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In Situ Measurement of Water Transparency

A modulation transfer function technique has advantages over the Secchi disk for measuring water transparency.

ONE OF THE simplest and most common devices for making *in situ* measurements of water transparency is the Secchi disk. This is a disk with known light reflectance properties that is lowered into the water until it just disappears from view. The depth of disappearance is recorded as the Secchi disk depth which can, in principle, be related to various water transparency parameters[1]. However, the complexity of the disk-eye-water-sun optical system makes the interpretation of these measurements difficult. In this note an alternative to the Secchi disk is described which retains its simplicity, but is more quantitative, produces a permanent record of the result which can be partially interpreted by an unskilled observer, and can be used at any depth. This technique consists in taking an in-water photograph of a target which can be analyzed in terms of a modulation transfer function (MTF). Del Grosso[2] has used very precise measurements of the MTF to describe the optical quality of water. A photographically recording nephelometer of considerably more complexity than the device reported herein has been used for some time by the Lamont-Doherty Geological Observatory[3]. The emphasis here is on a method which represents a compromise between simplicity of the instrumentation and precision of the measurement.

ABSTRACT: *This paper describes how the well-known MTF theory and experimental technique can be employed to monitor suspended particulates in the aqueous environment by using instrumentation that rivals the Secchi disk in simplicity, but which has many advantages over this older method. The design of a simple low-cost underwater camera-light source-target system is reported and its use is demonstrated by observing the temporal variation in the transparency of Biscayne Bay water during the passage of a barge-tug vehicle.*

For a linear system, following Mertens[4],

$$M_o(\omega) = M_i(\omega)T(\omega) \quad (1)$$

where M_i is the frequency dependent input modulation, M_o is the output modulation, and $T(\omega)$ is the MTF. We have, for an alternate white and black line target,

$$M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (2)$$

where I_{max} is the light intensity from the center of a white line and I_{min} is the intensity from the center of an adjacent black line. Photographs of this target actually measure the sqaure wave response function not the sinusoidal MTF, however the distinction, as described by Coltman[5], is not resolvable within the accuracy of the experiments reported here.

The deterioration of the image by refractive effects and particle scattering of light can be expressed[4] by

$$T(\omega) = \begin{bmatrix} 1.0 & \omega = 0 \\ C \exp(-0.5\,\sigma^2\,\omega^2) & \omega > 0 \end{bmatrix} \quad (3)$$

where spacial angular frequency, ω, is obtained from

$$\omega = \pi r/d \quad (4)$$

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Here r is the viewing distance and d is the line width.

The deterioration of the direct image (that is, light from the subject to the viewer) as a result of forward scattering and absorption by water and suspended particles is described by the standard deviation σ of a Gaussian approximation to the direct light spreading function. The contrast transmittance factor, C, accounts for image deterioration produced by loss in contrast due to light scattered from water and particulates into the image transmission path. Since pure water is responsible only for very small angle scattering, $C = 1$ for pure water and $\sigma \simeq 1.9 \times 10^{-4}$ radian.

