LARS Information Note 052770
Purdue University

A Preliminary Study of Image Quality Improvement Through Data Processing

by

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Introduction

It would appear to be quite feasible to remove certain types of distortion from images using quantitative data processing techniques provided that the distorting influence can be precisely determined in quantitative form. For example, it should be possible to reduce the effects that camera motion during film exposure cause in a photograph provided that the values of the various optical and motion parameters are available. In order to test this hypothesis a specific type of distortion in optical scanner data was chosen for initial study. The details of this study follow.

The electronic equipment employed in recording and playing back airborne scanner data may distort the signals if this equipment does not have sufficient bandwidth. This is the case for scanner data being analyzed at LARS. The system function is that of a sharp cutoff low pass filter. As a result, the response of the system to a discontinuity in the scene scanned such as might be encountered as the scanner sweeps from a field of high intensity to one of low intensity (or vice versa) shows overshoot and ringing. This phenomenon is quite apparent on the gray scale printouts of 1968 flightline PF21 which has a highway running down the center of the printout. Figure 1 shows a gray scale printout

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1/ Under the direction of Professor C. D. McGillem of the data in the band from 0.62 to 0.66 micrometers. On the left side of the highway alternating vertical light and dark bands portray the problem. Figure 2 shows a graph of eleven consecutive lines of data from run number 68000200 (Flightline PF21) for columns 185 to 230, lines 630 through 640. The scan is from right to left. Figure 3 shows the average of these eleven lines. The large peak at column number 215 is caused by the highway referred to above. The ringing to the left of the peak is clearly visible and can be seen to damp out in approximately 4 cycles. The problem is quite evident in the vicinity of the road because the apparent width of the road is approximately one half the period of the oscillation. Thus the first portion of the input signal is a positive step and just as the response completes its overshoot and starts down, the negative step occurs and reinforces it. The problem is also observed when a single step function in the signal is encountered.

Computation of the Impulse Response

In order to process the data to correct for the distortion caused by the system it is necessary to know the system impulse response. The system impulse response may be computed from the equation:

$$H(\omega) = \frac{Y(\omega)}{X(\omega)}$$

where $Y(\omega)$ and $X(\omega)$ are the Fourier Transforms of the output and input signals respectively and $H(\omega)$ is the system function. This, of course, assumes that the input and output signals are accurately known. Then the impulse response $h(t)$ is given by:

$$h(t) = F^{-1}\{H(\omega)\}$$

In the case of the scanner data, the input to the system is the record of the spatial intensity variation which the scanner senses from the scene. It was decided to pick special ground features that would make it possible to deduce the shape of the input signal by looking at the output and using a priori knowledge of the ground scene. Attempts to determine the input signal corresponding to the scan of the road, which is seen in Figure 3, were unsuccessful evidently due to the fact that the road's profile is not a simple combination of equal positive and negative steps. Several different scenes from other runs were studied to determine if a reasonable estimate of the impulse responses for the system could be obtained from the scanner data. All of the attempts to compute h(t) from these data were unsuccessful.

It became clear that a carefully controlled experiment in which the scanner would scan a known scene was needed. A special flight over an area where the scanner would see a pulse of relative brightness in the channel for which the impulse response is to be computed would be required.

On at least one occasion, a flight was made over just such a scene. Special flights had already been made over large color panels laid out on the ground for the purpose of calibrating the scanner. These panels are about 800 square feet and are of several colors.

A double resolution digital tape, 440 samples per scan line, was prepared (Run 66005200). The color panels were located in the region bordered by lines 686 and 787 and columns 338 through 381. Figure 4 shows the gray scale printout of this block for channel 5, corresponding to 0.62-0.66 micrometers. The problem in question may be clearly seen in the upper left color panel as vertical bands of gray (symbolized by minus signs) and white shading. Figure 5 shows graphs of lines 690 through 694, columns 300 through 400. Two color panels are seen with the obvious overshoot and ringing. Figure 6 shows graphs of lines 701 through 705, columns 300 through 400. Figure 7 is the average of the five lines in Figure 6. The data of Figure 7 were used in the determination of the impulse response of the system.

The data of Figure 7 were preprocessed, redefining column number 381 as the origin for the abscissa, and subtracting 52.5, which is the data value at column 381. Forty data points were used to define the output of the system, y(t). Figure 8 shows the preprocessed data for y(t). Figure 9 is the assumed value of the input signal, x(t), which is to be used in deconvolution to produce H(ω), the desired system function.

The system impulse response, h(t), can then be computed. The Fast Fourier Transform algorithm was used to perform the deconvolution. The number of points chosen for N was 512 in order to achieve good resolution in the frequency domain. Figure 10 shows Y(ω) on an arbitrary frequency scale. The spectrum of y(t) shows it to be a low pass band limited signal. Figure 11 is the magnitude of Y(ω)/X(ω). It is seen that Y(ω)/X(ω) contains discontinuities due to the inaccuracy of the assumption on x(t). This inaccuracy causes the zeros of X(ω) and those of Y(ω) not to coincide. This coincidence is a necessary condition if Y(ω) is to be the result from passing X(ω) through the system with system function H(ω). As a result the data of Figure 11 was hand smoothed so as to remove these discontinuities, see Figure 12. Also in the process of the hand smoothing of the data, the frequency was truncated at 150 frequency units, which is somewhat larger than the bandwidth of y(t). Finally, Figure 13 shows $F^{-1}\{Y(\omega)/X(\omega)\}$, the computed estimate of the impulse response, h(t). Thus, h(t) has the properties expected of it, i.e., those of a sharp cutoff, low pass system.

