# NASATECHNICAL MEMORANDUM 

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TECHNIQUE AND COMPUTER PROGRAM FOR CALCULATING<br>PHOTOGRAPHIC FILM DENSITY VARIATIONS<br>BY Craig W. Oh hhorst

(NASA-TM-X-72664) TECHNIQUE AND COMPUTER PROGRAM FOR CALCULATING PHOTOGRAPHIC FILM DENSITY VARIATIONS (NASA) $32 \mathrm{p} \mathrm{HC} \mathrm{\$ 3.75}$ CSCL.14E UnClas $G 3 / 35 \quad 11084$

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## SUMMARY

A technique and computer program have been developed to calculate the film density difference between the unexposed film border and any point on a. photograph. The program calculates the angle off the principal axis of the camera lens so that a correction can be made for vignetting and atmospheric backscattering. The program also plots the computed values as a function of position on the photograph so that a three-dimensional.picture is produced. Ranges of density difference can be predetermined, and the program will place each data point into its corresponding range so that the percentage of points in each ranget can be calculated.

SYMBOLS

AA
proportionality constant, mm/BCD

AVERAGE number in BCD format representing the density of the unexposed film area

BB proportionality constant representing the gradient of the linear density wedge, density/mm
microdensitometer recorded film density
CI represents the number of data points recorded from the border line trace

Sum represents the summation of BCD numbers for the data points recorded from the border line trace

XMM: calculated film density difference, density
ZZ correction factor for vignetting and atmospheric backscattering
$\triangle B C D \quad$ difference in $B C D$ numbers between any two.points
$\phi \quad$ angle off the principal axis of the camera lens, degrees

| $\phi_{\mathrm{Aj}}$ | vertical component of $\phi$, degrees |
| :--- | :--- |
| $\phi_{\mathrm{pi}}$ | horizontal component of $\phi$, degrees |
| $\theta$ | camera horizontal half angle, degrees |

## INTRODUCTION

It takes considerable time and money to collect and analyze water samples to determine the health state of a body of water. Development of an instrument that could remotely determine the water quality of a body of water would be of great benefit to the effort of monitoring the water quality of this nation's rivers and lakes.

The NASA Langley Research Center, in conjunction with other federal. agencies, has been working on a program to develop and evaluate instruments that will have the capacity to remotely determine various water quality parameters. One of the instruments being evaluated is a wide-angle lens, aerial photography system with appropriate lens filter combinations. The wide-angle lens is used to get both high spatial resolution and a synoptic view at the same time. Film density of the photographs are then analyzed to see if there is a correlation between radiance intensity and certain water quality parameters. It has been shown in reference 1 , for example, that the film density difference between the unexposed film border and a point on a photograph can be correlated to chlorophyll a concentrations.

Data obtained using the wide-angle lens require a mathematical correction to the film densities to compensate for atmospheric backscattering and lens vignetting. The correction needed is a function of location on the photograph (angle off the principal axis of the lens). The principal axis is assumed here to be the same as the perpendicular vertical intersecting the center point of the photograph. Each data point will have a unique angle, so a method to calculate this angle is needed. A microdensitometer, an isodensitracer, and a magnetic tape encoder were combined to digitalize the film densities. This paper presents a technique and computer progran to convert digitalized film densities into a number representing the film density difference between the unexposed film border and a point on the photograph.

PROBLEM TASK DESCRIPTION

A National Instruments Laboratories' Isodensitracer and Magnetic Tape Digital Encoder System are used to digitalize film densities obtained from a Joyce, Label and Company Microdensitometer. These are recorded in Binary Coded Decimal (BCD) format. The problem considered in this paper is that of calculating the film density difference between the unexposed film border and any recorded data point.

## TECHNIQUE FOR COMPUTING FILM DENSITY DIFFERENCES

The Joyce, Lobel and Company Microdensitometer, Model Mark III C, has been modified electronically to utilize the automatic interval stepper of the isodensitracer so that the microdensitometer can automatically scan a full photograph. The microdensitometer uses a double-beam system in which two light beams from a single source are alternately impinged on a photomultiplier tube. ${ }^{2}$ The photomultiplier alternately sees the beam going through the specimen and through a reference linear density wedge, thus providing an electrical signal which causes movements of a servomotor to bring the linear wedge into optical balance with the specimen beam. A pen attached to the linear wedge carriage plots the position of the wedge resulting in a plot of the density. The vertical distance that the tracing pen moves, (see figure l), equals the distance that the linear wedge is shifted to optically balance the reference and specimen beam. Multiplication of this vertical pen distance by the slope ( $B B$, density $/ \mathrm{mm}$ ) of the linear density wedge will give a film density difference value.

