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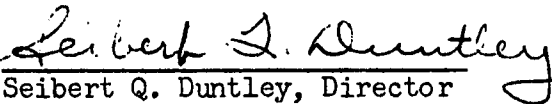
VISIBILITY CALCULATIONS

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The Contrast Transmittance Distribution as a Possible Tool in
Visibility Calculations[*]

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INTRODUCTION

The purpose of this note is to introduce the concept of the
contrast transmittance distribution $\mathcal{T}_i(z_j,\cdot)$ and to point out its
potentially useful application to the general visibility problems
in natural aerosols and hydrosols. In particular, we will show that
the contrast transmittance distribution:

(a) Can quite generally be assigned the status of
an (apparent) optical property of scattering-
absorbing media. Furthermore, $\mathcal{T}_i$ together
with the radiance function N , may serve to
completely document an optical medium for the
purposes of solving the problems of the apparent
contrast of objects.

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(b) Possesses certain useful analytical properties
which are precisely analogous to those of the
well-known beam transmittance function T_1 .

(c) Can eliminate the need for the explicit
determination of the volume attenuation func-
tion α insofar as α is required in the
customary solution procedures of apparent
contrast problems.

OUTLINE OF CURRENT PROCEDURES

The current procedure for determining the apparent contrast
$C_r(\underline{x}, \underline{\xi})$ of a given object is outlined in reference 1. Here
$C_r(\underline{x}, \underline{\xi})$ stands for the apparent contrast of an object at distance
r in the direction $\underline{\xi}$ as seen by an observer at $\underline{x}$. In
essence, the current procedure is based on the general contrast
transmittance formula:

$$\frac{C_r(\underline{x}, \underline{\xi})}{C_o(\underline{x}, \underline{\xi})} = \frac{{}_tN(\underline{x}_r, \underline{\xi})}{{}_bN(\underline{x}, \underline{\xi})} T_r(\underline{x}, \underline{\xi}) . \tag{1}$$

The beam transmittance $T_r(\underline{x}, \underline{\xi})$ for a path of sight (of
length r , oriented in the direction $\underline{\xi}$, and with initial point
at $\underline{x}$) is determined by first explicitly measuring the attenua-
tion length $L(\underline{x}') = 1/\alpha(\underline{x}')$ at each point $\underline{x}'$ of the path
of sight and then combining these L -quantities in the manner shown

in equation (16) of reference 1. Knowledge of the radiance distribution $N(\underset{\sim}{x}, \cdot)$ at each point $\underset{\sim}{x}$ of the medium supplies the remaining information to evaluate the right-hand side of (1) which, along with information about the reflectance properties of the given object, finally allows a determination of $C_o(\underset{\sim}{x}_t, \underset{\sim}{\xi})$ and hence the required $C_t(\underset{\sim}{x}, \xi)$.

The weakest link in the presently employed chain of computations leading to $C_t(\underset{\sim}{x}, \xi)$ is the one concerned with the determination of $L(\underset{\sim}{x}')$: the present method requires that $L(\underset{\sim}{x}')$ be determined by a particular case of the following formula:

$$L(\underset{\sim}{x}) = \frac{N_q(\underset{\sim}{x}, \underset{\sim}{\xi})}{N_*(\underset{\sim}{x}, \xi)} \tag{2}$$

(equation (11) of reference 1). Specifically, it is required to find a direction $\underset{\sim}{\xi}_0$ along which $N_*(\underset{\sim}{x}, \underset{\sim}{\xi}_0)$ (and hence $N_q(\underset{\sim}{x}, \underset{\sim}{\xi}_0)$) is independent of $\underset{\sim}{x}$. Strictly, in real media, no such direction $\underset{\sim}{\xi}_0$ generally exists; however, the current procedure makes use of the fact that any horizontal $\underset{\sim}{\xi}_0$ in horizontally stratified atmospheres or hydrospheres comes very close to satisfying the above requirements for most practical purposes. But the attendant effort required to continuously and accurately align airborne or submarine-borne instruments precisely in these distinguished directions $\underset{\sim}{\xi}_0$ becomes exceedingly difficult. Other means of determing $L(\underset{\sim}{x}')$ also exist. But these, too, are made to depend on various

assumptions about the atmosphere (such as optical standard atmos-
phere, special lighting conditions, etc.).