Check of the Computed Impulse Response

The impulse response resulting from the computations above was used to correct a complete data line starting in the dark area before the scene and ending in the dark area far enough beyond the scene. In order to do this, a special tape was converted with contained data for a complete revolution of the scanning mirror. The data line in question scans two of the color panels. Figure 14 is a computer-made graph of this line before correction. The Fast Fourier Transform was used with N equal to 1024 to accomplish the deconvolution. In order to reduce the Gibbs phenomenon apparent at discontinuities of x(t), the Hamming window function was used to weigh the data in the frequency domain. In effect this tends to correct the system function to the Hamming shape rather than a rectangular one. The deconvolution of the data of Figure 14, employing the Hamming window, results in Figure 15. Figure 15 shows only the corrected line of data. The overshoots and ringing are clearly reduced in this function.

Conclusion

Correction of the one line of data in Figure 18 shows a definite improvement. A further step is to correct all the data for a particular run and observe a gray scale printout in order to note the reduction in oscillations formerly observed. Further study is required to see if the

the impulse response is invariant with respect to the channel used. Once each channel's impulse response has been computed, a crop classification could be carried out with the corrected data to analyze for improvement in classification accuracy results.

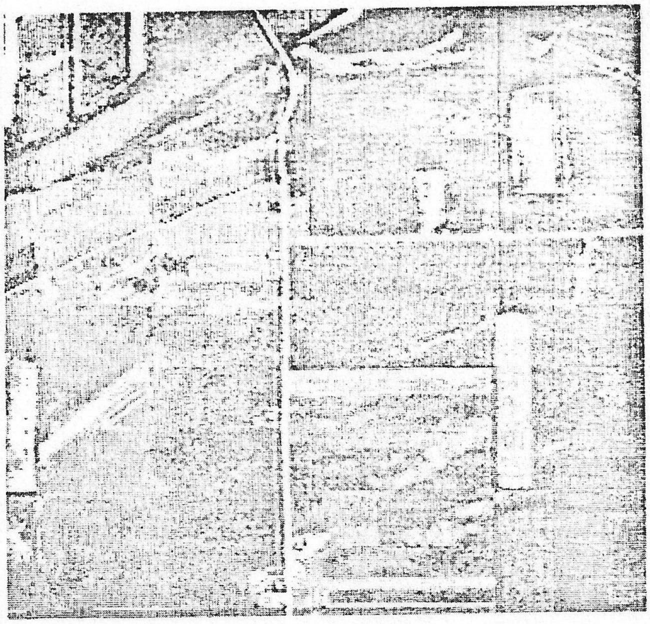

Figure 1. Gray scale printout produced from scanner imagery in the .62-.66 micrometer wavelengths.

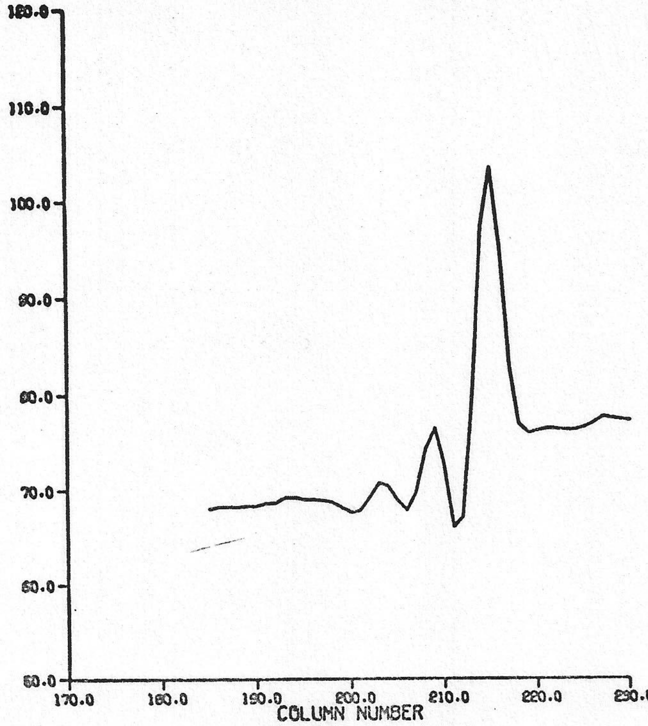

Figure 3. Average of the eleven lines of Figure 2.

