and include: $a+b_b$, which approximates the diffuse attenuation coefficient (K) and dictates the amount of light penetrating through the water column as well as the amount of light reaching the surface from mechanical stimulation of bioluminescent organisms (E_{BL} surface), depth (z), ambient light ($E_{ambient}$) and vehicle-stimulated bioluminescence intensity (E_{BL}).

Development efforts will be divided between primary implementation and development of operational capabilities. Of importance is deployment of the initial and subsequent prototypes on two key platforms, namely REMUS-600 operated by Cal Poly and the X-boat SDV operated by NSW-PCD. Testing the operational capability of the prototype(s) and model are an ongoing aspect of the project. This coupled with iterations of system modifications are critical to the development of the full suite of operational capabilities and the overall success of the project.

WORK COMPLETED

1. Completed build of prototype-1

The first prototype was completed July 2010 (Figure 1). Instruments were mounted to a base plate on two customized rails that were used to mount the instrument to the REMUS-600 for deployment. A hydrodynamic fairing enshrouds the main instrument package to provide buoyancy and limit turbulence caused by the instrument package. The fairing is designed to allow water to flow through the astar ($a+b_b$) sensor by forward movement of the vehicle. However to ensure constant flow, a small pump was used for the initial field evaluation. The astar ($a+b_b$) sensor utilizes a WET Labs cstar body modified for use as an absorption sensor, with a 10 cm reflective tube and diffuse light detector. The astar uses a 500 nm LED light source for detection, because the attenuation of bioluminescence is green-shifted in coastal systems (Moline et al. 2007). A Satlanic PAR sensor, with increased gain and modified diffuser is used to sense ambient light ($E_{ambient}$). System control, data processing and data logging components are contained in a separate housing. Each instrument is cabled directly to the system control module. Battery power is provided by a NiMH rechargeable battery, capable of providing 4.5 hrs of battery power. The PMT is separated from the main instrument and electronics housing so that it can be mounted facing the propeller of the REMUS-600 where the mechanically-stimulated bioluminescence (E_{BL}) is expected to be brightest.

2. Evaluation of the predicted level of risk, RYG output by BRDA

The first evaluation of the prototype was conducted August 9-13, 2010 in Avila Beach, CA at the Cal Poly Marine Science Research Center. Work was conducted during a new phase of the moon, between 10 PM and 2 AM, the period when bioluminescence is most intense. A REMUS-100, equipped with a bioluminescence nosecone sensor was deployed to determine the spatial distribution of bioluminescence potential, the maximum bioluminescence intensity from a mechanically stimulated volume of water, in the region of study. A validation cage, equipped with an astar ($a+b_b$), PAR ($E_{ambient}$), PMT (E_{BL}), acs ($a+b_b$ and c), Conductivity Temperature and Depth sensor (CTD), and WET Labs Underwater Bioluminescence Assessment Tool (UBAT, bioluminescence potential). The validation cage was deployed prior to and following the REMUS-600 launch. The BRDA prototype mounted on a REMUS-600 was programmed to fly at different depths while human observers, positioned above the vehicle looking down, determined if the vehicle-stimulated bioluminescence was visible. Results from human observations and the predicted risk output by BRDA were in agreement.