The Magnetic Tape Encoder System is mounted on the rear of the mi'crodensitometer and attached to one of the pulleys driving the linear density wedge. A multicommutator is mounted on the x-axis of the flat bed recorder. This commutator provides $5,10,20,50$, or 100 contacts per revolution and is so mounted to provide approximately 10 revolutions for one traverse of the recording table on the X-axis. At each point of contact, density datum is recorded. The encoder provides a BCD output corresponding to one of 175 positions evenly spread out along the length of the linear wedge; thus, there is a direct proportionality between the magnitude of the difference in $B C D$ numbers between any two points and the vertical pen distance between those points.

$$
\text { Vertical Pen Distance }=(A A)(\triangle B C D)
$$

The proportionality constant (AA) has been hand calculated and stored in the program. (See Appendix A for the calculation of AA.) A mathematical computation subtracting the recorded BCD number for a specific data point from the BCD number representing the unexposed film border (AVERAGE) will give the $\triangle B C D$ number for that data point. AVERAGE is calculated by summing up the BCD numbers of the border trace and dividing by the total number of points in that trace.

$$
\text { AVERAGE }=\text { Sum } / \mathrm{CT}
$$

As previously stated, multiplication of the vertical pen distance by constant BB would give the film density difference for a specific data point. Use of a wide-angle lens requires that a correction for vignetting and atmospheric backscattering be made. The correction must be applied to the vertical pen distance before multiplication by BB. The correction factor ( ZZ ), can be calculated and applies to each data point, provided the angle $\phi$ for each point is known (see fig. 2). For the photograph shown in this paper, ZZ was set equal to $\cos ^{2} \phi$. The angle $\phi$ can be broken up into its horizontal and vertical components with

$$
\tan ^{2} \phi=\tan ^{2} \phi_{p i}+\tan ^{2} \phi_{A J} .
$$

The angles $\phi_{p i}$ and $\phi_{A j}$ can be calculated since the number of points recorded per scan and the number of scan lines are known.

$$
\begin{aligned}
& \phi_{\mathrm{pi}}=\frac{\text { Camera horizontal half angle }}{1 / 2(\text { number of points per scan })} \times \mathrm{p}_{i} \\
& \phi_{\mathrm{A} j}=\frac{\text { Camera horizontal half angle }}{1 / 2(\text { total number of scan lines })} \times A_{j}
\end{aligned}
$$

$$
\text { where } \begin{aligned}
p_{i} & =i t h \text { point from the center of the film } \\
A_{j} & =\text { jth line from the centerline }
\end{aligned}
$$

These angles are calculated by the user, converted to $\tan ^{2}$ values by the user, and stored by Data Statements in the program. The program calls the appropriate $\tan ^{2} \phi_{p i}$ and $\tan ^{2} \phi_{A j}$ values for each data point, adds them together, and calculates $\phi$. Thus, the steps for calculating the film density difference are:

1. Calculation of AVERAGE
2. $A V E R A G E-B C D=\triangle B C D$
3. $(\triangle B C D) X(A A)=$ Vertical Pen Distance
4. Calculation of $\phi$
5. Calculation of $Z Z$
6. (Vertical Pen Distance) $/(\mathrm{ZZ})=$ Corrected Vertical Pen Distance
7. (Corrected Vertical Pen Distance) $X(B B)=X M M$

PROGRAM DESCRIPTION

Program CONVERT is written in Fortran IV for the Control Data 6000 series computers. It uses Langley Research Center Library subroutines PSEUDO, CALPLT, AXIS, LINPLT, NFRAME; and Library functions SQRT, ATAN, and COS. The program also uses Subroutine ENCOD, which is not in the Langley Computer Library but was developed by Langley personnel for use with the Magnetic Tape Encoder.

## Program CONVERT

Program CONVERT is used for the input and output of data. It initializes the variables. Subroutine ENCOD takes the information off the tape, and the program calculates the corrected film density difference values. Each value is placed in a range of density differences by the program so that the
percentage of points in each range can be calculated. The user specifies the desired density difference ranges. Program CONVERT also plots the computed values as a function of position on the photograph so that a threedimensional picture is produced with the third dimension being the density difference.

A specific order of data input onto the recording tape must be followed for the program to work properly. The specific order needed is explained in Appendix B, and a program listing is given in Appendix C. The flow diagram of program CONVERT is shown on pages 6 and 7 .

## PROGRAM USAGE

The program is run on the Control Data 6000 series computer under the Scope 3.0 operating system and requires a field length of 60,0008 storage locations. The Central Processing Unit (CPU) time will depend on the number of data points recorded. A CPU time of 150 seconds will usually be enough to analyze one 70 mm size photograph with 50,000 data points recorded.

## Input Description

Most of the input data comes from the user submitted tape. Other input data terms are as follows:

PPP array of Kodak step wedge densities corresponding to the wedge steps that were traced over by the microdensitometer, inputed by a Data Statement

CFX array of the $\tan ^{2} \phi_{\mathrm{pi}}$ values for each data point in a line,
inputed by a Data Statement
CFY array of the $\tan ^{2} \phi_{A j}$ values for each line, inputed by a Data Statement

AA constant, mm/BCD

BB constant, density/mm

Desired density difference ranges--entered by IF Statements.

Output Description

The output for program CONVERT consists of these elements:

1. Five lines of machine setting and other non-density data. See Table I for sample listing. The settings are recorded by the Fixed Data Switches on the Magnetic Tape Encoder (see Appendix D).


## continued Flow Diagram


2. Table of step wedge density versus assigned BCD number. Analysis of the BCD numbers will determine if the microdensitometer is working properly, There should be a constant difference, $\pm 1$, between any two BCD numbers. (See Table II.
3. A counter (y-number) specifying what trace the upcoming data represents. A zero means that the border trace is printed next. See top left corner of Table III.
4. The border trace is printed in BCD format so that the user can check the density variation. From these data, AVERAGE is calculated and printed out. See Table III.
5. Calculated density difference values for each scan. There are twelve data points printed per line of printout. See Table IV.
6. Table of density difference range, number of points in each range, and the percentage of total number of data points in each range. See Table V.

