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A NEW APPROACH TO AUTOMATIC IDENTIFICATION OF GROUND OBJECTS VIA THE REFLECTANCE LOOK-UP TABLES

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I. ABSTRACT

In the present study we describe a method to estimate the optical thickness of the atmospheric haze. A true surface reflectance data set is obtained from a LANDSAT data set by using the Atmospheric Effect Correction System developed at Kanazawa Institute of Technology. A data base of classes of land covers containing the statistical information on the spectral reflectance is constructed from true surface reflectance data sets. Finally a new and powerful table look-up approach in classification is described and the results are presented.

II. INTRODUCTION

It has been known that the contrast of the surface images obtained by the LANDSAT's multi-spectral scanner is frequently degraded by atmospheric haze. This atmospheric effect causes a significant decrease in classification accuracy. In the temporal analysis of a certain scene it is not possible to compare a LANDSAT data set with another LANDSAT data set quantitatively when they are taken on different dates (because of the different atmospheric haze conditions).

If the optical thickness of atmospheric haze is known, in principle, the true surface reflectances (albedo) can be obtained. This problem has been studied by Odell and Weinman(1975)[1] and more intensively by us(1978,1979)[2,3] Since it is not always possible to get the optical thickness of the haze by direct measurement, the development of methods to determine the optical thickness of the haze from the LANDSAT data itself is highly desirable. Potter and Mendlowitz (1975)[4] has studied on this problem.

In addition to the foregoing discussion, even if the value of the optical thickness of the haze is determined fairly accurately, we will face another difficulty when we try to make the ground truth data, such as the values of ground albedos, corresponded to the LANDSAT data. This difficulty is particularly true when various ground objects are mixed in a small area, such as those often found in a country like Japan. When thinking of the

cost and human resources, necessary to gather the albedo data of such a small area corresponding to only one pixel in the Landsat image, it should be concluded that this approach is not the right one and there must be an alternative way to get the same kind of information more effectively and cheeply. On the other hand, as the remote sensing of the Earth surface becomes operational and the volume of data increases, it is imperative to increase performance in data processing. These are major motivations by which we begin to work on the present study. Here we first describe a method to estimate the optical thickness of the haze. Then we make the true surface reflectance data set using the Atmospheric Effect Correction System. Finally a new and powerful table look-up method in classification is described using a data base of land cover classes with the statistical information on the surface reflectance. Such a data base is constructed from true surface reflectance data sets.

III. COMPUTATIONS FOR ATMOSPHERIC SCATTERING

Hansen(1969)[5] developed programs for computing atmospheric reflection and transmission, assuming a plane-parallel atmosphere containing the standard atmospheric gases, and arbitary vertical distribution of ozone and aerosol by adding and doubling method. In the computation the reflected intensity and the scattering phase function are expanded into Fourier series in the azimuthal angle. As the result, the reflected total intensity I_T(unit of $mw/cm^2 sr \mu m$) is a function of the optical thickness τ, polar angle, single scattering albedo w , and the surface albedo A.

Here we use the programs similar to Hansen's to compute the atmospheric effect on the Landsat data. The model atmosphere is bounded by the underlying surface with Lambertian characteristics. The scattering aerosols are assumed to be spherical particles with refractive index $n=1.33$. The scattering patterns are computed according to Mie theory. The haze model used here is a water haze M defined by Deirmendjian (1969)[6] Assuming the standard atmosphere of Elterman (1968)[7] as the model atmosphere, we compute the relationship between the reflected intensity and the surface albedo in the case of band 7 and it is shown in Figure 1. Almost linear relationship between the

intensity and the albedo holds in other Landsat bands. Figure 1 indicates that most photons received by sensor have at most twice interaction with the ground. The reflected total intensity and the direct radiance I_D may be expressed in quadratic form with respect to the surface albedo A.

$$I_T = P A^2 + Q A + R \qquad (1),$$

$$I_D = A (S A + T) \qquad (2).$$

These coefficients P,Q,R,S,and T are found by applying the least square method to the computed radiances , and the direct radiance is such radiance that it consists of photons which are reflected by the object on the ground and, reaching the sensor without suffering scattering.
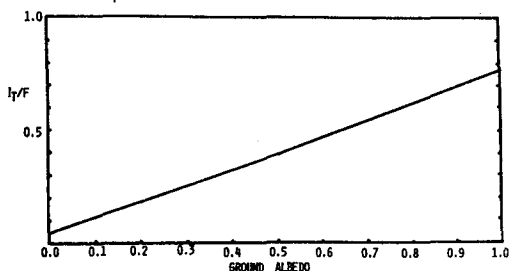

Figure 1. The theoretical intensity in band 7 against ground albedo. Incident solar flux is normalized to πF.

