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IMPLEMENTATION OF AN EXPERIMENTAL FACILITY AND MODELING STUDIES FOR TIME VARYING IMAGES

by

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Abstract

A wealth of experiments have been performed studying image encoding techniques as applied to non-time varying or single-frame images. However, to date little work has been done to apply these techniques to time varying images, with most of such works emphasizing various ad hoc redundancy reduction techniques.

In this work, a computer based experimental system is implemented which makes more methodological studies of time varying images possible. Particular attention is devoted to obtaining very accurate interframe registration and uniform quantization of the images. Using this system, a selection of 35 mm movie film images are digitized and stored on computer magnetic tape in a format compatible with many other computing installations, providing a standard data base for future experiments.

An often used model for describing picture data is the stationary Gauss-Markov model. In this work, the appropriateness of this model for describing time varying images is studied by comparing the autocorrelation functions as described by the model and as obtained by computation from the picture data. These results indicate that the autocorrelation function is best described by a function which is separable in the time dimension and nonseparable in the spacial dimensions.

A number of DPCM communication systems are then studied as a vehicle for evaluating the effect of using the Gauss-Markov model. These results indicate that, for the sample images studied here, the estimated performance using the Gauss-Markov model is good when the model is a good fit to the first data point of the computed autocorrelation function.

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I. INTRODUCTION

1.1 Motivation of Study

It is a well known fact that picture images contain a large amount of redundancy and therefore any channel used to transmit these images must necessarily operate well below the maximum capacity for that channel. Therefore some form of source encoding should be possible which would reduce the bandwidth requirement for transmitting a source and thereby make more efficient use of the communication channel. This concept has motivated a wealth of experiemnts studying possible source encoding techniques for non-time varying or single frame images. The major reason for the lack of experimentation with time varying images have been; 1) the added complexity of analysis when a third dimension is added to the situation, 2) the great difficulty in obtaining good quality experimental source images, and 3) the already high cost, in terms of both time and expense, of single frame processing is multiplied when a larger number of frames are used.

With the development of more sophisticated technology; most notably faster, more reliable, and less expensive computing facilities; it has recently become more practical to consider extending known image processing techniques to treat time varying images. However, to date very little quantitative work has been carried out in this area. Most work that has been reported has emphasized subjective comparison of results obtained from using various ad hoc redundency reduction techniques.

For these reasons, the motivation for the work in this thesis has been to develop an experimental computer based system capable of handling motion pictures and provide an appropriate data base for studying time varying images, as well as begin a more methodological study of

time varying image coding techniques.

1.2 Review of Related Work

When any physical phenomona is to be studied, it is usually convenient to use a model, involving only a few essential parameters, to describe that phenomona. When a model which adequately describes the phenomona has been chosen, analysis of that phenomona becomes more tractible. When the physical phenomona is to be modeled as a random process, the mathematical description of that process will be a statistical one.

Kretmer [1] was one of the first to measure some of the statistics of a video signal produced by a television camera. These statistics included the first order probability distribution of the amplitude of the video signal, the first order probability distribution of the error amplitude resulting from using a linear prediction scheme, and the autocorrelation function of a typical signal. More significantly, Kretzmer was one of the first to measure the autocorrelation between two adjacent frames for a time varying image.

Schreiber [2] has measured the second and third order probability distributions of the video signal amplitude as well as some measures of the second and third order entropies of typical picture images. Limb [3] has measured some first to fourth order entropies and concluded that most redundancy is associated with the second order probability density function for low detail images while higher order statistics are responsible for the redundancies in medium and high detail images. The time dimension was studied more seriously by Wallace [4] and by Seyler [5,6] who measured the first order probability distributions for television frame differences.

Measurement of some of the statistics of video images made it possible to develop analytically tractible models which were considered to be reasonable descriptions of these images. Franks [7] proposed a model for random picture images and derived expressions based on this model for the second order statistics. One of the expressions was the power spectral density which was found to be expressible as a product of three components each separately arising from the influence of point to point, line to line, and frame to frame correlation. This model was the stationary, wide sense Markov model which is commonly used today.

For his model, Franks assumed separability of the effects of the dimensions of the sequence. This necessarily produced a separable autocorrelation function. Kretzmer's work [1], however, suggested, at least in the spacial dimensions, that a nonseparable form might be more appropriate. This question will be discussed further in this thesis.

As has been previously mentioned, a wealth of literature exists on redundancy removal techniques for still or single frame images. Of these studies, the more recent ones have been most notably concerned with linear transformations and block quantization [8] - [11], and differential pulse-code modulation (DPCM) encoders [12] - [15].

In the area of redundancy removal techniques applied to time varying images, much less work has been done [16] - [19]. These works can be considered to be mainly ad hoc experiments since most researchers have applied purely subjective criterion for selecting their encoding methods and also for evaluating the results. Mounts [17], however, has applied a form of DPCM encoding whereby he used the sample in the immediately previous frame as the predicted value and then encoded the difference signal. In this thesis we determine the effect of coding

dimensionality and data model on DPCM coding efficiency for experimental data.

1.3 Scope of Thesis

The purpose of this study is to obtain a high quality data set which can be used for subsequent studies in image coding techniques and other communication system studies, to measure the autocorrelation function of selected time varying monochromatic images and to examine the ability of certain historical models to describe the autocorrelation function, and, finally, to measure the signal to noise ratio (SNR) of DPCM systems when different types of prediction schemes are used.

In chapter II the digitization system used to obtain a high quality data set is discussed. The system design requirements are presented, the evolution of the system into its final form is discussed, and the format of the digitized images as stored on computer magnetic tape is described.

In Chapter III a number of commonly used models for time varying images are discussed. The autocorrelation functions for two such images are measured and compared to the model descriptions in order to evaluate the models.

In Chapter IV several DPCM communication systems are examined in order to evaluate the effect of using models in determining theoretical system performances as compared to the measured performance with real data and to evaluate the effect of increased dimensionality on the system performance.

II. THE IMAGE DIGITIZER

2.1 Introduction

In experimental studies it is necessary to have both an experimental system and also the material or data on which the experiments will be performed. If the picture material or data can be procured from an external source, then we need be concerned only with procuring or building an experimental system. If, as in the case of this study, the test data is not available in a form which can be used directly, then the preparation or interfacing of the picture material can become a significant part of the project. The main purpose of this chapter will be to discuss the experimental picture processing system developed to digitize and study time dependent monochromatic images.

A primary objective in designing a high quality digitizing system is to achieve uniform sampling. For example, it would be impossible to differentiate between motion caused by translation of an object in an image and motion between frames caused by translation of the sampling points during digitization of the time varying image data. Similarly, errors would occur from non-uniform sampling in the spacial dimensions.

Maintaining the uniformity of sampling in the spacial dimensions had already been provided for prior to the beginning of this project in that a digitizing system for single frame images had already been built. This system consisted of a precision flying spot scanner operated under the control of a Supernova minicomputer. The minicomputer controls the position of the spot on the screen of the display and its duration. This light spot is then focused on an image transparency

and the resulting modulated light signal collected in a photomultiplier tube. The video signal produced by the photomultiplier is integrated for the duration of the spot and this level is then digitized and transmitted to the minicomputer for storage on magnetic tape. The problem then remaining to obtain digitized time varying images was a matter of applying this single frame processing to a sequence of frames in such a way as to obtain precise interframe registration.

At first it was felt that the most simple solution might be to apply software registration techniques. However this would require benchmarks to be added to each frame so that translational and rotational errors could be detected. Then individual frames could be corrected to some reference orientation provided the errors were small and the size of the images digitized were larger than the desired image size. It would then also be required to sample the image at a rate sufficiently high to make interpolation errors negligible when the reference sample points fell between the points actually sampled.

This, of course, would still not solve the redisplay problem. This feature would be necessary in future works involving subjective evaluation of results produced from applying image processing techniques. Redisplaying of the images would also require good quality interframe registration. In this case, the film would have to be held in a very accurate position while the film was being exposed. Realizing this need, it was proposed that it would be possible to use only one device for both scanning and redisplay purposes. Then software registration could be dispensed with entirely.

2.2 The Film Transport and Hardware

Photographs of the mechanical film transport designed to

provide high precision interframe registration and of the digitizing system are shown in figure 2.1. Lateral registration is performed by two sets of two rolling bearings located at either end of the image plane. The two bearings in each set are separated by exactly the width of the film. When the film passes between the bearings, the edges of the film ride on the bearings keeping the film exactly centred between them.

The film is kept flat in the image plane by making use of the natural curvature of the film. The film is inserted in the transport in such a way that the curvature would cause the film to flex out of the image plane toward the photomultiplier or back side of the transport. A smoothly polished pressure plate is then applied to this side of the film to keep it in the image plane. On the opposite side of the film to the pressure plate, the film rides on a set of rails situated at each edge of the film. The purpose of using rails on one side of the film is to reduce the force required to advance the film by reducing the friction.