These considerations lead us to search for an alternate experi-
mental-theoretical procedure leading to the determination of
$C_r(\underline{x}, \underline{\xi})$. The procedure proposed below eliminates the diffi-
culties centering around the explicit determination of $L(\underline{x}')$ by
replacing this quantity by another whose determination requires nei-
ther the horizontal stratification assumption nor the need to seek
out and align the measuring apparatus along certain distinguished
directions, nor any other special assumptions about the optical proper-
ties or light field structure in the medium.

THE CONCEPT OF THE CONTRAST TRANSMITTANCE DISTRIBUTION

The proposed alternate procedure is also based on formula (1).
However, the contrast transmittance C_r/C_o will not be decomposed
explicitly into the product of two quantities, namely the product
of the radiance ratio ${}_b N(\underline{x}_t, \underline{\xi})/{}_b N(\underline{x}, \underline{\xi})$ and the beam transmittance
$T_r(\underline{x}, \underline{\xi})$. Rather, the contrast transmittance will be considered
as a fundamental irreducible observable. In short, it will take
the role of an <u>apparent</u> optical property of the medium, just as
T_r takes the role of an <u>inherent</u> optical property of the medium.
Thus contrast transmittance takes on the same status as the
K -functions used in hydrological optics (reference 2): that is,
it is dependent upon the simultaneous combination of the ephemeral

light field (by virtue of the presence of the ratio $_{t}N(\underline{x},t,\underline{\xi})/_{t_0}N(\underline{x},\underline{\xi}))$

and the local inherent optical properties of the medium (by virtue

of the presence of $\overline{\underline{T}_{r}}$). However, as in the case of the K -func-

tions of hydrological optics, it possesses sufficient regularities

which serve to elevate it to the level of an apparent optical pro-

perty of the medium and to be used as such in both the experimental

documentation of the medium and in the subsequent visibility calcu-

lations associated with the medium. This thesis will now be developed.

Definition of $\overline{J}_1$

Consider the schematic representation of an experimental appa-

ratus in Figure 1. It consists of a Gershun tube G at point $\underline{x}$

and a target at range $r = 1$ meters (say) from G of inherent

radiance $N_0 = 0$. The line of sight is along an arbitrary

direction $\underline{\xi}$. The instrument is devised so that it reads directly

the observable ratio

$$\overline{J}_1(\underline{x},\underline{\xi}) = \frac{C_1(\underline{x},\underline{\xi})}{C_0(\underline{x},\underline{\xi})} = -C_1(\underline{x},\underline{\xi}), \qquad (3)$$

which is simply the negative of the apparent contrast of the target.

against its background as seen at $\underline{x}$ from a unit distance away

from the target in the direction $\underline{\xi}$. We observe that definition

(3) need not be restricted to the adopted special value $C_0(\underline{x},\underline{\xi}) = -1$

C_0 could actually be any real number other than zero, but for

simplicity, C_0 will be taken as -1 .

Now the analytic structure of $\mathcal{J}_1$ is of the same kind
as radiance: the complete specification of some value of $\mathcal{J}_1$ is
made only after the location $\underset{\sim}{x}$ and direction $\underset{\sim}{\xi}$ of $\ominus$ have been
given. Furthermore $\mathcal{J}_1$, is implicitly associated with a given
wavelength of radiant energy. Thus, in analogy to the radiance
distribution $N(\underset{\sim}{x}, \cdot)$ at $\underset{\sim}{x}$ which is a function assigning to
each direction $\underset{\sim}{\xi}$ a radiance value $N(\underset{\sim}{x}, \underset{\sim}{\xi})$ at $\underset{\sim}{x}$, we
have the notion of the <u>contrast transmittance distribution</u> $\mathcal{J}_1(\underset{\sim}{x}, \cdot)$
at $\underset{\sim}{x}$, which assigns to each direction $\underset{\sim}{\xi}$ a contrast transmittance
value $\mathcal{J}_1(\underset{\sim}{x}, \underset{\sim}{\xi})$ at $\underset{\sim}{x}$. We underscore the observation
that the concept $\mathcal{J}_1$, is a <u>local</u> concept in the same sense
that N , N_* , N_q , and $\mathcal{U}$ are local concepts which are
associated with a given point and direction at that point in an
optical medium. The key analytic property of the function $\mathcal{J}_1$,
which endows it with a utility favorably comparable to that of the
analogous beam transmittance function will now be discussed.