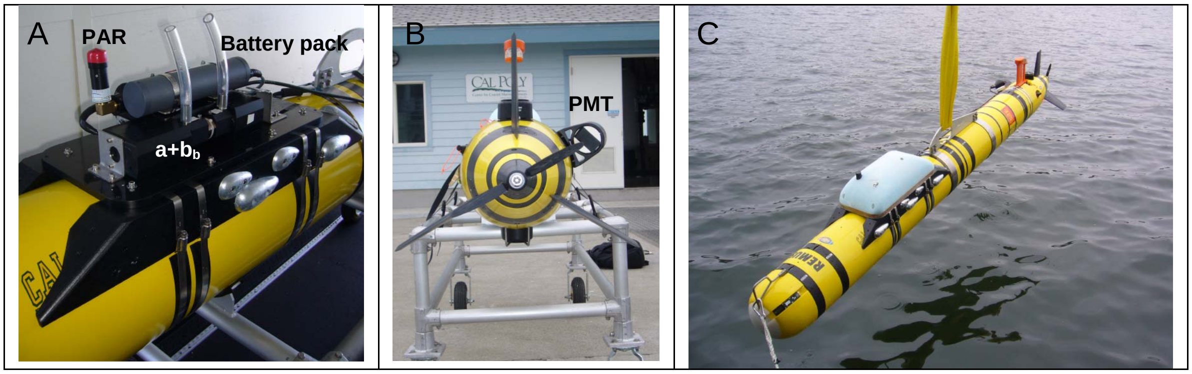

Figure 1: A. BRDA instrument package mounted on its base plate showing: astar ($a+b_b$) sensor, plumbed for pumped flow, battery pack, and ambient light sensor. The main instrument package is fixed to a mounting platform and attached to a REMUS-600). B. The PMT sensor oriented facing the REMUS propeller. C. REMUS-600 with instrument backpack (hydrodynamic fairing) lowered into the water.

3. Review meeting scheduled for October 25, 2010

A review meeting is scheduled for October 25, 2010 in Panama City, FL. This review is an opportunity for us to present results from the initial field evaluation of prototype-1 and receive feedback from our stakeholder group. Involvement of the stakeholder group during this phase of the project is critical. Input from this group will help define the system function and attributes prior to the build of prototyp-2 and ensures that the technology meets the needs of the operational Navy.

RESULTS

Initial field evaluation of the BRDA prototype-1 was conducted from August 9-13, 2010 at the Cal Poly Center for Coastal Marine Sciences pier in Avila Beach, CA. This region is dynamic and is well known for having bioluminescent blooms in the spring and summer. A REMUS-100, equipped with a bioluminescence nosecone, was used to map the spatial distribution of bioluminescence in the study region (Figure 2 A). Natural bioluminescence was present during the study period, with maximum bioluminescence at 2.0E+11 photons s^{-1}. For orientation, REMUS-600 transects were conducted in the lower 30 m of Figure 2 A. E_{BL} measured using the PMT facing the propeller shows temporal variation in bioluminescence as well as an increase in bioluminescence intensity during the REMUS dive, due to increased propeller RPM (Figure 2 B). During the study period, bioluminescence ranged between 0 and 14.0E+10 photons s^{-1} (Figure 2 B) and water optical properties ($a+b_b$) decreased from 0.65 to 0.25 m^{-1} (Figure 2 C).

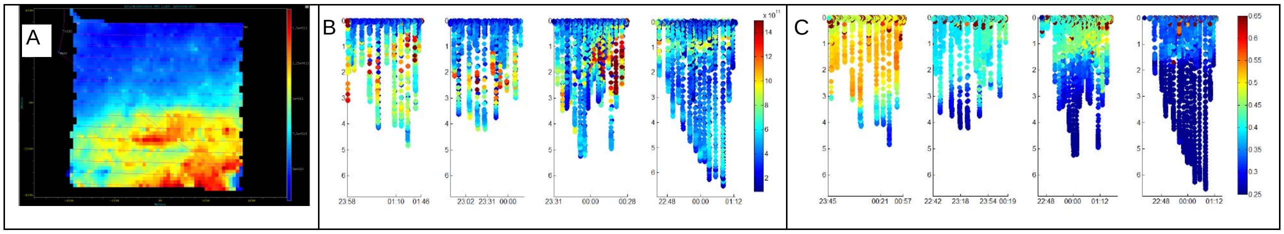

Figure 2: A. REMUS-100 transect, showing the variability in the bioluminescence potential of the study area on August 12, 2010 (400 x 400 m box). Maximum bioluminescence is 2.0E+11 photos s^{-1}. B. Propeller-stimulated log (E_{BL}) during August 9-13, 2010. C. astar (a+b_b) at 500 nm.