The width of the transport body near the film aperture was dictated by space constraints imposed by the optics of the digitizing system. The transport was required to present an image to a plane between two lenses which had to be closely spaced to obtain the desired optical focus.

Two light tight shutters are provided as well as a base for subsequent mounting of solenoids to operate them. These shutters, in combination with a light tight lid, will make it possible to use unexposed film in the transport for redisplaying time varying images. Only one shutter need be opened for redisplay purposes but both must be open to allow light to pass through while digitizing the image.

The film is driven through the image plane by using a sprocketed wheel, such is normally used in 35 mm projectors, to pull the

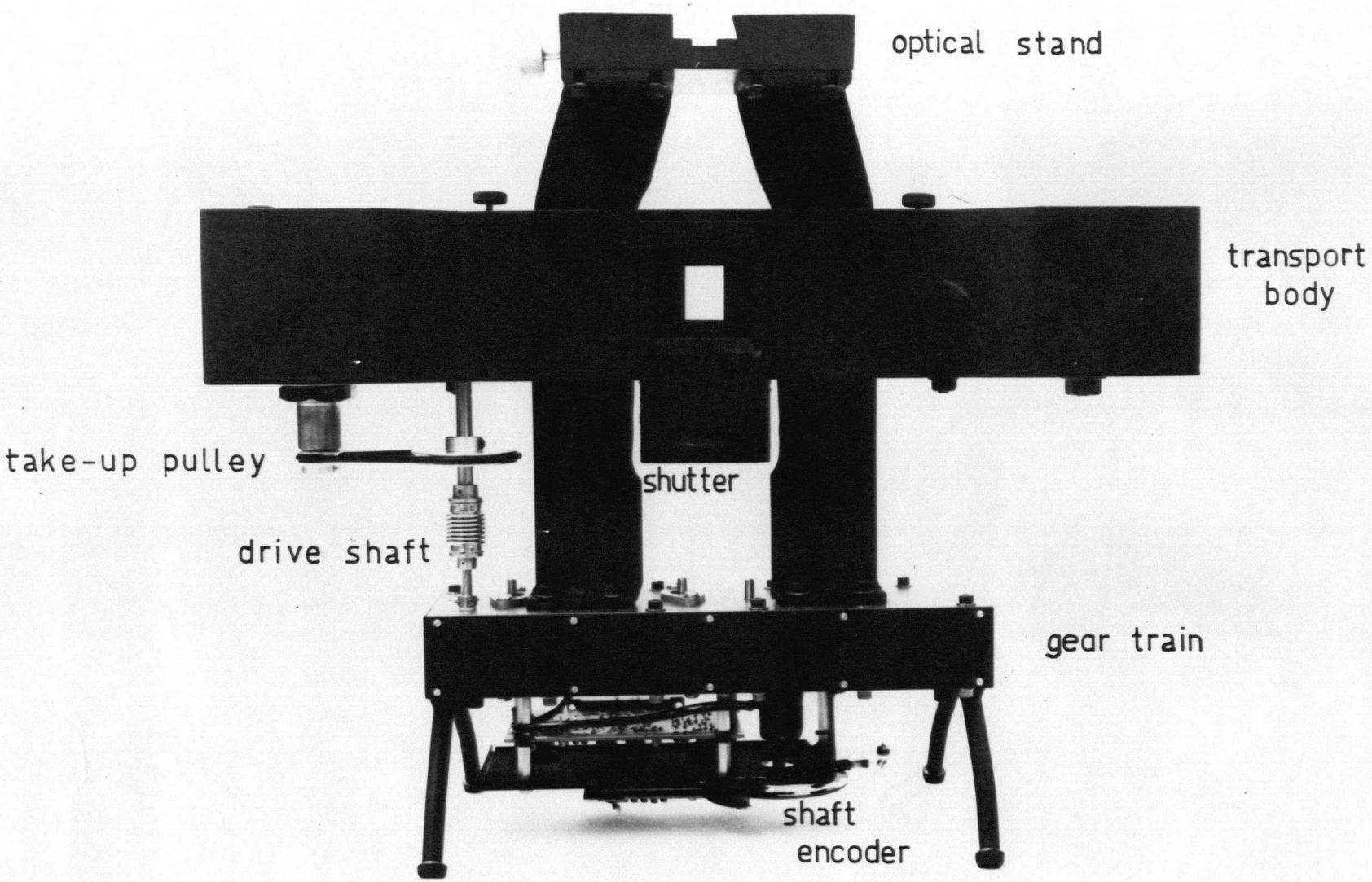


Figure 2.1A photograph of 35 mm film transport - front view

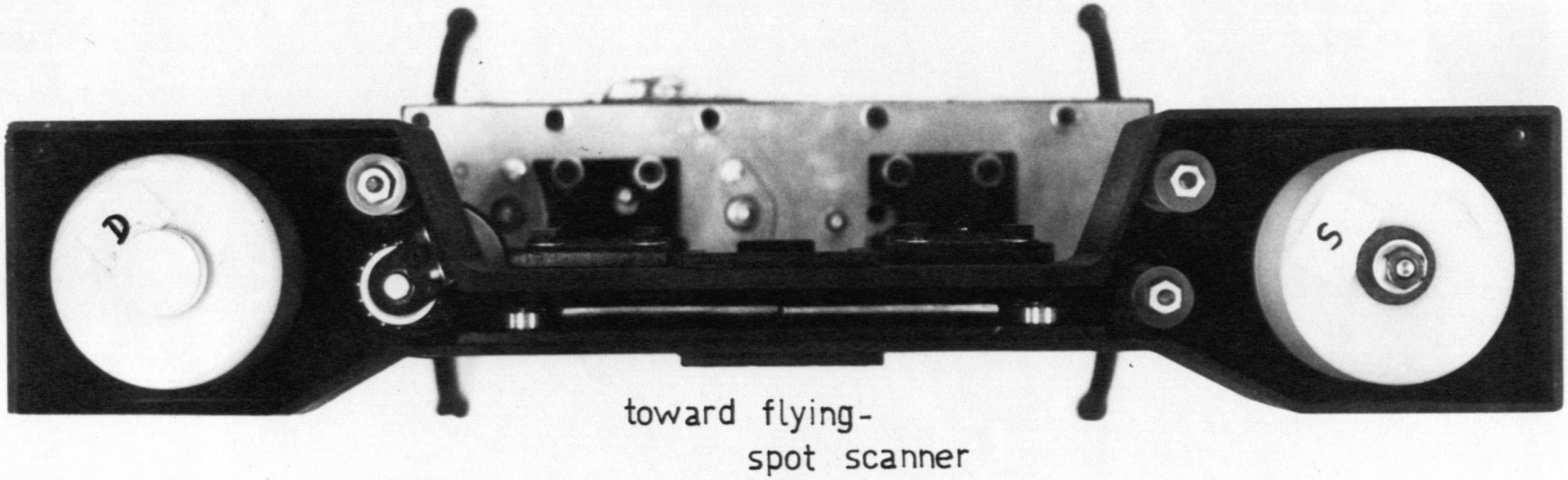


Figure 2.1B photograph of 35 mm film transport - top view

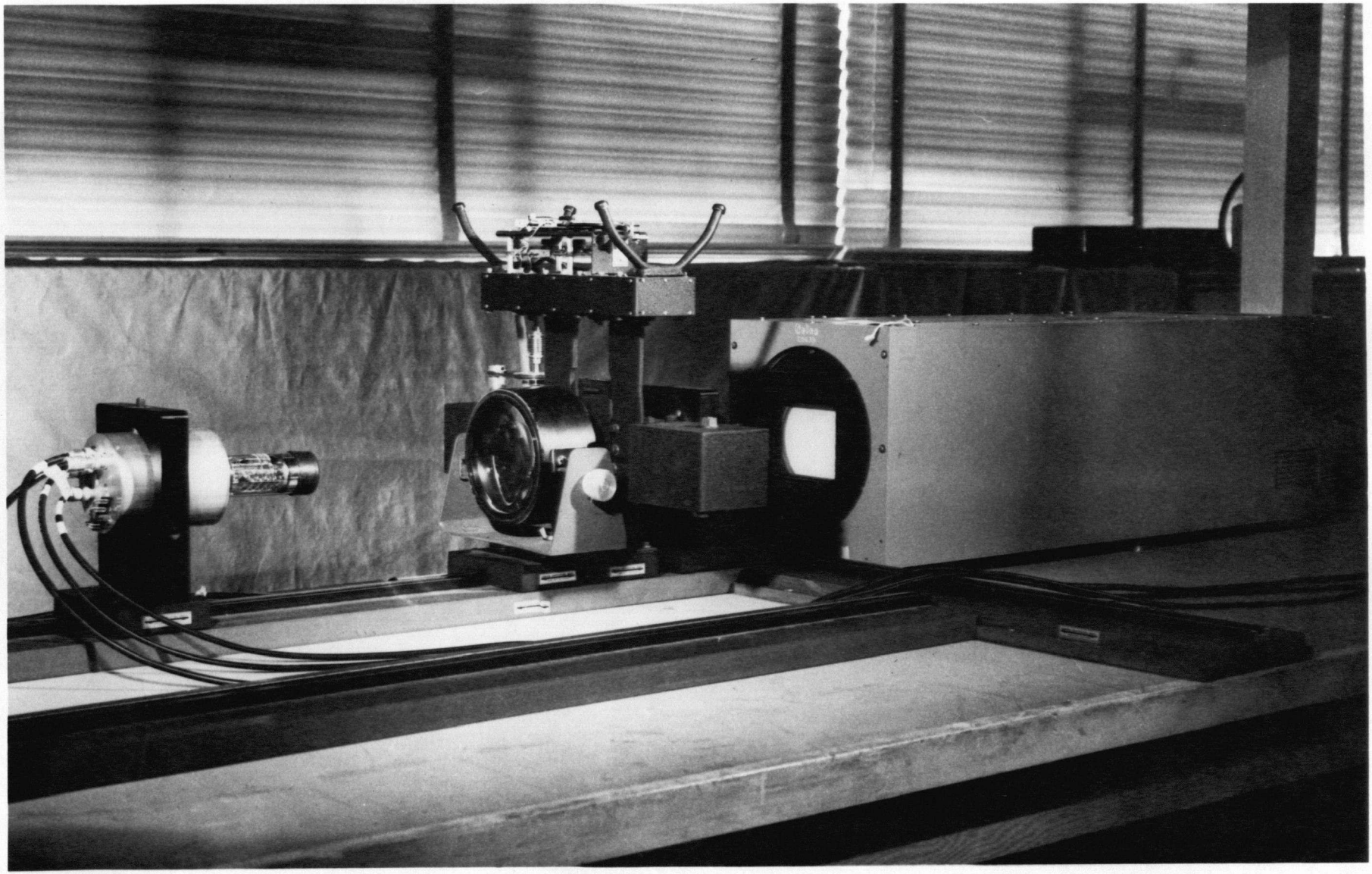


Figure 2.1C Photograph of image digitizing system - Layout

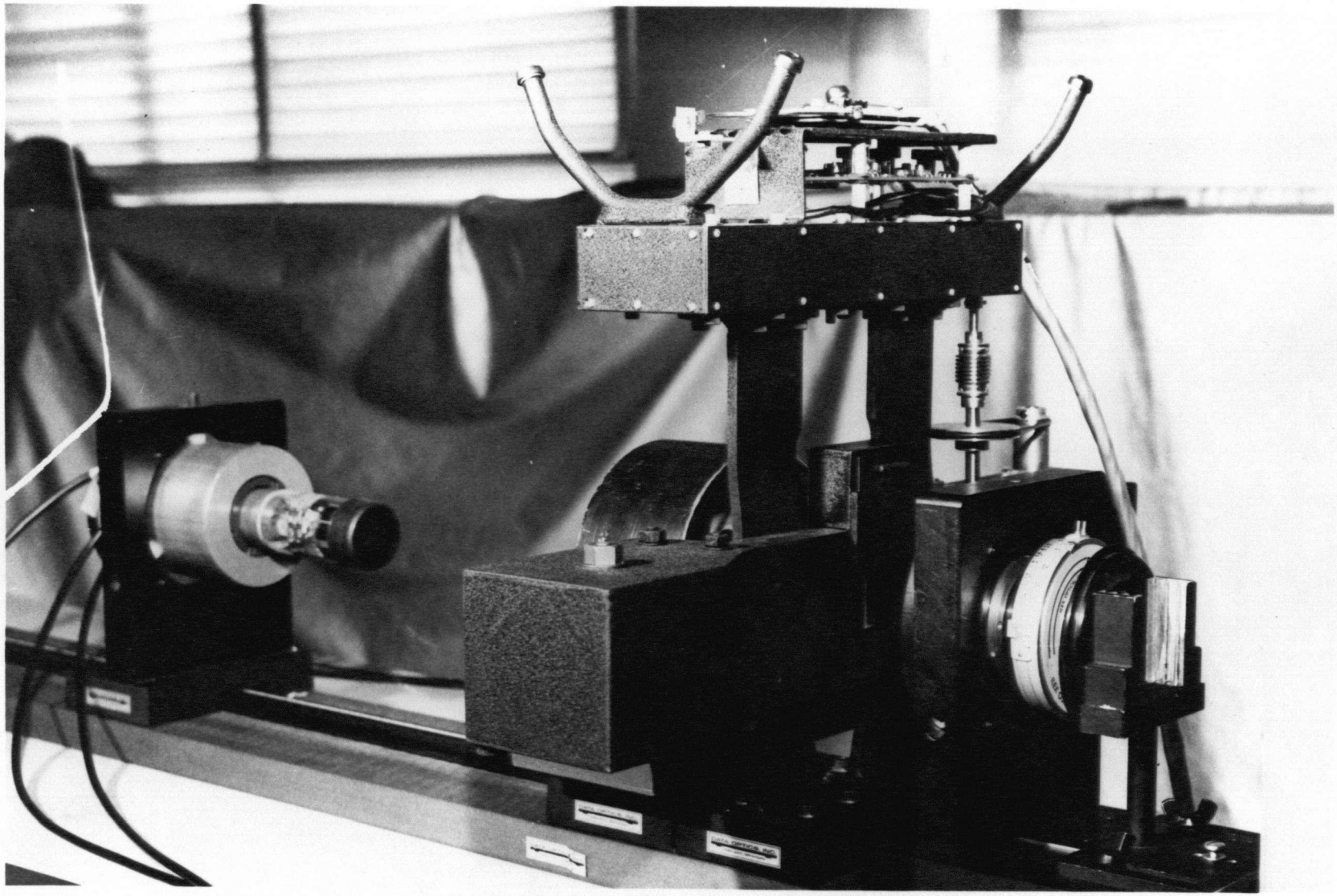


Figure 2.1D Photograph of image digitizing system - Close-up

film. The film is then drawn from the source reel (marked with an 's' in figure 2.1) which maintains back tension via a friction clutch; guided by two small spools into the image plane; and drawn across the film aperture onto the drive sprocket. From here the film is loaded onto a take-up spool (marked with a 'D' in figure 2.1) driven by a slipping drive belt. The slipping belt drive allows for the change in diameter of the take-up spool as more film is wound onto it and is also driven from the same drive shaft which drives the sprocket.

The driving power for the system is supplied by a small stepping motor which advances exactly fifteen degrees per step. This step size is further reduced through a high precision gear train to about 0.035 degrees rotation of the drive sprocket per step of the stepping motor. Since one full frame advancement requires ninety degrees of rotation of the drive sprocket, about 2800 steps are needed to advance one full frame. Note that this gives a possible interframe registration accuracy of about one tenth of a sampling interval when the image is sampled on a 256 by 256 grid.