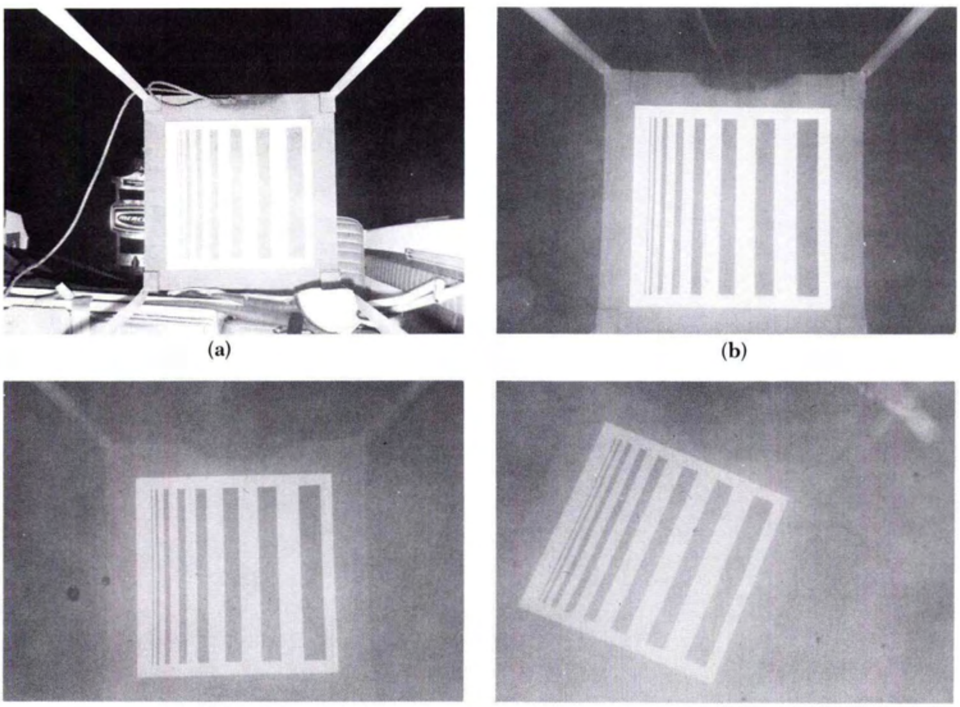
A black-on-white line photographic target was painted on a 2 by 2 ft square piece of ½-in. plywood. This target was mounted on an aluminum frame 6 ft from the mounting of a Nikonos camera and Seastrobe undersea strobe light. This arrangement gave a spatial angular frequency range, as calculated using Equation 4 from 42 to 330 radians/radian.

Ballast was added to the target end of this assembly so that, when it was lowered into the sea by a suspension cable, the camera viewed downward to the target. An additional line was used to trip the camera shutter and advance the film. Kodak Plus-X black-and-white film was used in all tests reported.

For demonstration purposes, this apparatus was used to measure an MTF for Gulf Stream surface water and to study the temporal variation of water transparency produced by the passage of a barge-tug vehicle in Biscayne Bay.

The data photographs were all taken at night to avoid the complication of interpretation that would be introduced by ambient light. Enlarged 3 by 5 in. film positives were made from the original film data, taking care in the enlargement and development process to maintain the same relative contrast between frames. By scanning the enlarged positive perpendicular to the black lines with a crude film scanning densitometer, the light intensity modulation function was determined.

Prints of film data are displayed in Figure 1. The frame shown in Figure 1a was taken in air for use as the reference response of the light-camera-target system. Frame 1b was obtained in the relatively clear water



(a) (b)

(c) (d)

FIG. 1. Photographic data. (a) Air. (b) Gulf Stream surface water. (c) Biscayne Bay undisturbed. (d) Biscayne Bay 35 minutes after barge passage.

TABLE 1. MODULATION FUNCTIONS

ω	M_i[a]	M_o[b]	M_o[c]	M_o[d]
42	2.95	1.36	0.55	0.54
49	3.00	1.64	0.61	0.37
58	2.61	1.53	0.59	0.27
85	2.60	1.10	0.57	0.27
114	2.70	1.20	0.63	0
154	3.02	1.27	0.40	0
330	2.97	.98	0.67	0

[a] Air
[b] Gulf Stream surface water
[c] Biscayne Bay undisturbed
[d] Biscayne Bay 35 minutes after barge passage

near the surface of the Gulf Stream just east of Pacific Reef light. The enlarged target dimensions are a result of the water magnification. Frame 1c was taken at a depth of about 7 ft in southern Biscayne Bay between Featherbed and Pelican Banks on 11 February 1976 at approximately 8:30 pm. It records the in-water visibility before the passage of a tug propelled barge which was proceeding southward toward the Florida Power and Light Power Station at Turkey Point. The clarity of the Gulf Stream water (1b) compared with the undisturbed bay water (1c) is easily noted. Five minutes after passage of the barge the particulate concentration was so great that light scattered from the strobe flash into the image transmission path completely obscured the image. This condition remained 20 minutes after the barge passage. The target image was again resolvable after 35 minutes of particulate settling (Figure 1d). The angular distortion of the photographic target in the frame 1d was the result of a minor failure in the strobe-camera-target structure.