The Semi-group Property of $\mathcal{J}_r$

The so-called semi-group property of T_r is well known.
Suppose we have two contiguous path segments of length r_1 and r_2
along a common natural path P (Figure 2). Then, in its simplest
form, the semi-group property of T_r asserts that:

$$T_{r_1} \, T_{r_2} = T_{r_1 + r_2} \, .$$

(4)

This property holds for an arbitrary path of length $r = r_1 + r_2$ over which the volume attenuation function α is of arbitrary structure.

To show that the semi-group property is possessed by the contrast transmittance function, we return to (1). In general, for an arbitrary path of length r , define

$$\mathcal{T}_r(\underline{x}, \underline{\xi}) = \frac{C_r(\underline{x}, \underline{\xi})}{C_0(\underline{x}', \underline{\xi})} \tag{5}$$

where $\underline{x}$ is the observation point and $\underline{x}'$ the (generalized) target point of the path P .

Then, according to (1) and the notation of Figure 2, we have, for each of the two locations $\underline{x}_1, \underline{x}_2$ along the path P , the following particular expressions for $\mathcal{T}_r$:

For the segment $(\underline{x}_1, \underline{x}_2)$ along P :

$$\mathcal{T}_{r_1}(\underline{x}_1, \underline{\xi}) = \frac{b N(\underline{x}_2, \underline{\xi})}{b N(\underline{x}_1, \underline{\xi})} T_{r_1}(\underline{x}_1, \underline{\xi}), \tag{6}$$

For the segment $(\underline{x}_2, \underline{x}_3)$ along P :

$$\tilde{\mathcal{J}}_{t_2}(x_2,\xi) = \frac{b N(x_3,\xi)}{b N(x_2,\xi)} \cdot T_{t_2}(x_2,\xi).   \tag{7}$$

For the entire path P :

$$\tilde{\mathcal{J}}_{t}(x_1,\xi) = \frac{b N(x_3,\xi)}{b N(x_1,\xi)} T_{t}(x_1,\xi).   \tag{8}$$

Then the product

$$\tilde{\mathcal{J}}_{t_1}(x_1,\xi) \; \tilde{\mathcal{J}}_{t_2}(x_2,\xi)$$

reduces to

$$\tilde{\mathcal{J}}_{t_1}(x_1,\xi)\tilde{\mathcal{J}}_{t_2}(x_2,\xi) = \frac{b N(x_3,\xi)}{b N(x_1,\xi)} T_{t_1+t_2}(x_1,\xi) = \tilde{\mathcal{J}}_{t_1+t_2}(x_1,\xi)   \tag{9}$$

in which the semi-group property (4) of T_t has been used. Thus, in the sense made clear in (9), the function $\tilde{\mathcal{J}}_t$ possesses its own semi-group property:

$$\tilde{\mathcal{J}}_{t_1} \tilde{\mathcal{J}}_{t_2} = \tilde{\mathcal{J}}_{t_1+t_2} .   \tag{10}$$

Application of the Semi-Group Property of $\widetilde{\mathcal{J}}_{r}$ to $\mathcal{J}_{l}$