CC Fepresents total number of data points
$E A, E B, E C, E D, E E, E F, E G, E H \quad$ represent the number of data points in specific difference ranges.
7. Computer plot

The plot is a three-dimensional picture of the calculated film density differences. Each line is plotted from right to left. The actual scales allow for each point on a line to be plotted $2.54 \mathrm{~mm}(0.1 \mathrm{in}$.$) apart, and$ the starting point of each successive line is shifted $0.762 \mathrm{~mm}(0.03 \mathrm{in}$.$) to the left. See$ figure 3.

Machine Setting Terms are as follows:

A

B

G
condenser
height of light spot on the aperture plate of the microdensitometer, recorded as two BCD numbers
width of light spot on the sperture plate of the microdensitometer, recorded as three BCD digits
width of light spot on the photograph, recorded as three $B C D$ digits
focuses the light beam on the photograph, number represents the lens power, recorded as two BCD digits

| wedge | represents density range of the linear wedge, recorded as two $B C D$ digits |
| :---: | :---: |
| commutator | represents the number of segments that the linear wedge is broken up into by the isodensitracer, recorded as two BCD digits |
| dif. control | an electronic control which varies the amount of feedback signal to the table drive unit, recorded as two BCD digits |
| pen damping | controls the speed of the tracing pen when the microdensitometer is used in manual mode, recorded as two BCD digits |
| write-out arm ratio | ```ratio of recording table movement to specimen table movement, recorded as three BCD digits``` |
| pen stop multiplier | number of 125 micron-steps that the isodensitracer recording pen takes between successive scans, used when the system is set to run in automatic mode, recorded as two BCD digits |
| spec. step multiplier | number of 25 micron-steps that the specimen table is moved between successive scans, used when the system is set to automatic mode, recorded as two BCD digits |
| objective | focuses light from the specimen table onto the aperture plate of the microdensitometer; number represents the lens power, recorded as two BCD digits |
| magnification | built into the microdensitometer, number represents lens power recorded as two BCD digits |
| resolution | number of data points recorded by the magnetic tape encoder system per inch of recording table movement, recorded as three BCD digits |
| film number | number assigned to distinguish the photograph from others, recorded as five BCD digits |
| cal. strip number | number specifying the Kodak step wedge used, recorded as five $B C D$ digits |

```
step low density number of the lowest Kodak density step
    traced over, recorded as two BCD digits
    number of the highest Kodak density step
traced over, recorded as two BCD digits
```

SAMPLE CASE

A positive transparency of a 70 mm photograph taken above Maryland Point on the Potomac River in October 1972 was used for the sample case. (See figure 1.) The picture was taken by a Hasselblad 500 EL camera at an altitude of $3,048 \mathrm{~m}(10,000 \mathrm{ft})$. The camera had a 40 mm focal length and a Wratten 89 B filter was attached. An F-stop of 8 was used with a shutter speed of $1 / 250$ seconds. The positive transparency was overdeveloped to bring out the features in the water. The white area covering the top third of the photograph is land. The rest of the picture is water. Ground truth data have shown the water to be heavily concentrated with blue-green algae. Analysis has shown that the white sections in the water are areas with sufficient algae density to produce chlorophyll concentrations greater than $34 \mu \mathrm{~g} / \mathrm{h}$.

Density data on the photograph were measured by the microdensitometer from left to right in the horizontal direction and from bottom to top in the vertical direction. The system was set up so that 406 data points were recorded from each scan with 101 scans evenly spaced and covering the whole photograph.

## Sample Input Data

PPP
$0.05,0.20,0.36,0.50,0.64,0.79,0.94,1.09,1.23,1.38,1.53$
CFX the array of $\tan ^{2} \phi_{p i}$ values inputed as printed out in the program listing (Appendix C)
CFY the array of $\tan ^{2} \phi_{A J}$ values inputed as printed out in the program listing (Appendix C)
$A A=1.1530 \mathrm{~mm} / \mathrm{BCD}$
$\mathrm{BB}=0.0130$ density change $/ \mathrm{mm}^{3}$
Density difference ranges $<0.143,0.143-0.195,0.195-0.260,0.260-0.299$, $0.299-0.546,0.546-0.650,0.650-1.400,1.400$

Sample Output
The printed output is shown in Tables I through Table $V$ with the computer plot shown in figure 3 .

A technique and computer program have been developed to calculate the film density difference between the unexposed film border and any point on a photograph. The program calculates the angle off the principal axis of the camera lens so that a correction can be made for vignetting and atmospheric backscattering. The program also plots the computed values as a function of position on the photograph so that a three-dimensional picture is produced. Ranges of density difference can be predetermined, and the program will place each data point into its corresponding range so that the percentage of points in each range can be calculated.

## APPENDIX A

## CALCULATION OF CONSTANT AA

Plotting of a density profile of a Kodak Step Weage (see figure 4) while at the same time recording the data on tape enables the constant AA to be calculated. The constant is computed by measuring the vertical distance between any two steps of the wedge on the profile and dividing by the difference between the corresponding $B C D$ numbers. The $B C D$ numbers are taken from Table II.

Example:
The distance between steps 3 and 7 of figure $A 1=62.2 \mathrm{~mm}$
The corresponding $B C D$ numbers are 97 for step 3 and 151 for step 7 .

$$
\triangle B C D=151-97=54
$$

$$
\frac{62.2 \mathrm{~mm}}{54}=\frac{1.1518 \mathrm{~mm}}{\triangle \mathrm{BCD}}
$$

The value of $1.1530 \mathrm{~mm} / \mathrm{BCD}$ assigned to AA in the sample case came about from the averaging of ten such calculations using the $F-140,2.4$ density wedge but should be good for any linear wedge used.