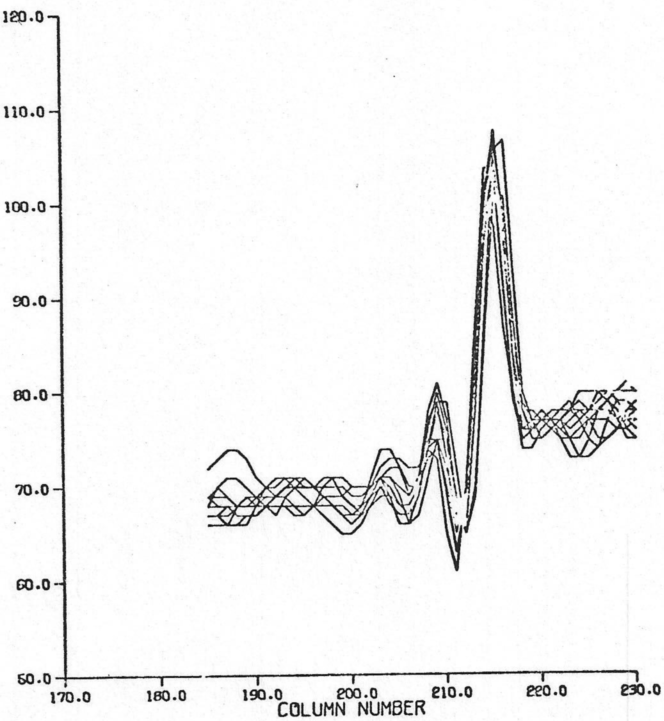

Figure 2. Data from run 68000200, lines 630-640, column 185-230.

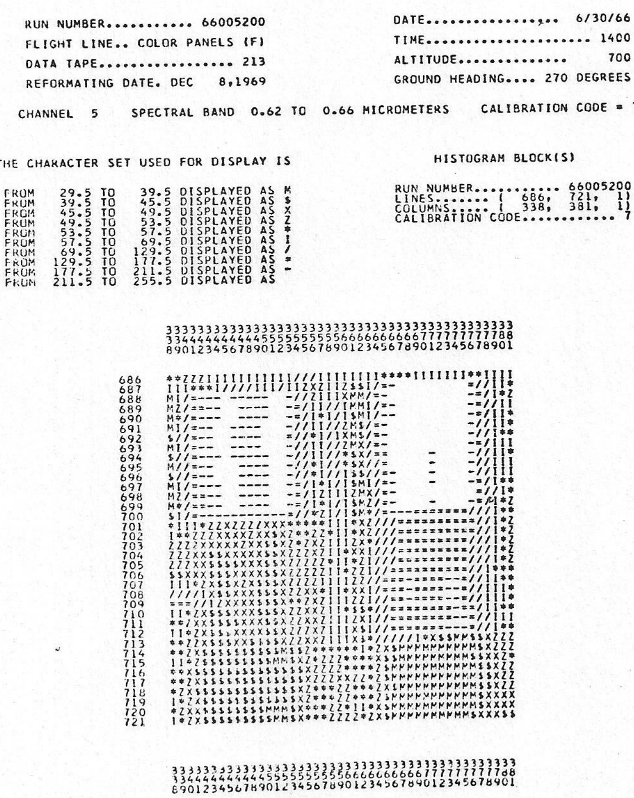

Figure 4. Gray scale printout showing color panels.

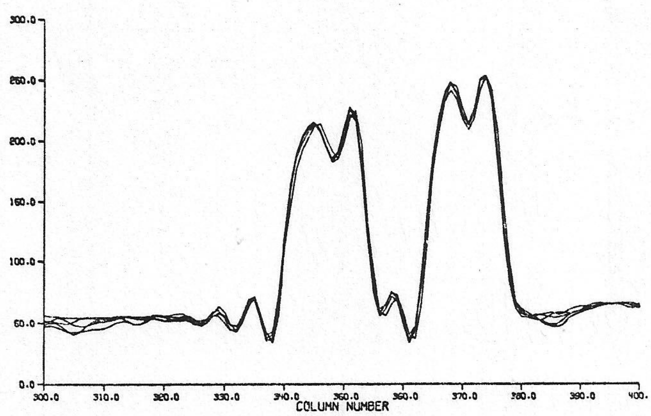

Figure 5. Color panel data, lines 690-694, column 300-400, channel 5.

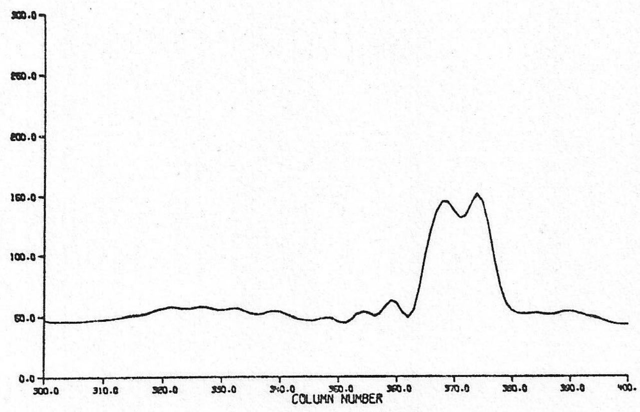

Figure 7. Average of the five lines shown in Figure 6.