IV. ATMOSPHERIC EFFECT CORRECTION SYSTEM

We have implemented a system of computer software programs called the Atmospheric Effect Correction System (AECS) which corrects the atmospheric effect for both the Landsat and aircraft data. If the optical thickness of the haze is given, the AECS gives true surface reflectances (albedos). The overall flow of the AECS is shown in Figure 2. There are two subsystems, that is, the Inter-extrapolation subsystem and the Correction subsystem. The parameterized radiance coefficients P,Q,R,S and T for typical atmospheric models are stored in the Radiance file. To make this file we computed the theoretical radiances for many combinations of the wavelength, flight altitude and atmospheric model. As for wavelengths, four cases(0.475μm,0.575μm, 0.670μm and 0.845μm) are used. They correspond to the central wavelength of the MSS bands of Japan Research Comittee of Environmental Remote Sensing's airborne sensor. As for altitudes, three cases of

1 Km, 3 Km and 50 Km are used. The first two cases are applicable to the typical aircraft flight altitude whereas the case of 50 Km is to the Landsat case. As for atmospheric models, four models with different optical thickness values of the atmosphere in a given band are considered. Although considerable amount of computer time is required for such computations, it is very useful. Once the Radiance File is computed, then the reflected total intensity is computed very fast for any wavelength, flight altitude and optical thickness with the aid of inter-extrapolation program.

Let us discuss the Correction subsystem. To do the conversion from the observed CCT levels to the surface albedo values, we assume that the underlying surface is characterized by an albedo A_t for the target and by a mean background albedo $\overline{A}$ of the area whose horizontal scale is estimated about 300 m. Using the following relations we can find the surface albedo values for each pixel in the Landsat image.

$$\overline{A} = (-Q + \sqrt{Q^2 - 4P(R - \overline{I}_{obs})})/2P \qquad (3),$$

$$A_t = I_{obs} / (S \overline{A} + T) \qquad (4)$$

where I_{obs} is the observed radiance for a target and $\overline{I}_{obs}$ is the observed average radiance around a target. The true reflectance data set is, thus, obtained by the procedure described in the above from the original Landsat data set. We note here that values of P,Q,R,S, T,I_{obs} and $\overline{I}_{obs}$ are expressed in the unit of $mw/cm^2-sr-\mu m$.

V. ESTIMATION OF OPTICAL THICKNESS OF HAZE

In order to estimate the optical thickness of the atmospheric haze τ , we plot loci of the points producing the observed average radiance over a certain area in a two dimensional space. The vertical and horizontal axis correspond to the optical thickness of the haze and the surface albedo, respectively. We plot loci of such points producing the observed average radiance over sea, taken from a particular Landsat-III data set with date of Oct.23,1979 in Figure 3. The points on a locus with a expression B7 gives a pair of the optical thickness value and the albedo which satisfies the average radiance in band 7 observed by the Landsat-III above sea. Similarly, a locus with B4 gives an appropriate pair of the optical thickness value and the albedo in band 4. From this figure the optical thickness of the haze in band 4 is estimated to be about $\tau \simeq 0.45$, assuming the albedo of sea $A \simeq 0.06$. If we assume the albedo value of sea $A \simeq 0.015$ in band 7, we will obtain the optical thickness $\tau \simeq 0.22$. Since in our computational scheme the effect of O_3 absorption is taken into account but that of H_2O or O_2 is not, the optical thickness values in band 5,6 and 7 by this method might not be so reliable because of the existence of such H_2O or O_2 absorption in these bands. Instead, we estimate the optical thickness in these band according to the Elterman's optical thickness ratios among the wavelengths, on basis of
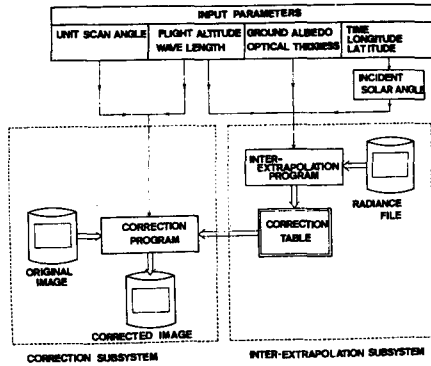
Figure 2. The block diagram of Atmosphere Effect Correction System.