Work was conducted during the new phase of the moon to limit the influence of ambient light and closely replicate naval operating conditions. This is significant to the study because as ambient light decreases the visibility of vehicle-stimulated E_{BL} at the surface decreases. In other words, it becomes harder for a human to detect the vehicle. Although, ambient light from both Port San Luis and Pismo Beach, CA was still visible in the study area our objective was to evaluate BRDA measurements and model output under dark-night conditions.

To evaluate the model used to predict risk and validate the results from BRDA deployed on the REMUS-600, vertical water column profiles were conducted prior to and following the REMUS-600 deployment. Full vertical water column profiles were collected to obtain a+b_b as a function of depth. To measure mechanically-stimulated E_{BL} as a function of depth, the cage was then maintained at the surface while an SBE pump was profiled beneath a downward-facing PMT. E_{BL} was also simulated, by profiling a Glo-Toob™ light source, peak wavelength at 465 nm. Data (a+b_b, E_{BL}, and depth) was used to solve the model for the attenuation of a point source. Control software for the profile cage output the RYG predicted risk versus the depth of the cage in real time (data not shown). The control software also allows the user to modify the human visibility threshold (the minimum amount of E_{BL} at the surface that can be seen by the average human), which is used to set the R-Y and Y-G boundaries for the risk prediction.

Figure 3 highlights the importance of using the point source attenuation model to predict risk, rather than other light attenuation models. For comparison three light attenuation models are shown: attenuation of a point source (black), $1/z^2 \exp(-(a + b_b)z)$; day time attenuation (red), $\exp(-(a + b_b) z)$; diver visibility (green), $\exp(-c z)$. A mean value of $a + b_b$ (500 nm) = 0.3841 m^{-1} and c (500 nm) = 1.6517 m^{-1}, obtained from the astar and acs, respectively were used to predict the attenuation of mechanically-stimulated bioluminescence and Glo-Toob™ simulated bioluminescence (E_{BL}). Our results agree with our hypothesis. Both mechanically-stimulated and simulated (Glo-Toob™) bioluminescence (E_{BL}) fit the point source attenuation model. As it is known from Moline et al. (2007), the observed bioluminescence is green shifted, especially in coastal environments, and a(500 nm) yielded the best fit (data not shown) which is why this wavelength was used in the astar (a+b_b).

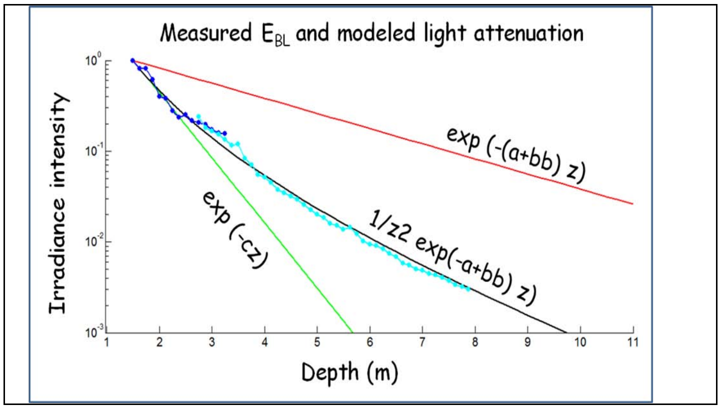

Figure 3: Fit of measured E_{BL} from August 12, 2010 (typical results) to three light attenuation models. Blue = mechanically stimulated bioluminescence and Cyan = Glo-Toob™ simulated bioluminescence (E_{BL}) measured with the PMT. Green = exp(-c z); Red = exp(-(a + b_b) z); Black = $1/z^2$ exp(-(a + b_b) z). Average optical values measured at 500 nm (a + b_b) = 0.38 m^{-1} and c = 1.65 m^{-1} were used to generate the models.