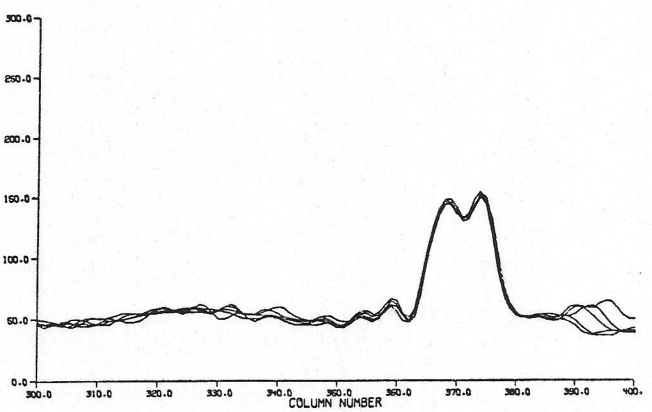

Figure 6. Color panel data, lines 701-705, column 300-400, channel 5.

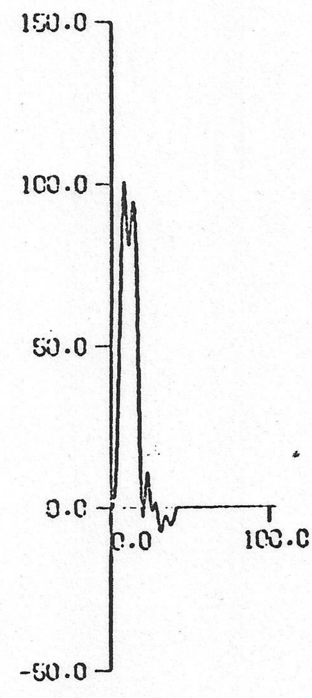

Figure 8. Preprocessed data of y(t).

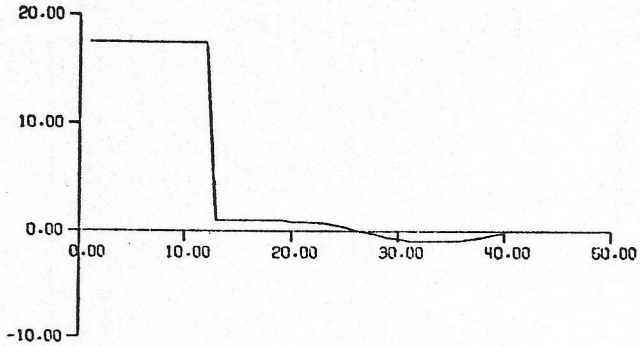

Figure 9. Assumed x(t) function.