After having built the apparatus as described above, a number of tests were performed to check for possible sources of error. It was discovered that the nature of the load on the motor was such that steps would be missed occasionally at some stepping rates and that the motor could only be started at low rates. It was also found that, once the motor had been started, the stepping rate could be advanced slowly to the maximum speed of the motor.

To overcome this problem, a shaft encoder was built and mounted on the stepping motor. This encoder and the associated digital hardware determines the direction and size of any motion of the motor and

increments or decrements a step counter accordingly. In this way it was possible to use computer control to obtain proper film advancement. The computer algorithm used for this is shown in figure 2.2. The step counter is first cleared (N10C 47 instruction on the Supernova). Then a number of pulses equal to the number of steps to be advanced is issued from the computer (N10P 47). At the completion of the sequency of pulses, the number in the step counter is read into the computer (DIA -, 47; where - is the desired accumulator) and compared to the desired number of steps. If some steps have been missed, the step counter is again cleared and the number of missed steps are reissued. This process continues until no steps have been missed.

The second problem, that of having to start at a low stepping rate, is really a non-problem if the amount of time taken to advance the film is unimportant. However, it was found that the time required at the highest stepping rate at which the motor would start was about 75 seconds per frame. This means that about six hours would be required for a three hundred frame film segment. For this reason, an acceleration function was programmed to accelerate the motor to optimum speed and then decelerate it again near the end of the advance. The deceleration was added in case overshoot was possible. With this ramping function the film advance time for three hundred frames was reduced to 1.5 hours.