To validate the RYG predicted risk output from BRDA with the visibility of the vehicle-stimulated bioluminescence, human observers were stationed above the water surface looking down as REMUS traveled at various depths. Results from August 12, 2010 show that the predicted level of risk, output as a RYG indicator, is in agreement with that observed by the human eye (Figure 4 A and B). To highlight this result, calculated E_{BL} at the surface for three vehicle profiles are shown in Figure 4 B. When the REMUS was at a maximum depth of 2.5 m 100% of human observers were able to detect the vehicle (red line). This corresponds with a calculated E_{BL} at the surface that is greater than the minimum E_{BL} that can be detected by the average human (1.0E+9 photons s^{-1}, indicated by the vertical black line). A portion (44 %) of the human observers detected E_{BL} at the surface when REMUS was at a maximum depth of 5.5 m (yellow line), thus crossing the human visibility threshold. However taking into account the variability of human visibility, E_{BL} at the surface would not be visible to most observers. When the REMUS was at a maximum depth of 6.5 m no observers were able to detect the E_{BL} at the surface (green line), which falls below the human visibility threshold. Note that when the REMUS is diving downward (solid lines) the vehicle is more visible to the observer, due to an increase in propeller stimulated bioluminescence as the propeller RPMs increases to reach the required depth. In comparison, when the REMUS is ascending the propeller RPM is not high and stimulated bioluminescence is not as intense. Therefore the vehicle is less visible. The visibility threshold of the diffuse E_{BL} observed at the surface agrees with that of other diffuse objects, like galaxies, where the minimum detection threshold for a human is 2.61E+8 photons $s^{-1}m^{-2}$.

It is important to note that it was necessary to fly the REMUS at 30 m away from the pier pilings to protect the REMUS from possible damage. However, this increased the angle of view and E_{BL} detected at the surface. Although in this study E_{BL} at the surface was corrected for the difference in the angle of view, it is important to consider this for future prototype evaluations, especially if the risk prediction is intended to provide accurate results for an above-water observer.

