

Rapid Algorithm for Estimating Underwater Distance Visibility of Low-Light Cameras and Divers

Robert A. Maffione

Hydro-Optics, Biology, and Instrumentation Laboratories

55 Penny Lane

Watsonville, CA 95076

Phone: (831) 768-0680 Fax: (831) 768-0681 Email: maffione@hobilabs.com

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LONG-TERM GOAL

The overall goal of this project is to develop a robust and viable method for estimating underwater visibility that will aid Navy mine hunting efforts in actual operation. The long-term goal is to transition this method, called DiVA (Distance Visibility Algorithm), to the operational Navy.

OBJECTIVES

There are several interrelated objectives developing, demonstrating, and ultimately transitioning DiVA. One of these objectives is to develop an instrument or instruments that can be easily deployed by Navy personnel from ships which will accurately measure necessary water-column optical properties for estimating underwater visibility. A related objective is to develop a rapid and robust algorithm that takes as input the measured optical properties and computes distance visibility for optical mine-hunting systems and divers. Another objective is to demonstrate the effectiveness of DiVA to the Navy and ultimately transition it to the Fleet.

APPROACH

The Navy has several types of optical mine-hunting systems, including divers, that are deployed from ships. It is highly desirable, and in some cases critical, for the Navy to have accurate performance predictions of these systems prior to deployment. The DiVA method is designed to provide the operators, in real time, with accurate system performance estimates based on actual measurements of water optical properties. Real-time in-situ optical measurements are feasible since at least one ship is already on station – the ship that deploys the mine-hunting system. Prior to deploying this system, a rapid profile of the water column is performed using a robust, self-contained, simple to deploy instrument that measures the necessary optical properties for estimating system performance. Two instruments have been developed for this purpose, a - β and c - β . a - β measures the diffuse attenuation, absorption, and backscattering coefficients and c - β measures the beam attenuation and backscattering coefficients. For imaging systems and divers, a - β is used, and for laser-based systems c - β is used. When performance estimates are needed for both types of systems, both a - β and c - β can be deployed together.

As soon as a profile is completed, the a - β measurements are fed into the Distance Visibility Algorithm (DiVA) which then computes a profile of the maximum visibility, or target acquisition distance for divers or a particular imaging system. The DiVA, which was developed on this project, is

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an analytical algorithm that computes image contrast as a function of range and, inversely, maximum visibility distance as a function of (minimum) image contrast threshold. A depth profile of maximum visibility range is then provided to the appropriate Navy personnel who can use this information to decide on appropriate search methods or whether a system should be deployed at all.

WORK COMPLETED

In the six months since this project began, we have completed the following tasks:

1. Built and calibrated an α -beta instrument and a c -beta instrument.
2. Developed the Distance Visibility Algorithm (DiVA).
3. Performed visibility experiments in Monterey Bay using divers, a digital underwater camera, and the α -beta and c -beta instruments to test and validate the DiVA.
4. Delivered a briefing of DiVA to Navy personnel prior to participating in the GOMEX / MIREM 99 mine-hunting exercise.
5. Participated in the GOMEX / MIREM 99 mine-hunting exercise to demonstrate and test DiVA. During this exercise we deployed the α -beta and c -beta instruments for eight days at 19 stations aboard the USS Pioneer. After each profile, the data were run through the DiVA and real-time distance visibility estimates were provided to Navy personnel in real time.
6. Delivered a post-exercise results briefing at ONR.
7. Prepared and submitted a manuscript of DiVA to Applied Optics [Maffione, submitted].

RESULTS

Starting with the radiative transfer equation, I have rigorously derived the following equation which gives image contrast C as a function of range R :

$$C(R) = C_0 \left\{ 1 + \bar{L} \left[\frac{\exp(K_L R) - 1}{K_L} \right] \right\}^{-1},$$

where C_0 is the inherent image contrast (image contrast at $R = 0$), K_L is the image radiance attenuation coefficient, and $\bar{L}$ is a parameter related to the path radiance. We conducted a test of this model by measuring image contrast as a function of range for a black and white “MTF” target in Monterey Bay. The attenuation parameter K_L was measured directly with α -beta [Dana and Maffione, 1998]. An example of our results is shown in Figure 1. The parameter $\bar{L}$ was determined by a least-squares regression to the contrast equation using the measured image contrast as a function of range and the measured K_L provided by α -beta. Since the target was black and white, the inherent image contrast is 1. In all cases, an excellent fit to the model was found. The parameter $\bar{L}$ was found to depend on K_L but was only a weak function of lighting conditions. Note that the contrast equation is easily inverted for range R . Thus, by using a minimum target contrast imaging threshold, typically 2% to 5%, the maximum target acquisition distance can be quickly computed.