2.3 Interframe Registration Technique

The mechanical system as it has been described thus far is more than adequate for obtaining the required interframe registration precision between any two adjacent frames of a film sequence. However, when the number of frames to be registered becomes large, small registration errors which are insignificant between two adjacent frames could

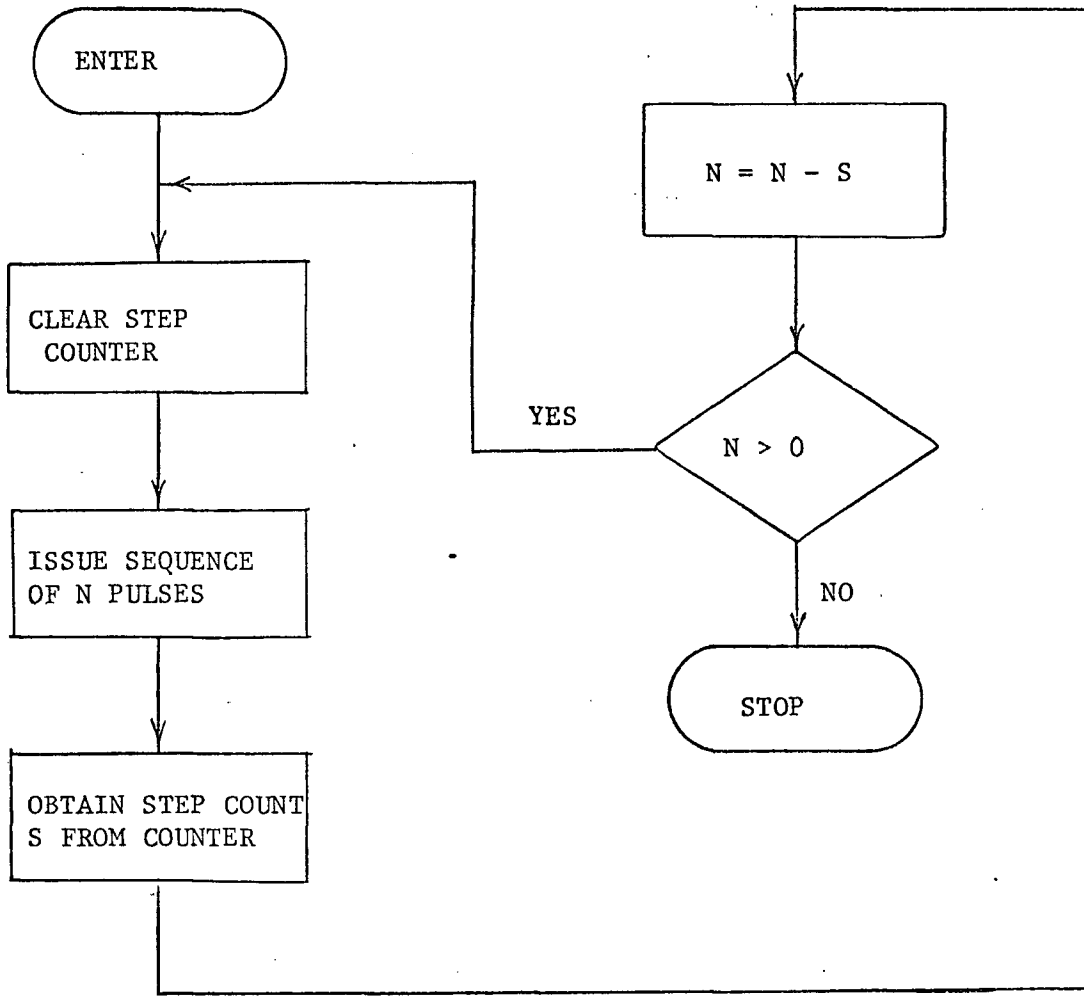


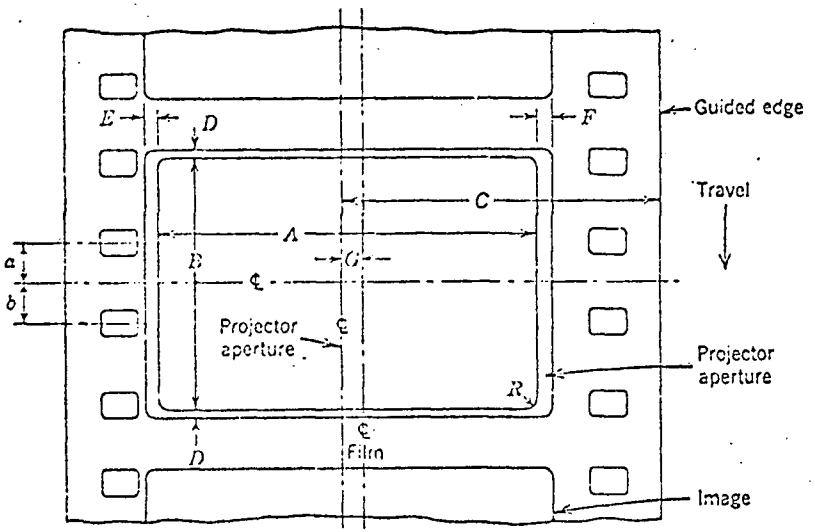
Figure 2.2 Flow diagram for film advance algorithm

accumulate, resulting in a large overall misregistration. For this reason it is desireable to have some references on the film so that, when the cummulative error begins to grow, it can be corrected.

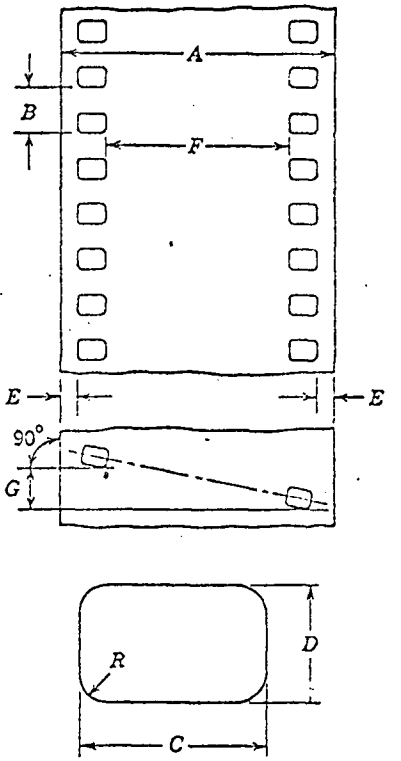
Conventional motion picture equipment provides for frame registration while filming and projecting motion pictures. The references used are the perforations located along the edges of the film which draw the film through the camera on projector. As shown in figure 2.3, the motion picture industry standards [20] require a very accurate location of these perforations with respect to the film image.

The aperture size of the film transport was increased allowing the performations along one edge of the film to be scanned by the flying spot scanner. A sketch of the output video waveform thus generated is shown by the solid line in figure 2.4. The high level corresponds to light passing through the perforations and the low level corresponds to light passing through the film. The spikes at the transitions can best be explained by light being scattered when striking the edges of the perforations.

Based on the characteristics of the output video waveform, a scheme was devised to determine the locations of the edges of the perforations, with a very low sensitivity to variations in flying spot intensity and opacity of the film. The algorithm used first determines the mean of the video waveform. Then all values of the waveform which are above the mean are set to a logical high level and all those below the mean are set to a logical low level, resulting in the square waveform shown by the dashed line in figure 2.4. Transitions from a logical high level to a logical low level and vice versa are taken to correspond to an edge of a perforation of the film.



Dimensions	Inches	Millimeters
A	0.825 ± 0.002	20.95 ± 0.05
B	0.600 ± 0.002	15.25 ± 0.05
C	0.738 ± 0.002	18.74 ± 0.05
D	0.0155	0.394
E	0.022	0.56
F	0.021	0.53
G	0.049	1.24
R	Not > 0.005	Not > 0.13



	Dimensions	Inches	Millimeters
A	Film width	1.377 ± 0.001	34.975 ± 0.025
B	Perforation pitch	0.1870 ± 0.0005	4.750 ± 0.013
C	Perforation width	0.1100 ± 0.0004	2.794 ± 0.010
D	Perforation height	0.0780 ± 0.0004	1.981 ± 0.010
E	Edge to perforation	0.079 ± 0.002	2.01 ± 0.05
F	Width between perforations	0.999 ± 0.002	25.37 ± 0.05
G	Perforation skewness	0.001 max	0.03 max
L	100 consecutive perforation pitch intervals	18.700 ± 0.015	474.98 ± 0.38
R	Radius of perforation fillet	0.020 ± 0.001	0.51 ± 0.03