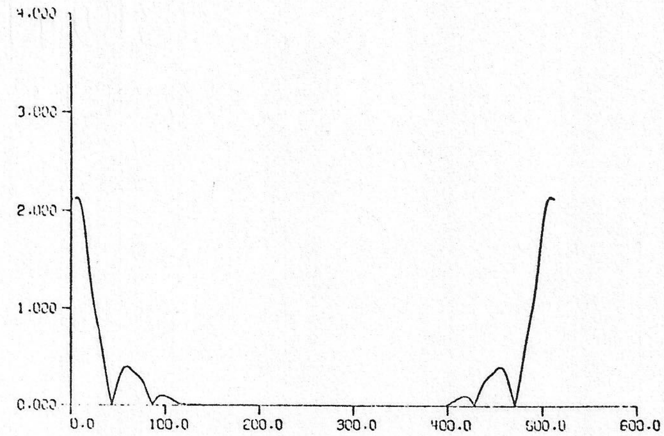

Figure 10. $|Y(\omega)|$

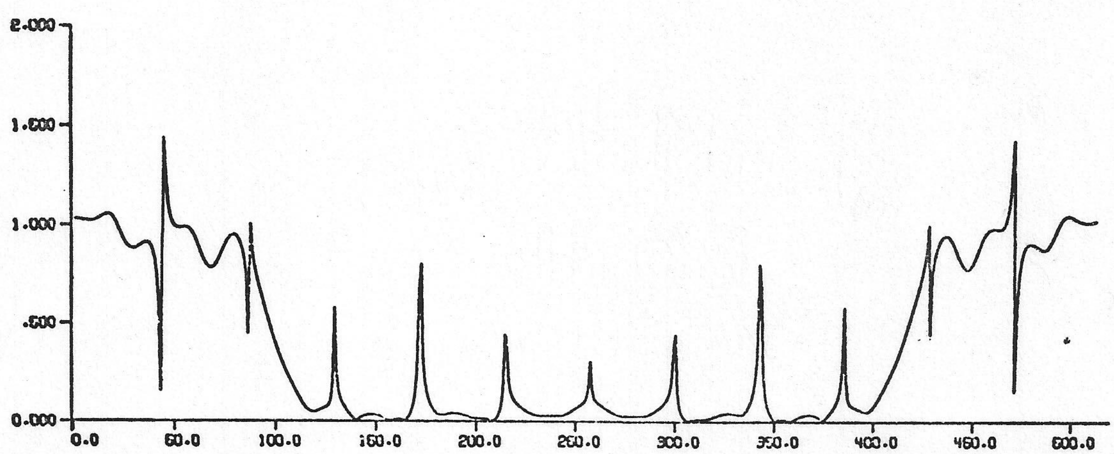

Figure 11. $|Y(\omega)/X(\omega)|$

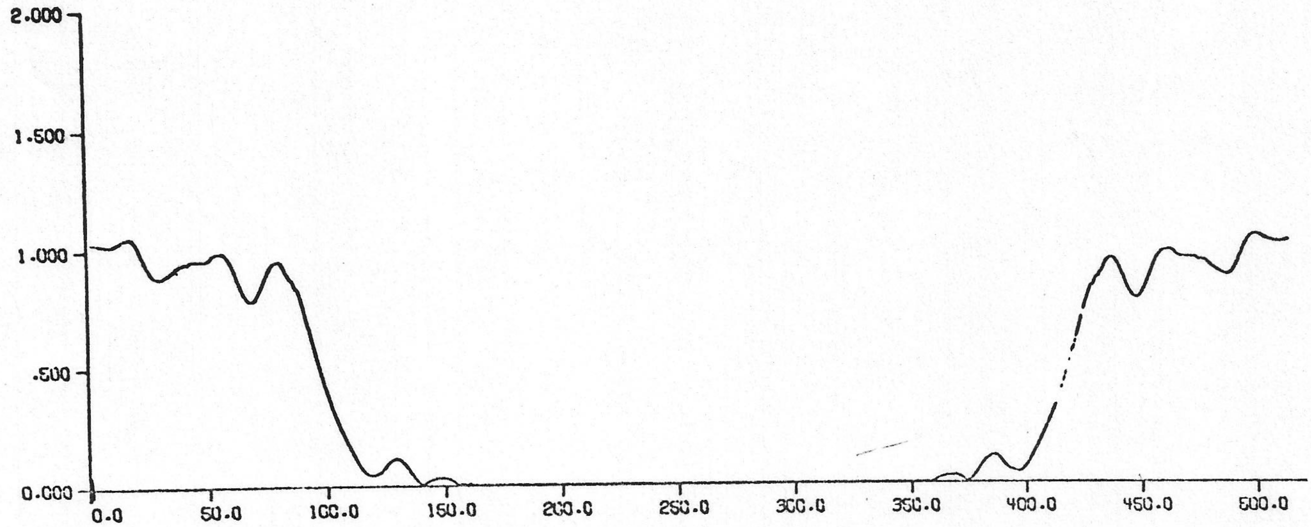

Figure 12. Smoothed version of $|Y(\omega)/X(\omega)|$