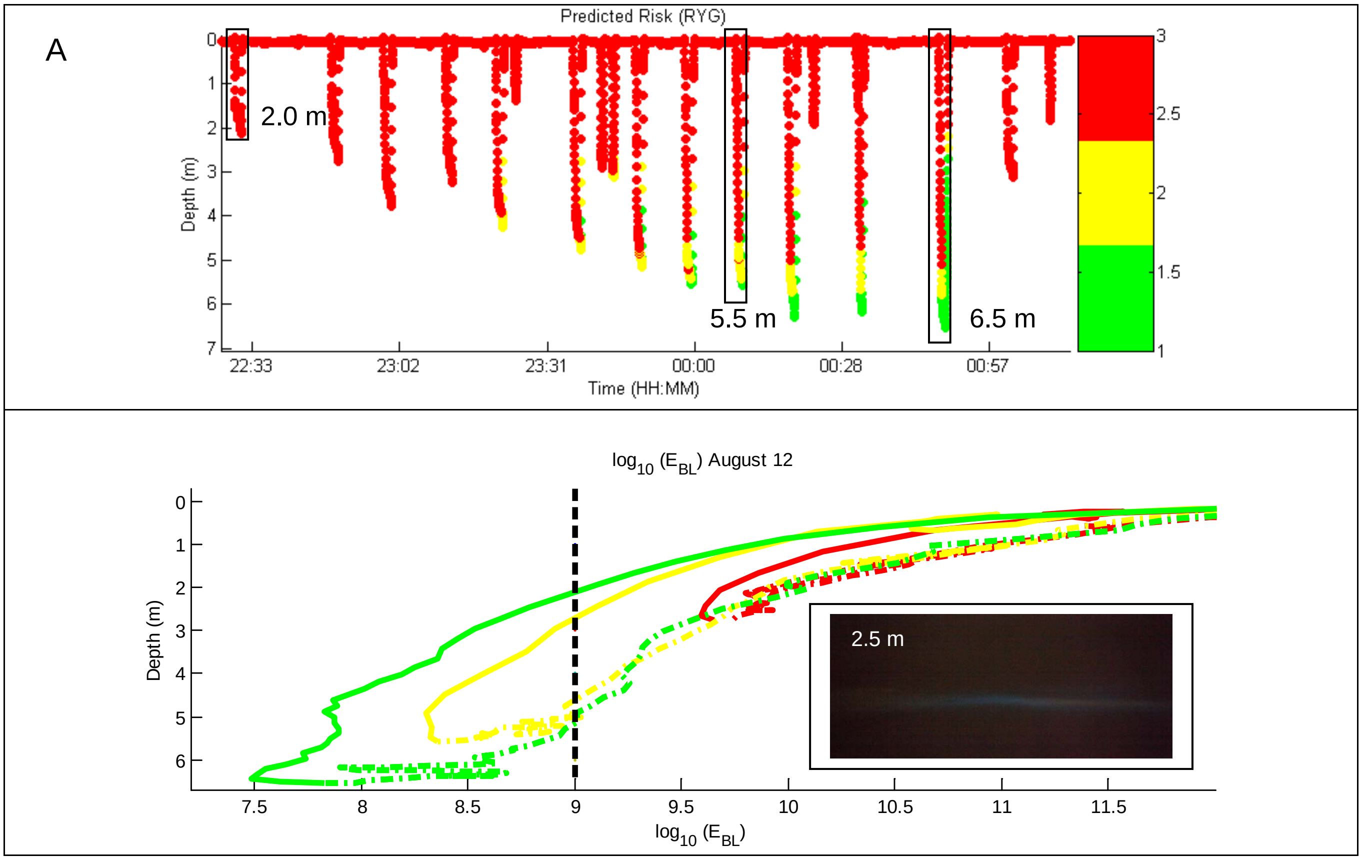

Figure 4: A. RYG predicted risk for August 12, 2010 using the model for the attenuation of a point source, propeller stimulated E_{BL} and $a+b_b$. Boxes show three selected REMUS depths. B. BRDA calculated E_{BL} at the surface versus depth of visibility for the corresponding REMUS depths. The human visibility threshold = 1.0E+9 (black line) is the minimum light level that can be detected by an average observer. RED = REMUS vehicle diving to a maximum depth of 2.5 m. Inset is an image of the vehicle-stimulated bioluminescence at that depth. Yellow = REMUS vehicle diving to 5.5 m. Green = REMUS vehicle diving to 6.5 m. Observations were corrected for the angle of observation.

IMPACT/APPLICATIONS

This work directly addresses the needs of the operational Navy and the resulting prototype will provide a navigation aid for underwater vehicles that will sense vehicle-stimulated bioluminesce, measure local environmental conditions and ingest the information to solve a simple radiative transfer model to provide a real-time assessment of the probability of being detected by an above-water observer. Continued input from project stakeholders ensures that the prototype provided will meet the needs of the operational Navy.

RELATED PROJECTS

The Underwater Bioluminescence Assesment Tool (UBAT), is in the process of becoming a commercial product and its successful transition from the research group at UCSB to WET Labs is a result of the ONR-STTR award N00014-06-C0426. UBAT measures bioluminescence potential, which is the maximum bioluminescence that can be obtained from mechanical stimulation of the organisms present, and is used as the validation measurement for bioluminescence detected with BRDA. A UBAT been deployed in Avila Beach, CA since 2007 and along with other water column measurements bioluminescence has collected profiles every ½ hr since 2007. Therefore, we have access to a long-term dataset of bioluminescence to use for validating the simple radiative transfer model used to provide the BRDA level of risk. Since, peak bioluminescence is seasonal in Avila Beach, CA, the historical dataset can also be used to identify the best time periods to conduct evaluations of BRDA under natural bioluminescence conditions as we showed during the August 2010 experiment.

In 2008 and 2010, UBAT was evaluated by NAVO. Results from the 2008 cruise show that UABT agrees with the naval standards OTiS and Biolite (PMT 2). This evaluation was conducted in a region of high bioluminescence. Unfortunately, results from the 2010 evaluation are inconclusive due to low bioluminescence intensities in the study region and differences in instrument sampling times. NAVO recently purchased several units and is continuing to evaluate UBAT.

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