## APPENDIX B

## ORDER OF DATA INPUT NEEDED FOR PROGRAM CONVERT

To insure that program CONVERT works properly, a specific order of data input onto the recording magnetic tape should be followed.

First - Five lines of machine setting data should be inputed onto the tape. Use the fixed data switches.

2nd - A trace of a Kodak step wedge should be inputed next
3rd - A border trace should then be inputed
After these three steps have been followed, the program is now ready for these film data.

When the user is finished with one photograph, a set of fixed data should be inputed onto the tape with the first switch being set to 3 and then another set of fixed data placed in the tape with the first fixed data switch set at 9. See Appendix $D$ for an explanation of this first switch. When digitalizing a second photograph on the recording tape, the first and second steps from above can be left out.

When the user is finished putting data on a tape, an END OF FILE marker (EOF) should be placed on the tape. The EOF signifies to the computer that there is no more data on this specific tape and thus terminates the program.


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70.22751,0.22405,0.22062,0.21724,0.21390,0.21058,0.20731,0.20406, $80.20085,0.19767,0.19453,0.19142,0.18834,0.18529,0.18229,0.17931$. $90.17636,0.17345,0,17054,0.16770,0,16488,0.16207,0,15931,0,15659$, A $0.15389,0.15123,0.14856,0.14595,0.14338,0.14083,0.13831,0.13579$, B0.13333,0.13089,0.12848,0.12610,0.12372,0.12140,0.11909,0.11682 $C 0.11457 .0 .11233 .0 .11014 .0 .10796,0-10582.0 .10370 .0 .10160 .0 .09953$. D0.09748,0.09546,0.09347,0.09149,0.08954,0.08763,0.08573,0.08386. E0.08200.0.08017.0.07837.0.07660.0.07484.0.07310.0.07139.0.06971. F0.06804:0.06640.0.06478.0.06.118.0.06161.0.06006.0.05853.0.05702 DATA(CFX(I), $1=126,250) / 0.05553,0,05407,0.05262,0.05120,0,04980$, $10.04842,0.04706,0.04572,0.04441,0.04311,0.04184,0.04058,0,03935$, $20.03814,0.03694,0.03577,0.03462,0.03349,0.03237,0.03128,0.03021$, $30.02916,0.02812,0.02111,0.02612,0.02514,0.02419,0.02325,0.02234$, $40.02144,0.02056,0.01970,0.01886,0.01804,0.01724,0.01646,0.01569$. $50.01495,0.01422,0.01351,0.01282,0.01215,0.01150,0.01086,0.01025$, $60.00965 \cdot 0.00907 \cdot 0.00851 \cdot 0.00797,0.00744 \cdot 0.00693 .0 .00645,0.00598$. $70.00552,0.00509,0.00467,0.00427,0.00389,0.00353,0.00319,0.00286$. $80.00255,0.00226,0.00198,0.00173,0.00149,0.00127,0.00107,0,00088$, $90.00071,0.00056,0.00043,0.00032,0.00022,0.00014,0.00008,0.00004$, A0.00001,0.00000.0.00001.0.00004,0.00008,0.00014.0.00022.0.00032,日0.00043,0.00056,0.00071,0.00088,0.00107,0.00127,0.00149,0.00173, C $0.00198,0.00226,0.00255,0.00286,0.00319,0.00353,0.00389,0.00427$, D $0.00467 \cdot 0.00509 \cdot 0.00552 \cdot 0.00598 \cdot 0.00645 \cdot 0.00693 \cdot 0.00744$,0.00797, $E 0.00851,0,00907,0.00965,0.01025,0.01086,0,01150.0 .01215,0.012820$ F0.01351,0.01422.0.01495,0.01569.0.01646.0.01724,0.01804,0.018861 DATA (CFX(I), $1=251,3751 / 0,01970,0,02056,0,02144,0,02234,0,02325$, $\frac{10.02419,0.02514,0.02612,0.02711,0.02812,0.02916,0.03021,0.03128 .}{20.03237,0.03349 .0 .03462,0.03577,0.0369, ~}$ $30.04184,0.04349,0.03462,0.03577,0.03694,0.03814,0.03935,0.04058$, $50.06478,0.06640,0.06804,0.06971 ; 0.07139,0.07310,0.07484,0.07660$. $60.07837,0.08017,0,08200,0,08386,0.08573,0.08763,0.08954,0.09149$ $70.09347,0.09546,0.09748,0.09953,0.10160,0.10370,0.10582,0.10796$, $80.11014,0.11233,0.11457,0.11682,0.11909,0.12140,0.12372,0.12610$, $90.12848,0.13089,0.13333,0.13579,0.13831,0.14083,0.14338,0.14595$, A $0.14856,0.15123,0.15389,0.15659,0.15931,0,16207,0.16488,0,16770$. B0.17054,0.17345,0.17636,0.17931,0.18229,0.18529,0.18834,0.19142, C0.19453.0.19767,0.20085,0.20406,0.20731,0.21058,0.21390,0.21724, $00.22062,0.22405,0.22751,0.23100,0.23453,0.23810,0.24170,0.24534$, E0. $24901,0.25274,0.25649,0.26029,0.26412,0.26799 .0 .27192,0.27587$, F0.27987,0.28391,0.28798,0.29211.0.29627,0.30048,0.30474.0.30904/
DATA(CFX 11$\}, 1=376,420) / 0,31338,0,31776,0,32218,0,32667,0,33119$,
$10.33576,0.34037,0.34504,0.34975,0.35451 .0 .35933,0.36419,0.36909$,
$20.37405,0.37907,0.38413,0.38925,0.39442,0.39964,0.40492,0.41025$, $30.41565,0.42108,0.42659,0,43214,0.43777,0.44344,0.44917,0.45496$, $40.46081,0.46673,0.47271,13 * 0.000001$
$C$ TAN * ${ }^{\circ}$ ? VALUES FOR EACH LINE STARTING AT BOTTOM OF PHOTOGRAPH
DATA CFY $(K K), K K=1,110) / 0,47271,0.44893,0,42610,0,40414,0,38309$, $10.36290 .0 .34348,0.32490,0.30709,0.29000,0.27362,0.25786,0.24279$, $20.22836,0.21452,0.20125,0.18852,0.17636,0.164 .72,0.15359,0.14294$, $30.13274,0.12303,0.11376,0.10493,0.09652,0.08851,0.08089,0.07368$,