Figure 2.3 Standard dimensions for 35 mm motion picture film

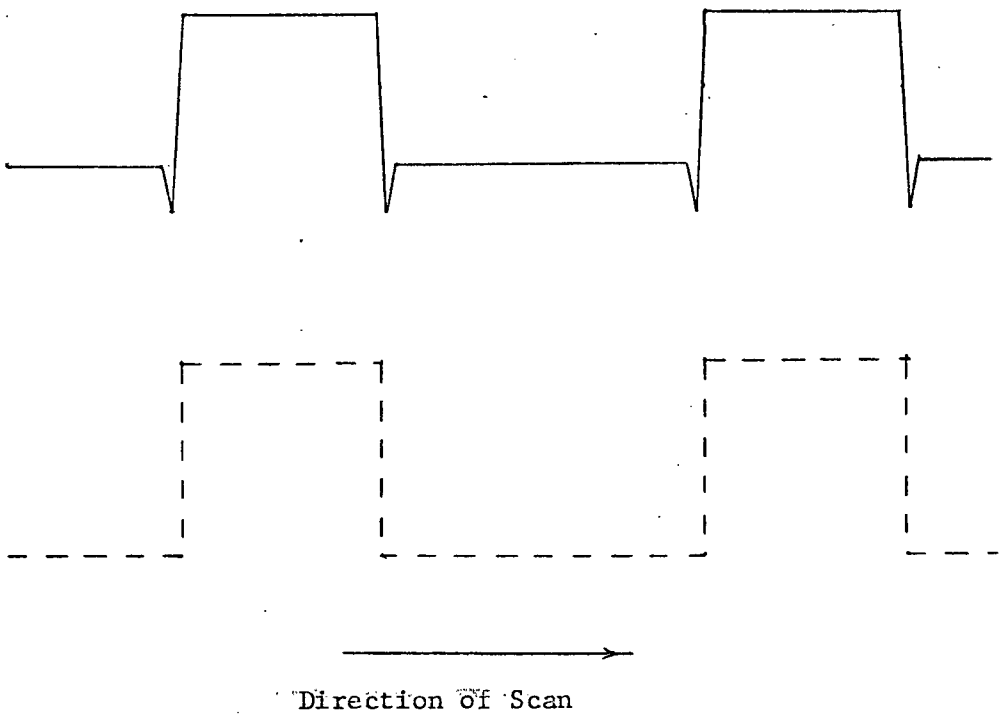


Figure 2.4 Sketch of video waveform from single scan along perforations of 35 mm film and the associated decision waveform generated.

The algorithm described above was implemented digitally. Sampling was done at a much higher rate than that used to sample the film images in order to provide more than sufficient interframe registration accuracy. Using this technique it was found that the location of an edge could be determined repeatedly over a large range of film segments and with scanning intensities varying from saturation to very low levels.

In order to process a section of film, the algorithm shown in figure 2.5 is used. Before any processing takes place, the position of the first perforation is determined as an origin position. Subsequent frames are then properly registered by aligning their perforations with the original perforation position.

2.4 Automatic Intensity Control for the Flying Spot Scanner

Once the interframe registration techniques described above had been developed, it was possible to maintain uniform sampling in all three image dimensions. There only remained the problem of guaranteeing consistent quantization with time.

Sources of error in quantization could arise due to time drifts in the electronic hardware. To determine the possible causes and the degree of drift over time, experiments were conducted using a single frame placed in the digitization aperture and then scanned repeatedly. Numerous parameters were measured for both short term and long term variations. The only variation detectable was in the intensity of the beam spot of the flying spot scanner. This variation was not detectable on a frame by frame basis, but a gradual decrease of intensity, was measured. In 3.5 hours the intensity of the beam decreased from normal digitizing intensity to zero.

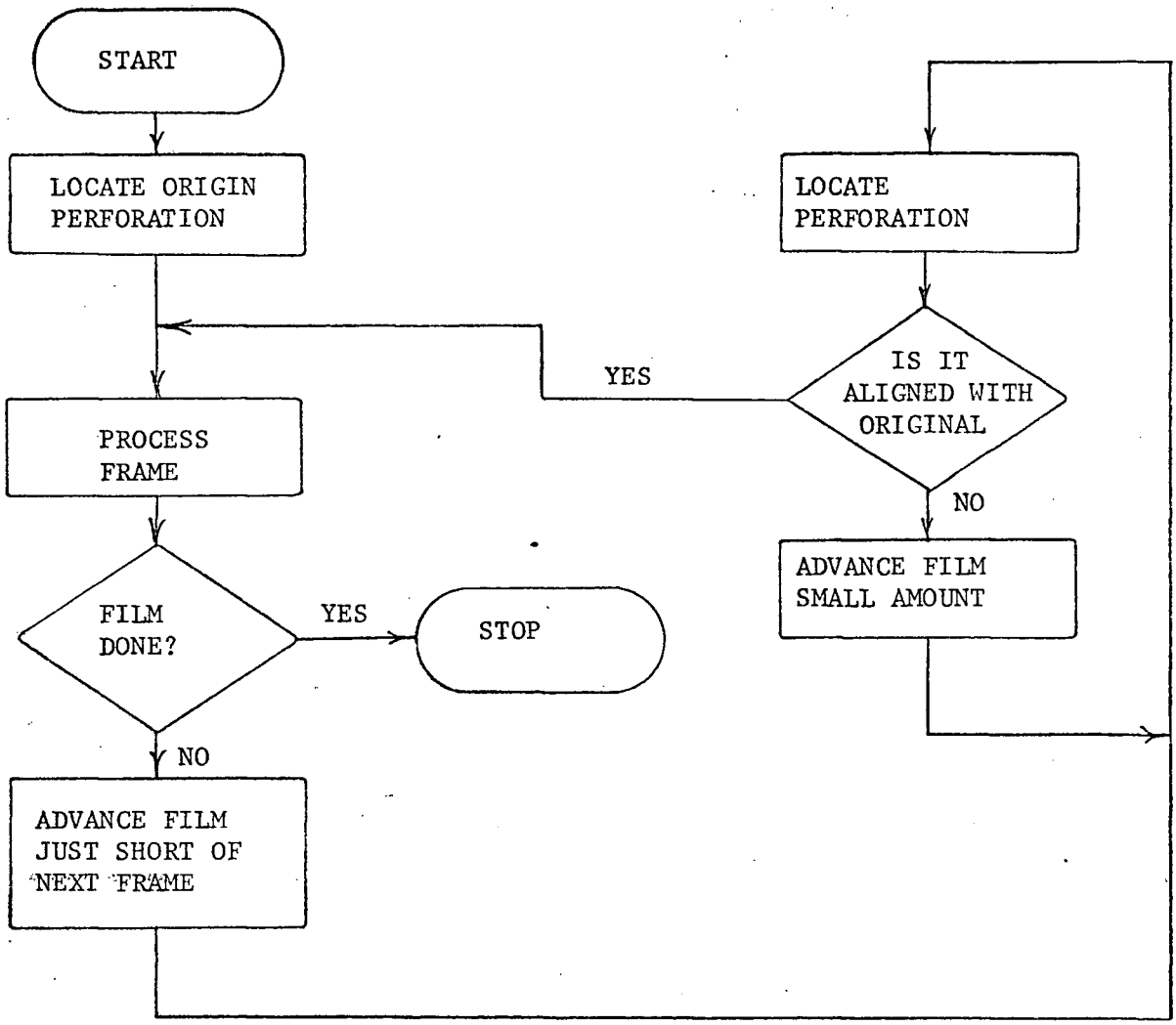


Figure 2.5 Flow diagram for a general film processing algorithm.

The beam intensity is directly measurable as a result of the addition of the perforation detection scheme discussed earlier. Since the location of the perforation is known, it is possible to scan a number of points in the perforation. The digitized values thus obtained can be averaged to obtain a measure of the beam intensity. Having measured the beam intensity, the computer can transmit a digital number to a digital/analog converter which controls the gain of the video amplifier of the flying spot scanner. The computer algorithm used in controlling the beam intensity is shown in figure 2.6. The computer hunts for a prespecified intensity, increasing the beam intensity when it is too low and decreasing it when it is too high. When the correct intensity is found, the algorithm is terminated.

2.5 The Digitized Images

The complete flow diagram for the image digitizing algorithm is shown in figure 2.7. This algorithm incorporates all the features of the system described previously in this chapter. All the subroutines written to implement the algorithm are included in the appendix. Care must be exercised if modifying calls to routines since two different calling sequences are employed. Some routines are written in fortran and calls to and from them use the normal fortran calling sequence in Data General's DOS fortran package. Assembler routines called from fortran routines and assembler routines calling fortran routines will use the DOS sequence for these calls. However linkages between two assembler routines use normal accumulator parameter passing techniques and not the DOS sequence. These facts are well documented in the routines.