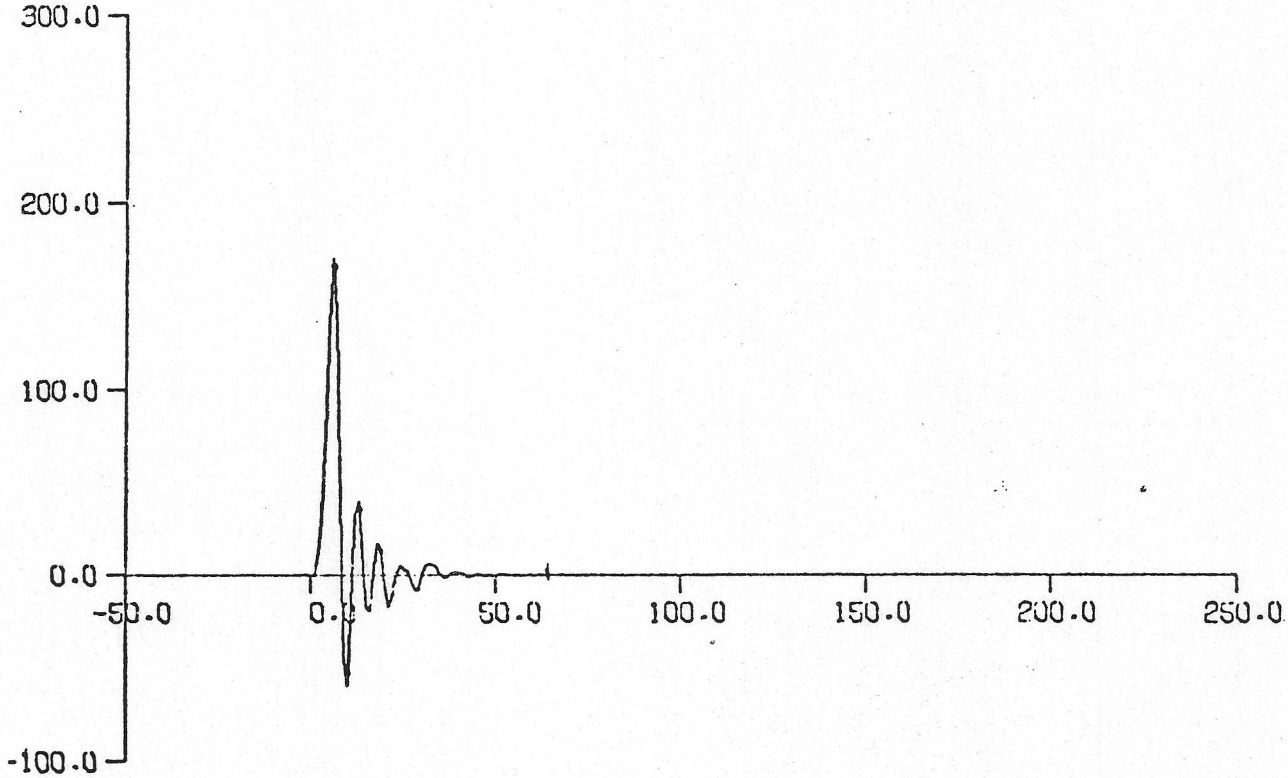

Figure 13. $h(t) = F^{-1}\{Y(\omega)/X(\omega)\}$

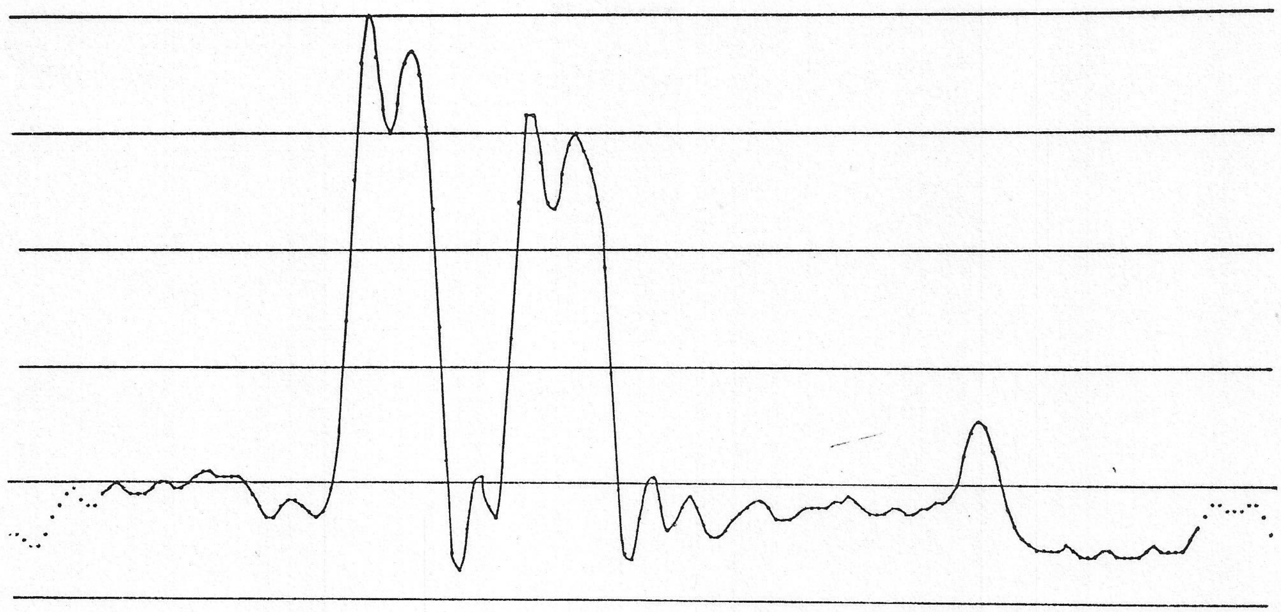

Figure 14. Data line through color panels before correction.