The general property (10) of $\widetilde{\mathcal{J}}_{r}$ is immediately applicable to the basic contrast transmittance distribution $\widetilde{\mathcal{J}}_{l}$ by setting $r = l$. Suppose that the distribution $\widetilde{\mathcal{J}}_{l}(x, \cdot)$ has been experimentally determined at all points $\underset{\sim}{x}$ of an optical medium (e.g., some aerosol or hydrosol). Then its values are known in particular all along some given line of sight P (Figure 3). This information allows the computation of the contrast transmittance $\widetilde{\mathcal{J}}_{r}(x_{1}, \xi)$ for the entire line of sight as follows:

Divide the line of sight into n segments, each of unit length (i.e., the unit of length associated with $\widetilde{\mathcal{J}}_{l}$). Then since $\widetilde{\mathcal{J}}_{l}$ is a special case of $\widetilde{\mathcal{J}}_{r}$, we have immediately, by successive applications of (10):

$$\widetilde{\mathcal{J}}_{r}(\underset{\sim}{x}_{1}, \xi) = \prod_{\lambda=1}^{n} \widetilde{\mathcal{J}}_{l}(x_{\lambda}, \xi). \qquad (11)$$

THE N-DISTRIBUTION AND $\mathcal{J}_i$ -DISTRIBUTION AS BASIC EXPERIMENTAL OBSERVABLES

The various observations presented above may be summarized as follows:

(a) The contrast transmittance function $\mathcal{J}_i$ defined

in (3) is a directly observable quantity of the

light field in natural optical media such as the

atmosphere and the sea. It may be viewed, for the

purposes of the experimental documentation of real

media, as an (apparent) optical property of these

media. It possesses the same basic analytic

properties as the beam transmittance function T_i

(equations (4) and (10)) which has made T_i

useful in engineering calculations of contrast

transmittance, but is free of certain fundamentally

difficult intermediate measuring procedures

required to determine T_i .

(b) In view of the general relation (1), the basic

formula for the apparent contrast $C_r(x, \xi)$ may be

written

$$C_r(x, \xi) = \widetilde{\mathcal{J}}_r(x, \xi) \, C_0(x_t, \xi) \, ; \quad (12)$$

in which $\mathcal{J}_i(x, \xi)$ is determined from

knowledge of $\widetilde{\mathcal{J}}_i$ by means of formula (11).

(c) The complete solution of the general problem of
determining the apparent contrast $C_i(\underline{x}, \underline{\xi})$
of an object can be made to rest on the experi-
mental knowledge of two basic distributions: the
N -distribution, and the $\mathcal{T}_1$ -distribution.
That is, the N -distribution will allow the
determination of the inherent contrast C_o of a
given object. The required apparent contrast then
follows by use of the basic relation (12). In this
way the explicit determination of T_r is obviated,
and the problem of experimentally documenting any
given optical medium may be reduced to the deter-
mination of the two functions N and $\mathcal{T}_1$.

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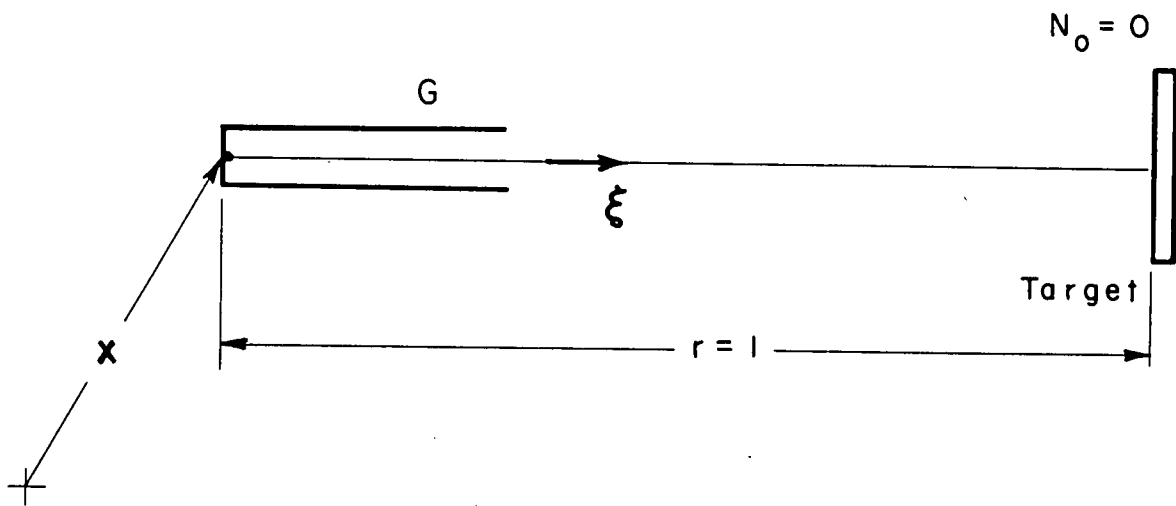
$N_o = 0$