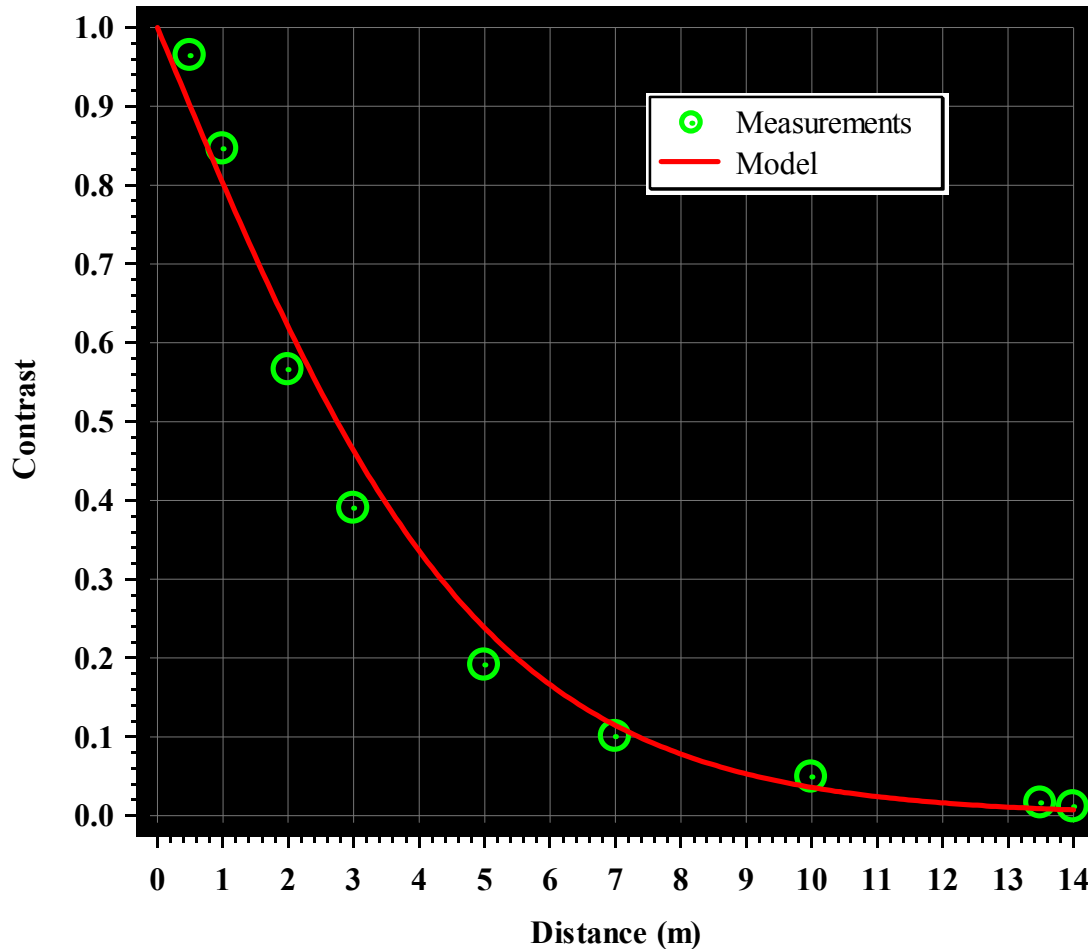


Figure 1. Plot of target contrast as a function of range. Circles are measured contrast of a black and white “MTF” target and the solid line is a regression using the contrast equation (see text) with the free parameter being $\bar{L}$. These measurements were performed in Monterey Bay and divers reported that they could no longer see the target at a contrast of about 2%.

During the GOMEX / MIREM 99 mine-hunting exercise, we performed DiVA profiles at 19 stations and provided the Navy with real-time profiles of maximum target acquisition distance. At several stations, DiVA was tested against the SLQ-48 mine-hunting system which searched for planted targets. At one station, after we performed the DiVA profile and provided the SLQ-48 operator with a maximum target acquisition distance of 7 feet, we were informed that the target was acquired at 7 feet and that it could not be seen beyond this distance, which was a solid confirmation of the utility of DiVA to the Navy.

IMPACT/APPLICATIONS

Understanding underwater visibility has been an important subject of investigation for many decades. Because DiVA is the first underwater visibility model that has been tested and validated, it will no doubt have a profound impact on both the science of understanding underwater visibility and on underwater imaging systems. DiVA may provide the key model to properly interpreting the huge

database of Secchi depth measurements in terms of inherent optical properties. For the operational Navy, DiVA has the proven potential for providing critical information to divers and operators of mine-hunting systems.

TRANSITIONS

DiVA was demonstrated to the Navy for the first time during the GOMEX / MIREM 99 mine-hunting exercise and the results were used in real-time by two mine-hunting systems, the SLQ-48 and a laser-line scanning system. The DiVA method and results from the exercise are currently being used by NRL scientists who are investigating underwater visibility problems. These personnel include Robert Arnone and Alan Weidemann (Stennis) and contractor Walter McBride.

RELATED PROJECTS

1 – α -beta and c -beta instruments are being used by Alan Weidemann's group at NRL as part of their underwater visibility work and they will undoubtedly be conducting their own tests of DiVA.

2 – An α -beta was recently used by Mike Contarino and Linda Mullen (NAWC) on a joint exercise with the British navy to measure water-column optical properties as an aid in estimating ocean lidar system performance.

3 – Discussion is underway with CSS personnel to provide c -beta instruments for their laser-line scan systems as an aid in understanding system performance and interpreting results.

4 – I am working closely with program managers to further demonstrate the utility of DiVA to the Navy and eventually transition it to the fleet.

5 – I am collaborating with Piotr Flatau (Scripps) to develop a Monte Carlo model of α -beta which will help us to further understand and validate the utility of this instrument.

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PUBLICATIONS

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