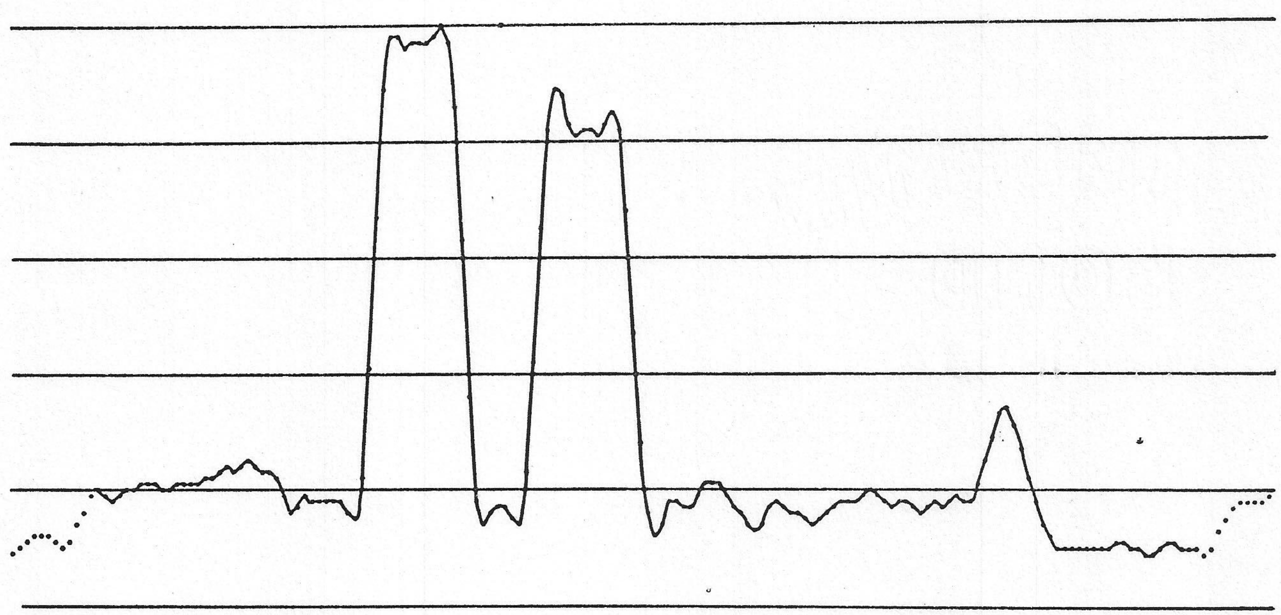

Figure 15. Data line through color panels after correction.

Appendix A

Fortran program to compute the impulse response of the system.

Appendix A

```
MF059
15106,DERRY,T31,P5,L20000,CM60000.
MAP(PART)
RUN(S)
LIBCOPY(CSCBIN,LGO,FORT)
LGO.
COPYPLT(DERRY,15106,11X80,,BLACK,GO)
EXIT.
COPYPLT(DERRY,15106,11X80,,RED,GO)
      PROGRAM LARZO(INPUT,OUTPUT,PLOT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMPLEX F, DFTF, X, DFTX, H, DFTH
      DIMENSION F(512),DFTF(512),X(512),DFTX(512),H(512),DFTH(512)
      DIMENSION RF(42),S(256),RH(514),DER1(512),DER2(512),RX(42)
      DIMENSION RUF(10 ),ABSC(514),DHMAG(514),RRF(514),XH(514)
      EQUIVALENCE (RRF(1),RH(1)),(DER1(1),F(1)),(XH(1),DHMAG(1))
      CALL PLOTS $ CALL PLOT(1.,5.46,-3)
      N=512 $ M=9
      DO 90 I=1,N
   90 ABSC(I)=I
      READ(5,501) (RF(I),I=1,40)
  501 FORMAT(12F5.1)
      DO 60 I=1,40
   60 F(I)=RF(I)-52.2
      DO 10 I=41,512
   10 F(I)=0
      DO 15 I=1,N
   15 RRF(I)=REAL(F(I))
      CALL GRAF2(ABSC,RRF,N,6.,4.) $ CALL PLOT(0.0,-5.0,-3)
      CALL FORT(F,M,S,-1,JACK) $ DO 20 I=1,N
   20 RRF(I)=CABS(F(I))$CALL GRAF2(ABSC,RRF,N,6.,4.)$CALL PLOT(9.,0,-3)
      READ(5,502) (RX(I),I=1,40)
  502 FORMAT(13F6.2,2X)
      CALL GRAF2(ABSC,RX,40,5.,3.)
      CALL PLOT(7.,5.,-3)
      DO 30 I=1,40
   30 X(I)=5.*RX(I)
      DO 40 I=41,N
   40 X(I)=0.0
      CALL FORT(X,M,S,-1,JACK)
      DO 50 I=1,N
      H(I)=F(I)/X(I)
   50 DFTH(I)=H(I)
      DO 51 I=1,N $ RH(I)=REAL(H(I))
   51 XH(I)=AIMAG(H(I))
      READ(5,503) (RH(I),I=41,46)
  503 FORMAT(12F6.3,8X)
      DO 120 I=41,46 $ II=514-I
  120 RH(II)=RH(I)
      READ(5,503) (XH(I),I=35,52)
      DO 130 I=35,52 $ II=514-I
  130 XH(II)=-XH(I)
      READ(5,503) (RH(I),I=86,91)
      DO 140 I=86,91 $ II=514-I
  140 RH(II)=RH(I)
      READ(5,503) (XH(I),I=83,91)
      DO 150 I=83,91 $ II=514-I
  150 XH(II)=-XH(I)
      READ(5,503) (RH(I),I=127,134)
      DO 160 I=127,134 $ II=514-I
  160 RH(II)=RH(I)
      READ(5,503) (XH(I),I=123,136)
      DO 170 I=123,136 $ II=514-I
  170 XH(II)=-XH(I)
      DO 180 I=161,353
  180 RH(I)=0.0
      DO 190 I=151,363
  190 XH(I)=0.0
      CALL GRAF2(ABSC,RH,N,13.,4.) $ CALL PLOT(0.,-5.,-3)
      CALL GRAF2(ABSC,XH,N,13.,4.) $ CALL PLOT(15.,5.,-3)
      WRITE(6,601) ((I,RH(I),XH(I)),I=1,N)
  601 FORMAT(1H1///(20X,I4,2F20.6))
      DO 200 I=1,N
  200 H(I)=CMPLX(RH(I),XH(I))
      DO 55 I=1,N
   55 DHMAG(I)=CABS(H(I))
      CALL GRAF2(ABSC,DHMAG,N,13.,4.)
      CALL PLOT(0.,-5.,-3)
      CALL FORT(H,M,S,1,JACK2)
      DO 70 I=1,N


   70 RH(I)=REAL(H(I))
      CALL GRAF2(ABSC,RH,N,13.,4.)
      CALL PLOT(15.,5.,-3)
      CALL DERS(RH,N,DER1,DER2)
      SUM=0
      NM2=N-2
      DO 80 I=1,NM2
   80 SUM=SUM+ABS(DER2(I))
      SUM=SUM/FLOAT(NM2) $ RUF( 1)=SUM
      WRITE(6,602)    SUM
  602 FORMAT(/  10X,       *, AVE. SEC. DER. = *,E10.3)
      WRITE(6,603) ((I,DFTH(I),DHMAG(I),H(I)),I=1,N)
  603 FORMAT(///(10X,I3,5F14.6))
      WRITE(6,607) (RUF(I),I=1,1)
  607 FORMAT(//10X,*THIS IS RUF*/ E10.3)
      CALL PLOT(0,0,999)
      STOP $ END
      SUBROUTINE DERS(X,N,DER1,DER2)
      DIMENSION X(1),DER1(1),DER2(1)
      NM1=N-1 $ NM2=N-2
      DO 10 I=1,NM1
   10 DER1(I)=X(I+1)-X(I)
      DO 20 I=1,NM2
   20 DER2=DER1(I+1)-DER1(I)
      RETURN $ END
52.2 54.8 60.6 74.2 97.6 126.4146.6153.  144.8134.8133.0139.0
146.2146.6138.4122.2101.275.4 56.   49.   53.   61.   63.2 58.4
52.6 50.6 53.   54.   52.   47.4 44.8 45.2 48.2 49.6 49.2 47.8
46.8 47.2 48.   49.8
17.5  17.5  17.5  17.5  17.5  17.5  17.5  17.5  17.5  17.5  17.5  17.5  1.
1.    1.    1.    1.    1.    1.    .8    .8    .75   .7    .5    .3    0.0000
 .2   -.4   -.7   -.8   -1.   -1.   -1.   -1.   -1.   -.9   -.75  -.6   -.35
 .2
 .472 -.525 -.567 -.605 -.641 -.675
 .902 -.9   -.89  -.875 -.855 -.838 -.815 -.795 1.77  -.74  -.71  -.675
 .642 -.605 -.575 -.54  -.51  -.47
.64   .695  .705  .71   .7    .685
.775  .69   .615  .542  .468  .395  .315  .24   .16
 .095 -.1   -.105 -.1   -.097 -.092 -.081 -.07
 906  -.062 -.065 -.065 -.062 -.060 -.055 -.050 -.04 -.03  -.022 -.015
 .005 0.000
```