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```
    88 FORMAT(IHI,*DENSITY*IOX*BCD NO.*)
        PRINT 89,(PPP(I),CPA(I), !=l,K8)
    89 FORMATI1HO,F6.2.12X,F3.0)
        GO TO 10
    26 IP=-1
    NO=NO+1
    KK=KK+1
    IF(NO.EQ.1) KK=0
    PRINT 22,KK
    22 FORMAT (1H0,4X:%Y=#,110/1)
        DO I I =1,ICNT
    C NEEDED TO NUMERICALLY ORDER THE BCD NUMBERS
    IF(D(I).LT.CPA(I)) D(1)=D(I)+175.
    IF(KK,EQ.O) GO TO I
    C CALCULATION OF DELTA BCD NUMBERS
    RD(I)=AVERAGE-D(I)
        IF(RO(I).LE.0.) RD(I)=0.
    1 CONTINUE
        IF(ICNT:LT.10) GO TO 350
        IF(KK.GE.1) G0 T0 902
        PRINT 200, (D(I),I=1,ICNT)
    200 FORMAT (6\times.12F10.2)
        CT=0
        Sum=0
        V1=ICNT-1
    C CALCULATION OF #AVERAGE#. THE REFERENCE PT.
    OO 3 I =1,NI
    CT=CT+1
    SUM=SUM*O(I)
    3 CONTINUE
    AVERAGE = SUM/CT
    PRINT }90
    900 FORMAT(58X,7HAVERAGE)
    PRINT 901,AVERAGE
    901 FORMAT (52x;F10.4)
    AA =1.1530
    BB=0.0130
    60 10 10
    350 KK=KK-1
    PRINT 200.(RD(II,I=1,ICNT)
    GO 10 10
    C CALCULAIION OF YERIICAL PEN DISTANCE FROM DELTA BCD NO,
    902 00 800 I=1,ICNT
    CC=CC+1.
    XMM(I)=RD(L) #AA
    800 CONTINUE
    IF(KK.LT.102) GO TO 803
    351 PRINT 351,
    C OFF-CENTER ANGLE AND CORRECTION FACTOR CALCULATION
    803 00 802 I=1,ICNT
```