The enlarged film positive corresponding to the frames shown in Figure 1 were scanned by the densitometer and the extrema of the resulting curves were used in Equation 2 to calculate the modulation functions. These modulation functions are presented in Table 1. The data obtained in air are used for the input modulation function M_i and the modulation transfer functions calculated from Equation 1 are shown in Figure 2. Since, for the range of spacial angular frequency used $0.5\sigma^2\omega^2<<1$, Equation 3 can be approximated by the expression

$$T(\omega) \simeq C(1 - 0.05\sigma^2\omega^2) \qquad (5)$$

A fit of Equation 5 is shown in Figure 2 for each set of data. The experimentally determined values of the constants C and σ are also given in Figure 2. The error bars indicate the uncertainty in determining T due to electronic noise in our crude densitometer used to measure I_{max} and I_{min}.

The accuracy of the determination of the modulation transfer function could be considerably improved by using a high quality commercial film scanning densitometer equipped with a microprobe in place of the crude homemade densitometer used in this investigation.

The photographic technique reported herein is shown to provide a quantitative measurement of parameters (C, σ) related to suspended particulates, parameters which provide a more detailed description of the underwater visibility than Secchi disk measurements. The method has the additional advantage of producing a permanent record of the water transparency which can be either analyzed in detail in the laboratory by a trained technician or interpreted qualita-

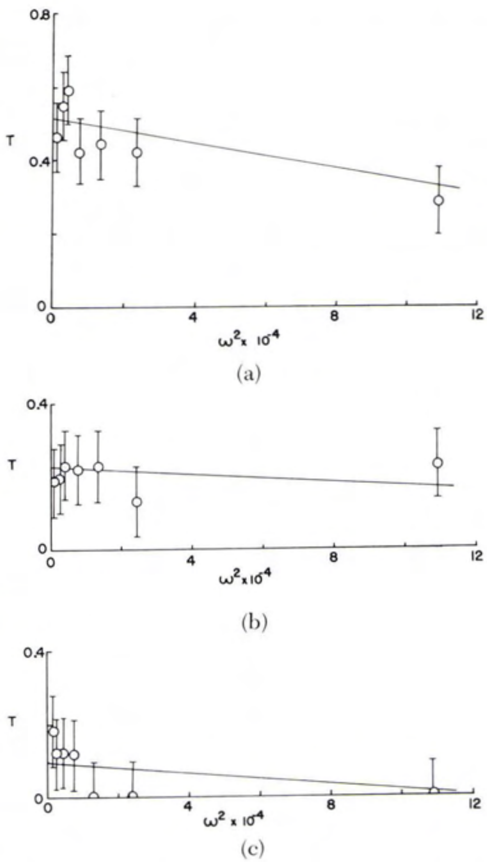


FIG. 2. Modulation transfer functions. (a) Gulf Stream surface water, $C = .52$, $\sigma = 2.7 \times 10^{-3}$. (b) Biscayne Bay undisturbed, $C = .23$, $\sigma = 2.3 \times 10^{-3}$. (c) Biscayne Bay 35 minutes after barge passage, $C = 0.094$, $\sigma = 12.6 \times 10^{-3}$.

tively by an unskilled observer. With the increasing use of scientific evidence in court cases involving environmental nuisance, it is important to have data which are not only quantitative, but which can also be given a qualitatively correct intuitive interpretation by a jury. The photographic modulation transfer function determination presented herein can also turn up evidence of macroscopic scatterers (fish or other organisms for example) which can be identified from photographs and yet would go undetected or produce spurious results with other pollution monitoring devices.

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