Appendix B.

Fortran program to correct the data line
of Figure 14 to produce Figure 15.

Appendix B

```
FORTRAN IV     MODEL 44  PS        VERSION 3,  LEVEL 3   DATE  70181

              DIMENSION ICONT(13)
              DIMENSION S(500),IY(1000),RX(1024),H(56),AX(1024),AH(1024)
              COMPLEX CH(1024),CY(1024),CX(1024)
              ICONT(1)=1
              ICONT(13)=1
              DO 110 I=2,12
      110     ICONT(I)=0
              PI316=3.14159/316.
              READ (5,501) (H(I),I=1,56)
        501   FORMAT(10F8.2)
              N=1024
              N2=N/2
              M=10
              DO 10 I=1,56
      10      CH(I)=CMPLX(H(I),0.0)
              DO 20 I=57,N
      20      CH(I)=0.0
              CALL FORT(CH,M,S,-1,JACK)
              ICOUNT=801
      2       READ (5,502) (IY(I),I=1,1000)
        502   FORMAT(20I4)
              DO 30 I=1,1000
      30      IY(I)=243-IY(I)
              WRITE(6,668) ICOUNT
        668   FORMAT(1H1///10X,'THIS IS LINE NO. ',I3///)
              CALL PLOTNI(IY,ICONT,41,740,1)
              WRITE(6,666)
              DO 35 I=1,700
      35      CY(I)=CMPLX(FLOAT(IY(I+40)),0.0)
              DO 40 I=701,N
      40      CY(I)=0.0
              CALL FORT(CY,M,S,-1,JACK)
              DO 50 I=1,316
              AI=I
      50      CX(I)=CY(I)/CH(I)*(0.54+0.46*COS(AI*PI316))
              DO 52 I=710,1024
              AI=I
              B=1026.-AI
      52      CX(I)=CY(I)/CH(I)*(.54+.46*COS(B*PI316))
              DO 55 I=317,709
      55      CX(I)=0.0
              DO 57 I=1,N
      57      AX(I)=CABS(CX(I))
              WRITE(6,665)
        665   FORMAT(//////)
              CALL FORT(CX,M,S,1,JACK)
      4       DO 60 I=1,N
      60      RX(I)=REAL(CX(I))
              WRITE(6,665)
              CALL PLOTNR(RX,ICONT,1,700,1)
              WRITE(6,666)
        666   FORMAT(1H1)
              ICOUNT=ICOUNT+1
              GO TO 2
              STOP
```