```
    CF=CFY(KK)
    CFF=CFX(1)
    IF(KK,GT.101) GO TO 330
    TANPHI=SQRT (CF&CFF)
    DHI=ATAN(TANPHI)
    Z7=COS(PHI)**2
    GO TO 331
    330 22=1.
    CALCULATION OF VERTICAL PEN DISTANCE WITH CORRECTION FACTOR APPLIED
    331 XMM(I) =XMM(I)/ZZ
    802 CONTINUE
        PRINT 203
    203 FORMAT (5BX:13HOELTA DENSITY)
    C CALCULATION OF FILM DENSITY OIFFERENCE
    DO 801 I =1, ICNT
    XMM(I) =XM# (I)*BE
    801 CONTINUE
    PRINT 201, (XMM(1), I=1,ICNT)
    201 FORMAT (6X,12F10.4)
    IF(KK.GT.101) GO TO 10
    C ASSIGNMENT OF EACH OATA PT. TO A DENSITY DIFFERENCE RANGE
    DO 301 I=1.ICNT
    IF(XMM(1).GE.0.1430) 60T0302
    EA=EA+1
    60 TO 301
    302 IF(XMM(I).GT.0.1950) GO TO 303
    EB=EB+1.
    60 TO 301
    303 IF(XMM(I).GT.0.2600) GO TO 304
    EC=EC+1.
    304 IF(XMM(I).GT.0.2990) GO TO 305
    ED=ED+1.
    GO TO 301
    305IF(XMM(1).GT.0.5460) GO TO 306
    EE=EE*1.
    306 IF(XMM(I).GT.0.6500) GO TO 308
    EF=EF+1.
    G0 %0 301
    308 IF(XMM(I).GT.1.4000) G0 T0 309
        EG=EG+1.
        GO TO 301
    309 EH=EH+1.
    301 CONT INUE
    PLOTTING OF DENSITY DATA
    XKK(1)=0.
    00 4 I=2.ICNT
    XKK(I) =XKK II-IT*.025
    4 \text { CONTINUE}
    XMM(ICNT +1) =0.
```





STOP

SUBROUTINE ENCOO(ICNT,KSKIP, DEN,ID,NSCPTS,NCODE)
INTEGER DEN(500) © ID (12), A(1049)
INTEGER CON(15) eLM(5) 2 $1 \mathrm{~L}(5$
MASK2 $=000000000000000000017$
MASK $3=077007700770077007700$
DO $978 \mathrm{~J}=1, \mathrm{KSKIP}$
950 ICNT $=$ IVAR (12;A,5.1050)
$60 \quad 10 \quad 950$
CSKIP
999 CONT INUE
ICNT $=$ IVAR(12,A,5,1050)
IF (ICNT •EQO 0) GO TO 77
DECODE $(10,20, A(2))$ ILL(MM), $A M=1,5)$
20 FORMAT $15(1 \times, R 1)$

$I=0$
$\mathrm{LEO}_{\text {DO }} 10 \quad \mathrm{~J}=1.3$
$1=1+1$
$70 \quad 14$
DECOOE (10,20, A(I)) (LL(MM), MME1:5)
$0099 \quad K=1,5$
$\operatorname{CON}(M)=L L(K) \cdot A \cdot M A S K 2$

99 CONTINUE
$27 \mathrm{LU}=\mathrm{M} / 3$
IF (LJ.EQ. O) GO 1015
00 11 $j=1, \mathrm{~L}$
$\mathrm{L}=\mathrm{L}+1$
1 CONTINUE
IF ILJ •LT. 51 GO 7015
14 WRTTE ( 6,101 )
15 VSCPTS=L-1


FIXED DATA SWITCHES

The Fixed Data that is inputed onto the recording magnetic tape is recorded as 12 separate Binary Coded Digits.

Switches


BCD digits, 0-9, can be recorded by each of the twelve switches. Switches two through twelve can be used to record non-density film data, i.e. machine setting data, etc.

Switch 1 is used as a code:
If Switch 1 *
equals 0 - means that the rest of the fixed data on that same line is non-density film data
equals 1 - means that the next set of non-fixed data represents the microdensitometer trace over a Kodak Step Wedge
equals 3 - tells the computer to go to Fortran Statement number 307 which starts the computation of the number and percentages of data points in specific density ranges up to that point
equals 4 - means that the following data are information collected from the photograph of interest
equals 9 - signifies the end of recorded data for a particular photograph, tells the computer to go to Fortran Statement number 107 which resets all counter variables back to zero for the start of a new piece of film.

## REFERENCES

1. Bressette, W. E.; and Lear, D. E., Jr.: The Use of Near-Infrared Reflected Sunlight for Biodegradable Pollution Monitoring, Presented at the Second Conference on Environmental Quality Sensors, National Environmental Research Center, Las Vegas, Nevada, October 10-11, 1973.
2. Instruction Manual For Automatic Recording Microdensitometer Model MK IIIC., Joyce, Loebl and Co. Limited, August 1963.
3. Grolier, Maurice; and Woolbridge, James J.: Specification and Acceptability Tests of the Joyce-Loebl Isodensitracer, Model MK III CS, Series 571, Density Range: 5.6. April 1966.

TABLE I.- MACHINE SETTING


| TABLE II.- STEP WEDGE DENSITY VERSUS "BCD" NUMBER TABLE |  |
| :---: | :---: |
| Density | BCD NO. |
|  | a |
| 0.05 | 71 |
| .20 | 85 |
| .36 | 97 |
| .50 | 111 |
| .64 | 124 |
| .79 | 138 |
| .94 | 151 |
| 1.09 | 163 |
| 1.23 | 1 |