For subsequent experimentation, digitized images consisting

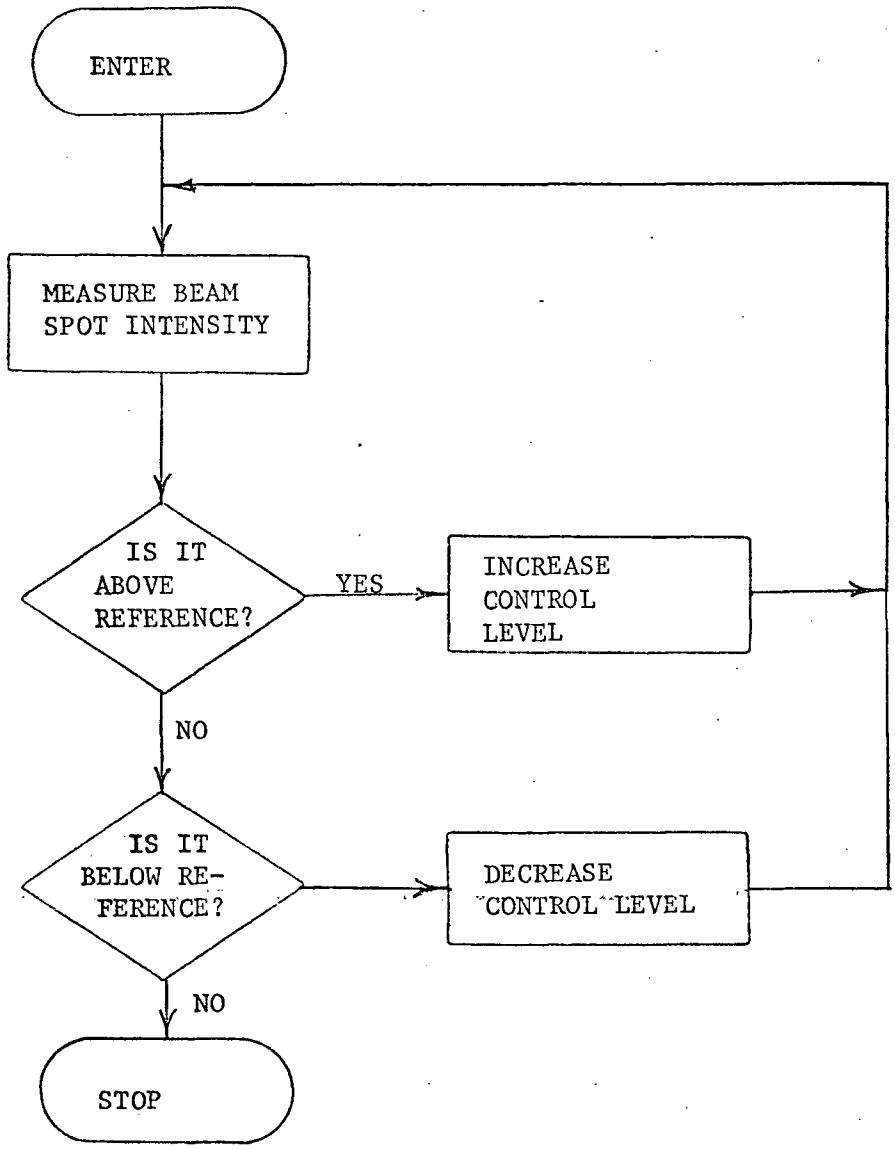


Figure 2.6 Flow diagram of beam intensity control algorithm

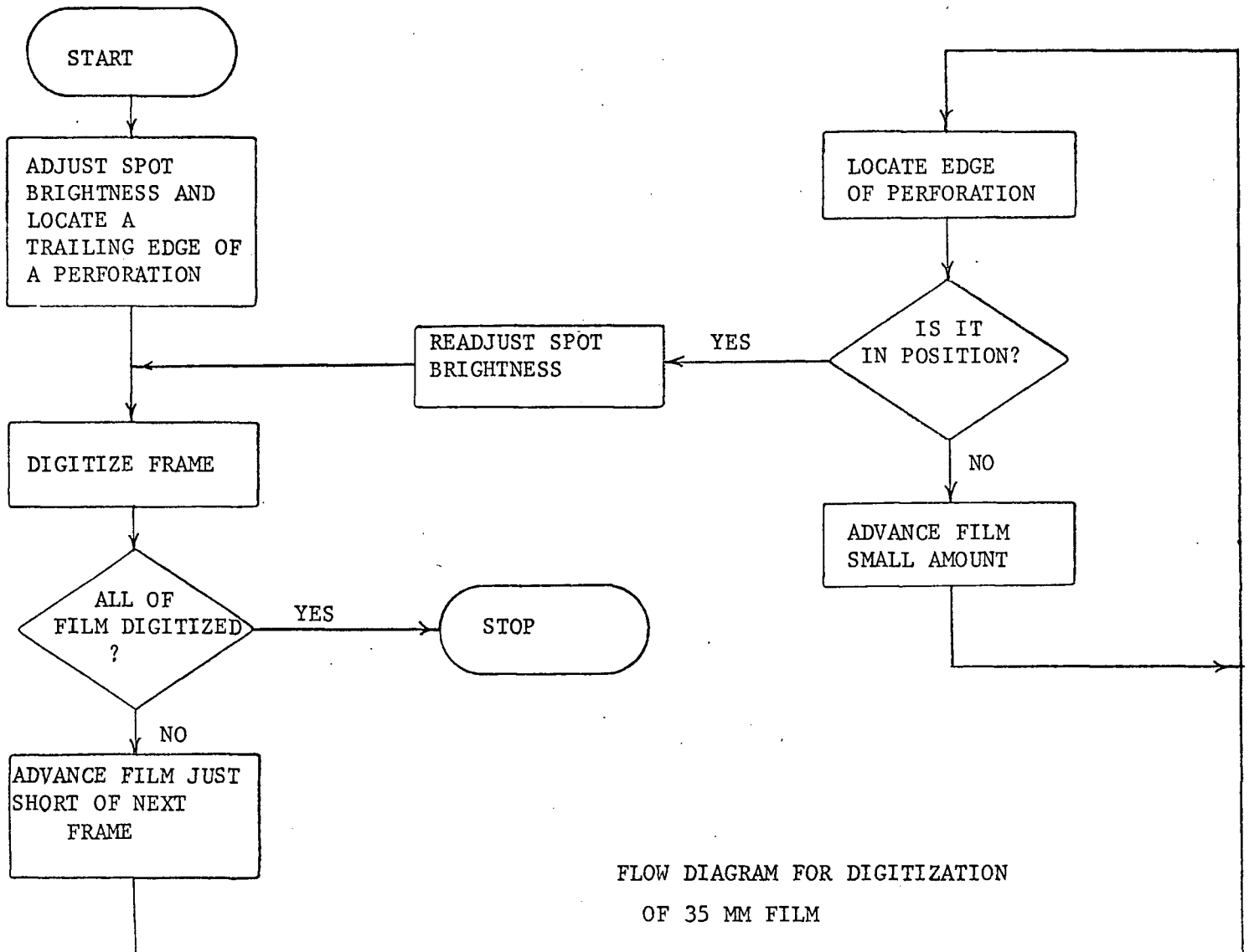


Figure 2.7 Flow diagram for the Image Digitizing Algorithm

of 256 by 256 eight bit samples per frame were stored on magnetic computer tape compatible with the IBM system. The information is stored in two eight bit image samples per word with the first byte as the odd numbered sample and the second byte as the even numbered sample. These words are stored in blocks of 2048 words corresponding to sixteen lines from the image. Sixteen blocks therefore make up a single frame. Successive frames are delimited by end of file markers with an additional end of file being placed before the first frame. No end of file was placed after the last frame but this can easily be added for situations where it is needed.

III. MODELS FOR IMAGES

3.1 Introduction

In this chapter, we consider the question of statistical modelling of monochromatic time varying images. A measure is presented for comparing the validity of certain popular models which assume data stationarity. Non-stationary models would probably describe the physcial phenomona more closely. However the criterion of analytic tractability makes the choice of a stationary model imperative.

In section 3.2, the models of interest are presented and discussed relative to their analytic tractability. The ability of these models to represent picture data is then evaluated as a result of experiments on selected test data.

3.2 Stationary Models for Monochromatic Time Varying Images

A monochromatic time varying image constitutes a three dimensional source which can be specified by its grey level $u(x,y,t)$ at each of the coordinates (x,y,t) where x and y are the spacial coordinates and t is the time coordinate. Sampling and quantization of the continuous source function $u(x,y,t)$ generates a three dimensional field of discrete samples $u'(x_i, y_j, t_k)$. An ensemble of such images can then be modelled by interpreting $u'(x_i, y_j, t_k)$ as a random field.