G

ξ

Target

$r = l$

x

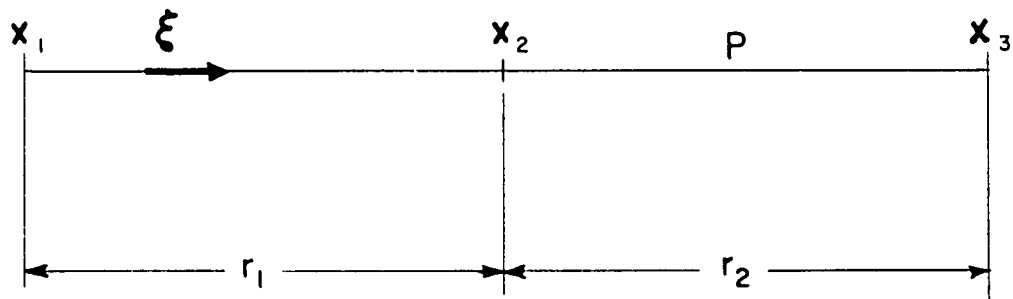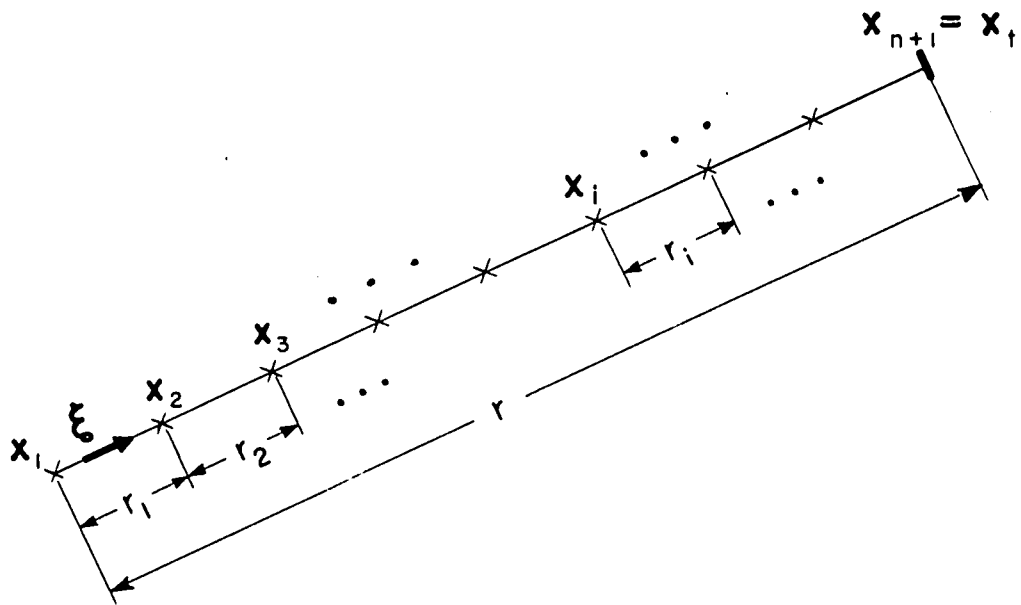Figure 1

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Figure 2

$$r_1 = r_2 = \cdots = r_i = \cdots = 1$$

Figure 3

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