| 1.38 | 14 |
| 1.53 | 27 |

$a_{B C D}$ numbers go up to 175 and then start over again at 1.

|  |  |  |  |  |  |  | 189.00 | 190.00 | 189.00 | 187.00 | 187.00 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 187.00 | 186, 180 | 187.000 | 188.00 | 188000 | 1890.00 | 189.07 | 189.00 | 189.00 | 190.00 | 189.00 | 189.00 |
| 189.00 | 189.00 | 188, 00 | 188-00 | 190.00 | 190.00 | 191.00 | 191.00 | 190.00 | 192.00 | 192.00 | 194.03 |
| 191.00 | 192.00 | 190.00 | 192.00 | 191.00 |  | 192.00 | 192.00 | 192.00 | 192.00 | 192.00 | 192.00 |
| 192.00 | 192.00 | 192.00 | 191.00 | 191.00 | 193,000 | 192.00 | 192.00 | 192.00 | 192.30 | 192.00 | 192.20 |
| 192.00 | 192.00 | 192.00 | 192.00 | 194.00 | 191.00 | 190.00 | 190.00 | 190.00 | 190.00 | 191.00 | 191.00 |
| 192.00 | 192.00 | 192.00 | 191.00 189.00 | 181.00 | 189.00 | 188.00 | 189.02 | 190.20 | 191.00 | 190.00 | 190.30. |
| 180.00 | 190.00 | 190.00 | 189.00 18.00 | 1898.00 | 188.00 | 187.00 | 187.00 | 187.00 | 185.00 | 184.00 | 188.00 |
| 189500 | 189000 | 188.00 | 188.00 187.00 | 187.00 | 187800 | 188.00 | 188.00 | 187.02 | 188.20 | 188.00 | 188.00 |
| 187.0n | 187.90 | 187.00 | 187.00 187.00 | 18.8 | 188, 00 | 188.00 | 188.00 | 188.00 | 188.00 | 187.00 | 187.00 |
| 18tann | 187.00 | 187.00 | 187.00 | 187.00 | 187.00 | 187.00 | 187.00 | 187.00 | 187.00 | 187.00 | 187.90 |
| 187.00 | 187.00 | 187.00 | 187.00 187.00 | 187.00 | 187.00 | 187.00 | 197.00 | 187.00 | 187.00 | 187.00 | 187.00 |
| 187000 | 187.00 | 187.00 | 187.00 187.00 | 1818.00 | 187.00 | 187.00 | 187.00 | 188.00 | 188.00 | 187.00 | 187.00 |
| 187.00 | 187.00 | 187.00 | 187.00 188.00 | 188800 | 188.00 | 188.00 | 188.00 | 188.00 | 189.00 | 189.00 | 189.09 |
| 187008 | 187.00 | 187.00 | 188.00 | 188.00 | 188.00 | 187.00 | 187.00 | 188.00 | 188.90 | 187.00 | 187.09 |
| 188.00 | 188.00 | 188.00 | 188.00 188.00 | 190.00 | 190.00 | 188.00 | 188.00 | 188.70 | 188.20 | 188.00 | 188.00 |
| 187.00 | 188.00 | 188.000 | 188.00 | 182.00 | 116.00 | 193.02 | 188.02 | 188.00 | 189.00 | 189.00 | 189.00 |
| 188.00 | 188.00 | 189.00 | 189.000 | 188.00 | 18700 | 187.0n | 188.00 | 188.00 | 188.00 | 188.00 | 189.00 |
| 189.00 | 189.00 | 189.00 | 189.0 | 188600 | 189.00 | 189.00 | 189.00 | 189.00 | 189.30 | 190.00 | 190.00 |
| 189000 | 188.00 | 189000 | 189.00 | 189.00 | 189.00 | 189.00 | 189.00 | 189.00 | 189.00 | 189.09 | 189.00 |
| 189, 00 | 189.00 | 1.89.00 | 189.00 | 1.90.00 | 189.00 | 189.00 | 189.00 | 190.00 | 191.00 | 192.00 | 191.00 |
| 189.00 | 189.00 | 189.00 | 189.00 | 189.00 |  | 189.00 | 189.00 | 189.00 | 188.00 | 189.00 | 188.00 |
| 190.00 | 190.00 | 190.00 | 190.00 188.00 | 189.00 188.00 | $188.00$ | $188.00$ | 188.00 | 188.00 | 188.00 | 188.00 | 189.00 |
| 189.00 | 188.00 | 188.00 | 188.00 189.00 | 189.00 | 18.9.C0 | 188.00 | 188.00 | 188.20 | 188.00 | 188. 180 | $\frac{188.00}{188.00}$ |
| 188.90 | 189.00 | 189.00 | 189.00 | 188.00 | 188.00 | 189.00 | 192.00 | 192.00 | 189.00 | 186.00 | 188.00 |
| 188.00 | 188.00 | 188.00 | 188.00 | 189.00 | 189.00 | 189.00 | 189.00 | 189.00 | 189.00 | 190.00 | 189.09 |
| 190.00 | 190.00 | 189.00 | 189.00 189.00 | $\frac{189.00}{190.00}$ | 190.00 | 189.00 | 189.00 | 190.00 | 189.00 | 187.00 | 190.00 |
| 189.00 | 189.00 | 189.00 | 182.00 | 189.00 | 189.00 | 190.00 | 189.00 | 189.20 | 189.20 | 189.00 | 18.9 .00 |
| 198.09 | 189.00 | 189.00 | 189.00 | 189.00 | 189.00 | 188.00 | 187.00 | 188.00 | 188.00 | 188.00 | 188.00 |
| 189.00 | 189.00 | 189.00 | 189.00 187.00 | 188.00 | 188.00 | 188.00 | 188.00 | 187.00 | 187.00 | 187.00 | 188.00 |
| 187.00 | 187.00 | 187.00 | 181.00 188.00 | 191.00 | 197.00 | 208.00 | 211.00 | 422.00 |  |  |  |
| 189.00 | 189.00 | 188.00 | 188.00 | 191.00 | YERAGE | 208. 00 |  |  |  |  |  |

TABLE IV.- CALCULATED FILM DENSITY DIFFERENCES FOR SCAN $51^{a}$
$Y=51$

| 0.0000, | 0.00011 | 0.0000 | 0.0000 | 0,0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.0000 | 0.3000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0200 | 0.0000 | 0.0000 | 0.0000 | .0342 | .0341 |