Figure 3. Loci of points (τ, A) satisfying observations in bands 4 and 7. Study site: sea area.

an optical thickness value in band 4 estimated by the above method. The resulting optical thickness values are $\tau(B4)=0.45$, $\tau(B5)=0.350$, $\tau(B6)=0.284$, $\tau(B7)=0.225$. The values in band 7 estimated by both methods are about equal. The optical thickness of the haze will be estimated by using the foregoing procedures from the Landsat data itself.

VI. DATA BASE AND TABLE LOOK-UP APPROACH

Let us introduce a classification technique by table look-up approach. The major advantage of the table look-up approach is a drastic reduction in computer time. An idea and its implementation of the table look-up algorithm in the classification has been developed by Eppler et. al.(1971)[8]and by Jones (1974)[9] But their method is aimed to classify a Landsat MSS frame quickly. Our study is intended to make a data base of class statistics from many Landsat frames and then to classify any Landsat frame using a table look-up approach. These procedures become possible only when the true reflectance data are possible. In our study they are obtained using methods described in the proceeding two sections.

We show the overall data flow in Figure 4. There are two phases,i.e., the Data Base phase and the Table Look-up phase. The Data Base phase consists of three program steps, that is, the AECS step, the Classification step, and the Updating step. In the AECS step the original Landsat data set is converted to the true surface reflectance data set. Then the Classification step produces both classification map and the statistical quantities for each class of the land cover. The Updating step updates the statistical quantities for certain classes if necessary. The human intervention is also introduced in the Data Base phase when it is needed. The conventional classification techniques based on the maximum likelihood decision rule is used in the Classification step. The accumulated statistics on pattern classes are stored in the form of Table of Reflectance Pattern Class (TRPC) in computer disk. In the TRPC each class is expressed in terms of three
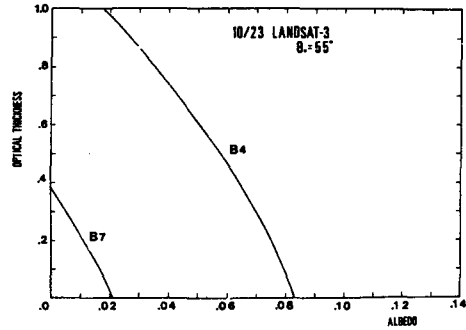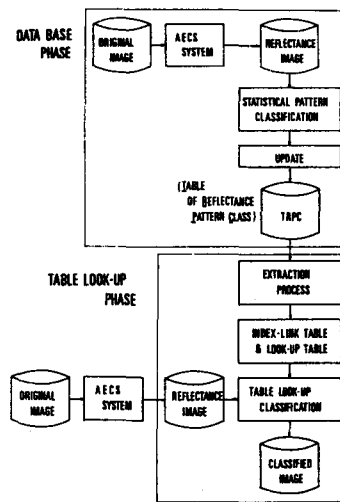

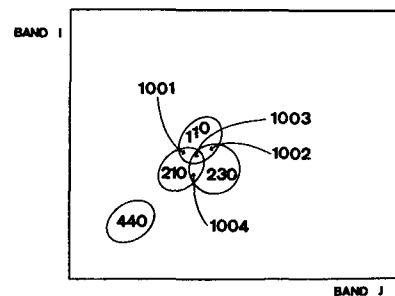Figure 4. The overall flow of Table Look-Up Approach.

Figure 5. The confidence regions of classes in a two dimensional band space.

digits. The first digit gives a basic land cover such as forest, sea, urban and so on. The next two digits specify more detailed category such as evergreen forest, deciduous forest, ocean and so on. The correspondence between this three digits class number and the actual land cover is done through the ground truth. The TRPC should contain the following information: three digits class number, its mean albedo values in bands 4,5,6, and 7, its covariance matrices, the reliability bound, the scene ID number, the date of exposure,etc. The reliability bound gives the seasonal reliability of class statistics.