For simplicity it can be assumed that the random field is a zero mean field. This can always be made true by determining the mean intensity of the field and then subtracting this mean from every point in the field. That is if

$$\bar{u} = E\{u'(x_i, y_j, t_k)\} \tag{3.2.1}$$

where $E\{\cdot\}$ denotes the expectation operator, then a zero mean field $u'_o(x_i, y_j, t_k)$ can be generated as

$$u'_o(x_i, y_j, t_k) = u'(x_i, y_j, t_k) - \bar{u}. \tag{3.2.2}$$

Previous experiments [7] have led to the adoption of the Gauss-Markov field as the most widely used model for pictorial data. This stationary model is specified in terms of its autocorrelation function as

$$R(x, x', y, y', t, t') = \sigma^2\{\exp[-\alpha|x-x'|-\beta|y-y'|-\gamma|t-t'|]\} \tag{3.2.3}$$

where σ^2 is the signal power of the source and α, β and γ are parameters. Defining $\Delta x = x - x'$, $\Delta y = y - y'$, and $\Delta t = t - t'$, (3.2.3) can be rewritten as

$$R(\Delta x, \Delta y, \Delta t) = \sigma^2\{\exp[-\alpha|\Delta x|-\beta|\Delta y|-\gamma|\Delta t|]\} \tag{3.2.4}$$

In what follows, we normalize our experimental data so that our interest lies with

$$R_o(\Delta x, \Delta y, \Delta t) = \frac{R(\Delta x,\Delta y,\Delta t)}{\sigma^2} = \exp[-\alpha|\Delta x|-\beta|\Delta y|-\gamma|\Delta t|] \tag{3.2.5}$$

The primary attraction of the Gauss-Markov field model is the analytic simplicity arising from the separability of the autocorrelation function into a product of one dimensional autocorrelation functions

$$R_o(\Delta x, \Delta y, \Delta t) = Rx_o(\Delta x)\, Ry_o(\Delta y)\, Rt_o(\Delta t) \tag{3.2.6}$$

where
$$Rx_o(\Delta x) = \exp[-\alpha|\Delta x|]$$
$$Ry_o(\Delta y) = \exp[-\beta|\Delta y|]$$
$$Rt_o(\Delta t) = \exp[-\gamma|\Delta t|]$$

In addition, other analytic simplifications can result from the condition that all statistical information about a sample point is contained in

adjacent previous samples.

Consider what separability means for a field in two spacial dimensions

$$R_o(\Delta x, \Delta y) = Rx_o\ (\Delta x)\ Ry_o\ (\Delta y) \tag{3.2.7}$$

Assume a homogeneous field where $Rx_o\ (\Delta) = Ry_o(\Delta)$, then

$$R_o\ (\Delta, \Delta) = [Rx_o(\Delta)]^2 = [Ry_o\ (\Delta)]^2$$

or

$$R_o\ (\Delta, \Delta) = Rx_o\ (2\Delta) = Ry_o\ (2\Delta)$$

From this it can be seen that, for this model, the autocorrelation function decreases more rapidly with distance along the spacial diagonal than along either of the spacial axes. Intuitively this does not seem reasonable since the orientation of the spacial axes with respect to the image is somewhat arbitrary. Also, previous work [15] has shown the correlation along the spacial diagonal as predicted by this model to be much lower than the value measured for experimental images. Kretzmer [1] also supports this arguement by finding that, in general, there was no preferred direction of correlation for the images be studied.

On the basis of these arguements, another stationary model in two spacial dimensions is obvious with

$$R_o\ (\Delta x, \Delta y) = \exp\ [-(\alpha^2(\Delta x)^2 + \beta^2\ (\Delta y)^2)^{1/2}] \tag{3.2.8}$$

Note that for $x = 0$ or $y = 0$, this model reduces to the same form as the Gauss-Markov field. This means that the parameters α and β are identifiable with the α and β of the Gauss-Markov field model. Equation (3.2.8) may be extended to model a field generated by a time varying

image. In this case we have

$$R_o\ (\Delta x,\ \Delta y,\ \Delta t) = \exp\ [-(\alpha^2(\Delta x)^2 + \beta^2(\Delta y)^2 + \gamma^2(\Delta t)^2)^{1/2}] \quad (3.2.9)$$

The remainder of this chapter is devoted to the study of the models proposed by (3.2.5) and (3.2.9). The objective in what follows will be to obtain a measure of the closeness of fit of these models to selected experimental data.

3.3 Closeness of Fit Criterion

One aim of this thesis is to measure the accuracy of certain popular models in describing image data. In order to measure a model's closeness of fit to experimental data, a meaningful measure must first be chosen. The measure chosen here is the mean squared error (MSE) between the experimentally determined autocorrelation function and the model with parameters α, β and γ adjusted to provide a least squares fit to the experimental data. A more compact measure is defined by

$$D = -10 \log_{10} (\text{MSE}) \quad (3.3.1)$$

For example, if the MSE is 0.0001, the measure is D = 40.0. From (3.3.1) it can be seen that $D_1 > D_2$ when $\text{MSE}_1 < \text{MSE}_2$.

3.4 The Source Images

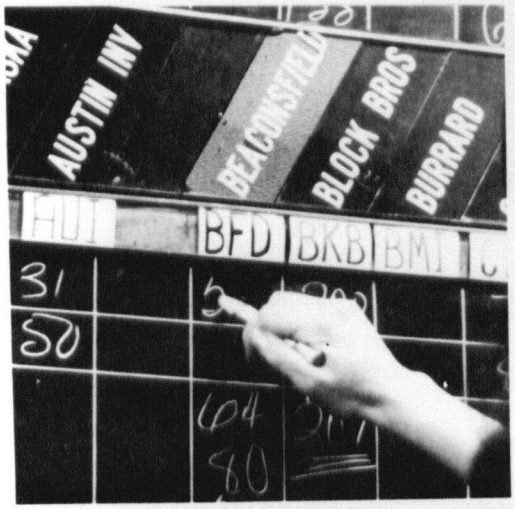
Two professionally produced 35 millimeter film strips were chosen as subjects for experimental computations. Figure 3.1 contains selected frames from these strips together with the subject number and a number corresponding to the location of the frame in the film strip. A large amount of degradation has occurred in the reproduction of these pictures for this thesis. These subjects were chosen subjectively on the basis of the amount of spacial detail and type of motion exhibited.