| .0340 | .0539 | .0538 | . 0735 | .0733 | . 0730 | .0728. | 0.0725 | .0723 | .0721 | .0523 | . 0522 |
| . 0520 | . 0711 | .0709 | . 0707 | .0322 | . 1084 | .1271 | .1267 | . 1452 | .1636 | . 1631 | . 1626 |
| . 1621 | .1803 | .1797 | .1792 | . 1787 | .1598 | . 1410 | . 1406 | . 1402 | . 1398 | . 1394 | . 1572 |
| . 1567 | . 1563 | .1380 | .1376 | .1194 | .1389 | . 1543 | . 1539 | .1535 | .1531 | .1703 | . 2050 |
| .2220 | .2389 | .2558 | .2726 | . 2719 | - 3405 | .4432 | . 4078 | . 4068 | 4.402 | . 4392 | 4724 |
| . 4543 | .7174 | . 2998 | . 3160 | 2985 | . 26.42 | 2468 | . 2463 | 2626 | 7954 | - 2949 | 2943 |
| 2937 | .2766 | .2760 | -3085 | -3244 | 3403 | 2561 | 3718 | 3875 | . 6154 | . 8100 | 1.1829 |
| -1.0509 | . 8707 | - 5778 | 4313 | 3661 | 3332 | 3005 | 2679 | 2515 | 2511 | 2507 | 2344 |
| --2181 | .2337 | . 2651 | . 2647 | .2643 | . 2482 | 2636 | . 2790 | 2786 | 3412 | . 3879 | 4355 |
| - $-465^{\circ} 3$ | 04334 | . 4642 | . 5416 | .6190 | -4780 | . 4464 | 4303 | . 4143 | . 4138 | . 3669 | 3201 |
| .3197 | 2885 | - 2728 | 2725 | . 2723 | 2720 | . 2117 | .2561 | . 2559 | 2557 | . 24011 | 2093 |
| -. 1786 | 1937 | 1936 | . 2087 | 2390 | 2692 | 3147 | 3601 | 40.54 | 5114 | . 6931 | . 6472 |
| . 7225 | . 7675 | .7822 | 9027 | . 8720 | . 9320 | 8.8107 | .7046 | . 65.90 | 5687 | 4926 | 4321 |
| 48169 | .3565 | 2812 | . 2510 | 26.59 | 24.59 | 2808 | 2657 | 2656 | 3106 | 3856 | 6605 |
| . 6904 | . 4903 | . 4753 | . 4602 | 0.4451 | . 4151 | 41.51 | 66600 | 4750 | 5849 | 6998 | . 7297 |
| -6998 | . 5649 | -5199 | -. 6450 | - 3851 | -3701 | . 3102 | . 2802 | 1907 | 2353 | 2354 | 2204 |
| . 2204 | .2355 | .2356 | . 2356 | . 2658 | . 2658 | 2960 | 2961 | 2962 | 2813 | 2814 | 2966 |
| .2967 | . 3119 | . 3271 | - 3773 | . 3879 | . 3437 | . 4336 | 5397 | . 40318 | 3738 | 3589 | 3894 |
| -. 3442 | . 3140 | - 2990 | - 2232 | -1930 | . 1627 | 1628 | 1629 | 1783 | 1784 | 1786 | 1940 |
| 1942 | 2097 | 2406 | 2408 | 2410 | 2105 | 1953 | 1955 | 1802 | 2113 | 2425 | 2272 |
| . 2275 | 1657 | .1659 | . 1661 | 1663 | 1665 | 1667 | 1669 | . 1877 | 1986 | 2145 | 2148. |
| . 2151 | 1839 | -1841 | . 1844 | . 1846 | 1849 | 1851 | . 1854 | 1257 | 2018 | 2021 | 2344 |
| . 2347 | . 2351 | . 2836 | . 3161 | - 4131 | . 4138 | . 4145 | . 3667 | .3673 | . 3030 | 2548 | 2553 |
| . 2394 | 2398 | . 2239 | .2407 | .2411 | .2416 | 2420 | .2260 | . 2098 | . 2268 | .1941 | . 1778 |
| - 1448 | . 1451 | 1.1454 | - 1289 | .1292 | . 1294 | . 1297 | -. 1300 | 1642 | . 1645 | . 1649 | . 1482 |
| 1485 | 1660 | . 1664 | . 1839 | 2189 | 2194 | 2199 | 2030 | 1861 | 1347 | - 1170 | 0997 |
| .1000 | 1002 | 1005 | 1007 | .1010 | .1013 | . 1015 | . 1376 | . 1559 | .1563 | .1567 | 1753 |
| .2120 | 2490 | . 3044 | . 3784 | . 5079 | .7854 | . 9537 | 1.0119 | .9777 | .8131 | 7781 | . 7804 |
| . 7827 | . 8604 | .9386 | 1.0172 | 1.0202 | 1.2141 | 1.3135 | 1.4136 | 1.5147 | 1.4225 | 1.2721 | 1.2180 |
| 1.1439 | 1.1672 | 1.1318 | 1.1750 | 1.2579 | 1.2819 | 1.3459 | 1.3705 | 1.4553 | 1. 5206 | 1.2638 | 1.1468 |
| 1.1306 | 1.1346 | 1.1386 | 1.1017 | 1.0439 | .9030 | . .9271 | 1.1804 | 1.2475 | 1. 5033 | 1.5306 | 1.0925 |
| 1.1604 | 1.2500 | 1.18197 | 1.0236 | -9630 | . 9452 | -8837 | -5910 | . 5844 | . 7186 | 1.0085 |  |

ATo conserve space only the density difference values for scan 51 are shown. The above is the digitalized data for the pen plot shown in figure 1 . These data are

TABLE V.- DENSITY DIFFERENCE RANGES, NUMBER OF POINTS, AND PERCENTAGES



Fig. 1. - Sample photograph and pen plots of line 51 and bottom border
$\theta$ horizontal half angle $\phi$ angle off the princple axis of the lens
$\phi \mathrm{Aj}$ vertical component of $\phi$ $\phi$ pi horizontal component of $\phi$


Fig. 2. - Pictorial representation of camera system angles


Number of plotted points
Fig. 3. - Computer plot of calculated densities (a)

Corresponding "BCD" numbers ${ }^{\text {a }}$


Fig. 4 - Microdensitometer pentrace of a Kodak step tablet