The Table Look-up phase consists of three steps, other than the AECS. In the Extraction step an appropriate part of the large data base TRPC is extracted according to the date when the Landsat data set to be classified was taken. If all patterns are normally distributed, it is said that the Mahalanobis distance $D^2(i)$ between a point belonging to a class with class number i and its class center has a chi-square distribution. Next, in the Table Look-up step, we construct confidence regions for classes in a two dimensional band space using the extracted class statistics. If a sample point satisfying equation (5), we can expect that a sample point belongs to a class with class number i, with $100(1-\alpha)$ % confidence.

$$D^2(i) \leq \chi^2(2\alpha) \qquad (5).$$

In our study $\alpha = 0.05$ is used. When the overlap domains appear as shown in Figure 5, they are sequentially numbered as 1001,1002,$\cdots$. Such numbers are called index numbers. The linked list structure is useful to determine which classs are involved in the overlap domain. We use two tables here,i.e., a index table INDEX and a linked list LINK. They are shown in Figure 6. Column 1 of INDEX contains the index numbers. Column 2 of INDEX contains nonnegative integers, called pointers, the value of which is the row of the array LINK. LINK contains the class numbers in column 1 and the pointers in column 2. The values of the pointers in column 2 of LINK is the row of its array containing the next class number. When the value of pointer becomes zero, it indicates the end of the list. For example, we will find classes with class number 210 and 110 by which the overlap domain 1001 is made, using tables in Figure 6. The confidence regions for pattern classes in a two dimensional band space are tabulated and stored in look-up table LUT. An element LUT(m,n) is a class number, where $0 \leq m \leq 100$, and $0 \leq n \leq 100$. Row numbers of LUT are equal to the albedo values expressed in percentage in band I and column numbers are the albedo values in band J. Values of I and J could be chosen from 4, 5, 6, and 7, but $I \neq J$. The sample array of look-up table LUT is shown in Figure 7.

The consultation of look-up table is done in the following. If an unknown albedo pattern having x = (15,10), the look-up table LUT will assign to a class with class number 440 for such a pattern (see Figure 7). Supposing an assigned class number
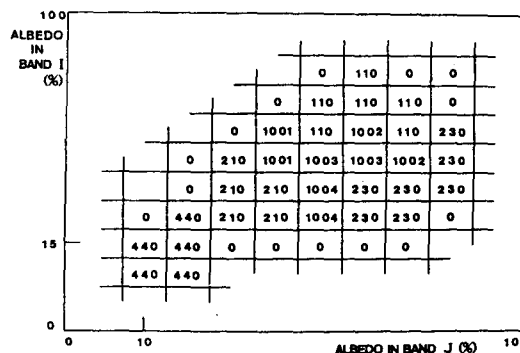

Figure 6. Tables of INDEX and LINK.

Figure 7. Sample array of Look-Up Table.

k >1000, then a pattern falls in an overlap domain. Tables of INDEX and LINK are referred and they identify classes involving an overlap. The Mahalanobis distances from a pattern to each class center are computed and a pattern is assigned to a class which gives the minimum D^2. Finally a classified map is, thus, obtained applying the foregoing table look-up approach to every pixel in a true reflectance data set.

VII. DISCUSSIONS

One of the most important results in the

present paper is that values of true ground albedos are obtained from those of observed CCT counts using the Atmospheric Effect Correction System. Without correcting the atmospheric effect, the same ground object might be assigned to different signatures in the classification. A table look-up approach which gives the quick identification of ground objects for an arbitary Landsat image will be a powerful tool in signature extension as the contents of the data base TRPC containing the class statistics increase.

As a preliminary test, we apply our methods to a subset of an actual Landsat data set. The results are as follows: The studied imagery consists of 256 x 256 pixels. Significant improvement was found in the accuracy of the classification using the true reflectance data set obtained by the Atmospheric Effect Correction System. This was particularly true for fine structures on the ground, such as canal, break water, etc. As for computer times, the time required to classify 256 x 256 pixels into 11 clases by a table look-up approach was about 50 seconds of IBM 3031 CPU time, whereas 8 minutes were needed to do the classification by a convensional method based on the maximum likelihood decision rule.

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