EXECUTIVE SUMMARY

Visibility Model Verification by Image Processing Techniques

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by

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Visibility reduction due to air pollutants is particularly severe in urban areas like Los Angeles with many pollution sources and unfavorable meteorology. Air pollution abatement programs can be designed to improve visibility, but to do so in a deliberate fashion requires accurate, verified models which predict the effects on visibility of altering the air pollutant mixture. This study investigates visibility modeling methods that use simulated photographs to display the results of the visibility calculations. Visibility models of this kind are in their infancy at present and have never before been tested to confirm their accuracy in representing the appearance of heavy urban photochemical smog conditions. The purpose of this project is to apply image processing-based visibility modeling methods to Los Angeles regional haze conditions and to develop methods for testing the accuracy of this type of visibility modeling approach.

Visibility reduction is caused by scattering and absorption of light by particulate matter and by gases in the atmosphere. The Lambert law of attenuation describes this decrease in light from object to observer:

$$I(s) = I(o)\, e^{-b_{ext} s} \qquad \text{(i)}$$

where I(s) is the observed intensity at a distance, s, from the object; I(o) is the unattenuated intensity at the object; s is the

path length; b_{ext} is the extinction coefficient and accounts for light extinction due to absorption by particles, scattering by particles, absorption by gases, and scattering by gases. Light reaching an observer along a particular line of sight either could have come from the target viewed or could have been scattered into the line of sight. A second equation can be developed which includes not only light from the target but also skylight which is scattered into the line of sight:

$$I(s) = I(o)\ e^{-b_{ext}s} + I_{sky}(1-e^{-b_{ext}s}) \qquad \text{(ii)}$$

where I_{sky} is the intensity of the horizon sky.

Equation (ii) can be used as the basis for a visibility model that produces synthetic photographs of the appearance of a scene under prescribed air pollutant loading conditions (Malm, 1983). Such a model begins with a photograph taken under very clear conditions. This is the base photograph. This base photograph is broken down into a matrix of millions of small picture elements. The color and brightness values of these picture elements are stored in a computer. Smog is "added" to this base photograph by modifying the color and brightness of each picture element in accordance with equation (ii). The modified image can be played back onto color negative film to produce a synthetic photograph of the smog condition being simulated.

The accuracy of the results obtained by previous investigators using this type of visibility modeling approach has not been tested extensively. In the present study, model verification tests will be devised based on comparing synthetic photographs to actual photographs taken under the conditions modeled.

In order to verify a mathematical modeling approach, it is necessary to obtain a high quality set of the input data on pollutant loading and visual appearance required by the model. An experimental program was developed in order to characterize the physical and chemical characteristics of the particulate matter and gaseous pollutants present in the atmosphere on a very clean day and on a very smoggy day in Pasadena, California.

During the experiments, standard photographs were taken of chosen scenes. The clean day image provides the substrate on which the synthetic smog calculations are performed, while the heavy smog day photographs will be compared to synthetic images produced by the visibility model. The physical and chemical information on pollutant properties obtained both on the clean and on the smoggy day was used to calculate the volume average refractive index of the aerosol and then the extinction coefficient for each event. The extinction coefficient, b_{ext}, is needed in equation (ii). Both I(o) and I_{sky} are determined from the clear-day photograph. The distance to objects, s, was determined using topographic maps and aerial photographs. Malm's (1983) modeling procedure based on equation (ii) assumes that I(o) and I_{sky} are independent of pollutant loading and are, therefore, constants. It is shown in the present report that this assumption is not strictly valid and that it leads to an overprediction in brightness levels, especially in the blue wavelengths.

Both the clear day and the smoggy day slides were digitized, i.e., converted into numerical form for image processing purposes. This digitization process measures the brightness level of each picture element in each of the red, green, and blue color planes which make up the photograph, and assigns a numerical density, DN, value to each point in the picture in each of the three color planes. DN values vary from 0 (black) to 255 (white) and represent the brightness level of a picture element. DN values can be related to optical density, D, values. Optical density is a measurement of light transmission through the film. From D values, the exposure, E, of the photographic slide at each point may be found using characteristic curves supplied by the film manufacturer. These exposure values are proportional to intensity values, I, and can be manipulated by using equation (ii). The extinction coefficient measured on the smoggy day is inserted into equation (ii) and is used to convert the exposure values for the clear day photo into exposure values corresponding to the smoggy day condition. The DN values corresponding to the new exposure level are found, and from this a synthetic image of the smog event can be formed. The synthetic smoggy image then is compared to the photograph taken of the actual smog event by considering both brightness and contrast levels.

The synthetic image that results from the model developed by Malm (1983) shows the contrast reduction characteristic of a smoggy day but differs from the actual image in one major respect. The synthetic photograph is too bright in all wavelengths, especially in the blue, due to an oversimplified treatment of the sky. This dominance of blue light results in synthetic photographs with a blue cast to them. This indicates that a more accurate model should be developed. Recommendations are made for the structure of an improved calculation scheme that includes the effects of multiple scattering, ground reflection, aerosol phase function, and object reflectivity.

The visibility model also was used in a predictive capacity. The appearance of scenes in the absence of sulfates and associated water and in the absence of aerosol carbon was created. On the day modeled, greater improvement in visibility resulted from the aerosol carbon removal.