subject one, frame 1

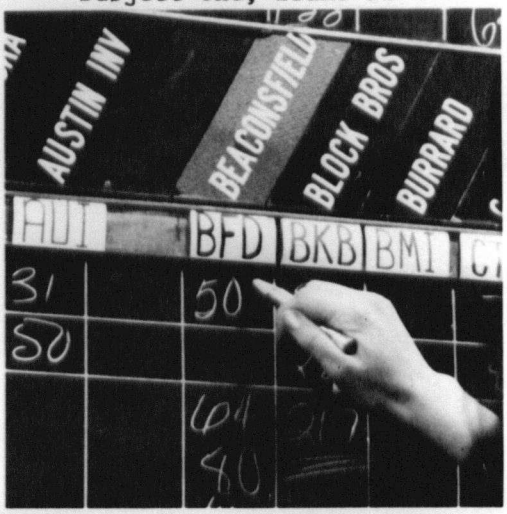
subject one, frame 18

subject one, frame 34

subject one, frame 51



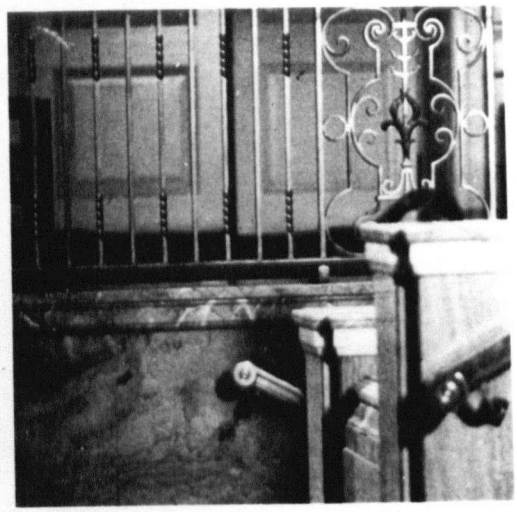
subject one, frame 68



subject one, frame 84

Figure 3.1A Photographs of selected frames from experimental image film strips

subject one, frame 100



subject two, frame 1

subject two, frame 18

subject 2, frame 34

subject two, frame 51

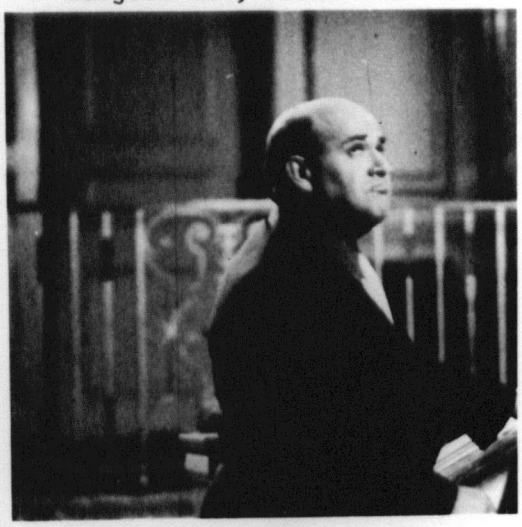
subject two, frame 68

Figure 3.1B Photographs of selected frames from experimental image film strips

subject two, frame 84

subject two, frame 101

subject two, frame 118

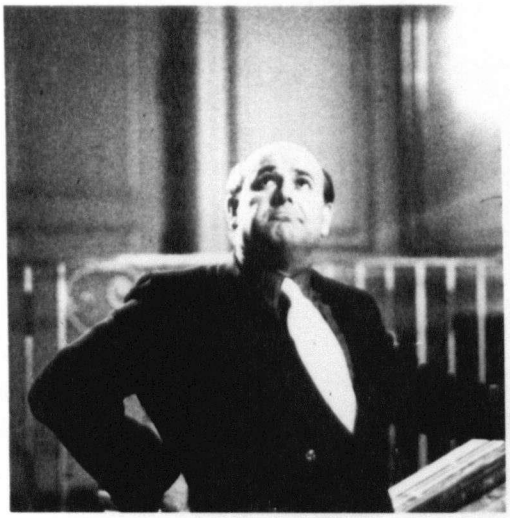


subject two, frame 134

subject two, frame 151

subject two, frame 168

Figure 3.1C Photographs of selected frames from experimental image film strips

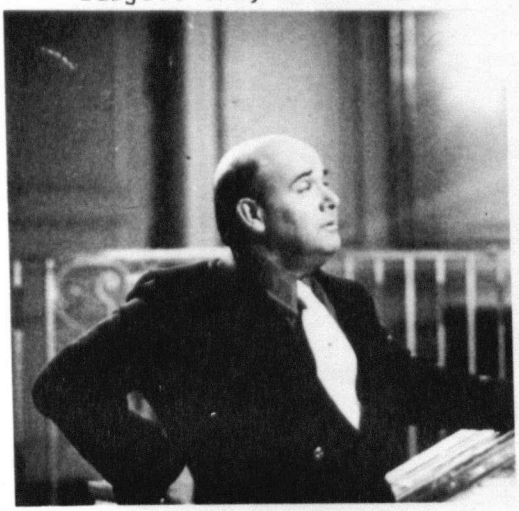


subject two, frame 184

subject two, frame 201

subject two, frame 218

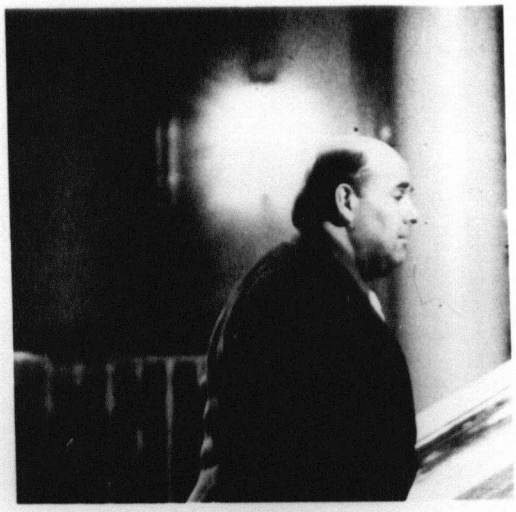
subject two, frame 234



subject two, frame 251

subject two, frame 268

Figure 3.1D Photographs of selected frames from experimental image film strips



subject two, frame 284

subject two, frame 300

Figure 3.1E Photographs of selected frames from experimental image film strips

It is believed the subjects chosen represent a good variation on subject detail and motion. Subject one and two consist of 100 and 300 frames, respectively, at 25 frames per second.

3.4.1 Subject One

Subject one was chosen primarily because of the specialized nature of the motion involved. Only a small portion of the image undergoes motion and this motion is executed quite quickly. Also, for the first half of the sequence, this motion has a periodic acceleration and deceleration. The background, which remains stationary throughout the sequency of frames, consists of a stock exchange board on which a grid has been drawn containing names and numbers. The lettering and grid are of high spacial detail and the board spaces are of low spacial detail.

Within the first ten frames, a woman's head and shoulders pass in front of the camera, but outside the depth of field and therefore out of focus. This constitutes a low spacial detail, moving image. For the remainder of the sequence, very little of the head remains visible, while a hand erases some of the numbers on the board and then enters new numbers in their place.

The erasure of the board takes place from frame fifteen to frame fifty-one. This section is temporally quite periodic in nature. Figure 3.2 demonstrates this periodicity. This diagram is a plot of the average temporal correlation at a time lag of one frame as measured along the sequence of frames. The rapid variation in the function of figure 3.2 from frame fifteen to frame fifty-one corresponds to rapid hand motion. The dashed line in figure 3.2 is the mean temporal correlation at a time lag of one frame over the entire 100 frame film sequence.

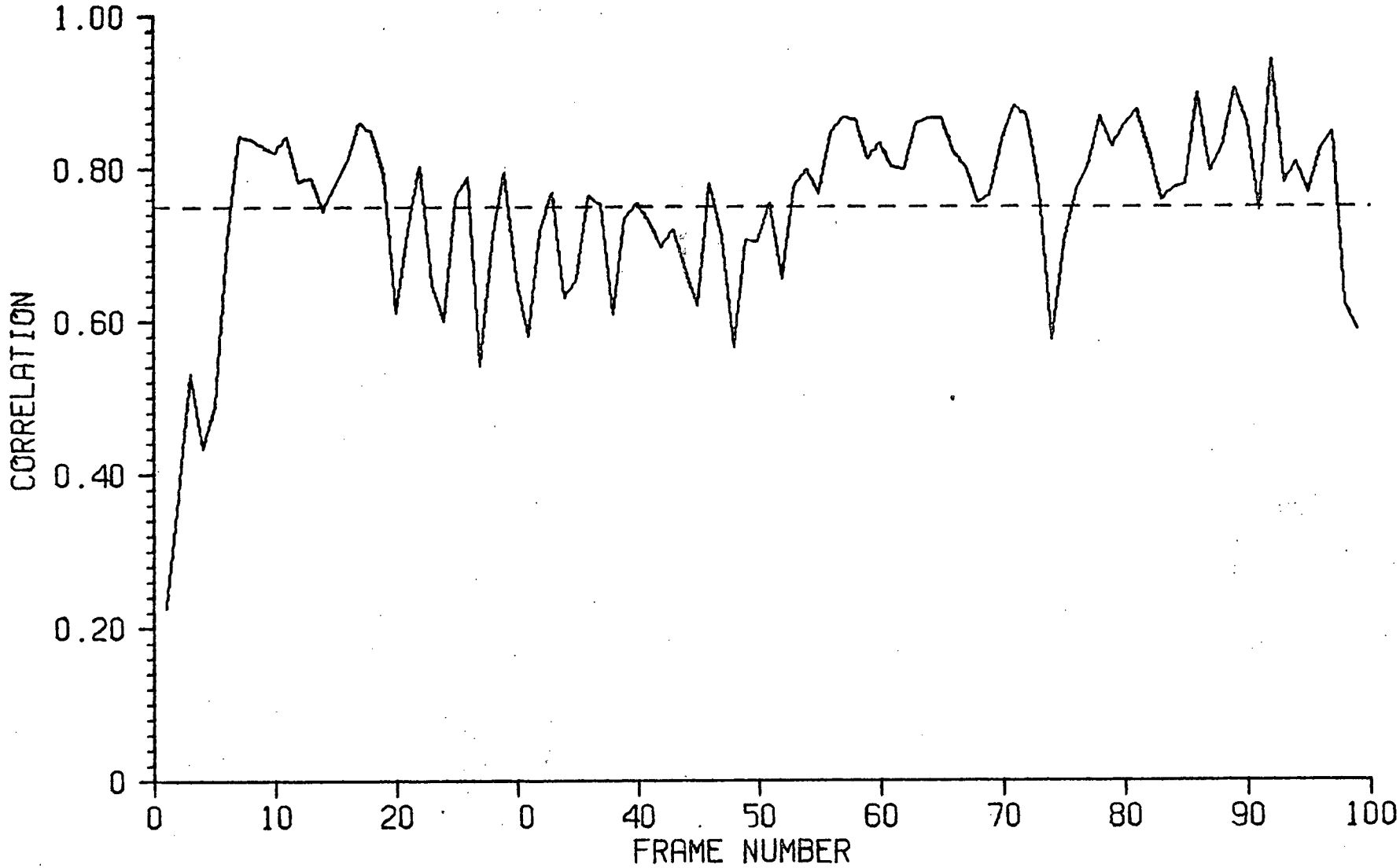


Figure 3.2 Average temporal correlation at a time lag of one frame versus the frame number of the first frame for subject one

3.4.2 Subject Two

Subject two was chosen because of its wide variety of content. Both the background and the foreground vary with time and contain varying amounts of spacial detail. This image also contains varying rates of motion, from rapid to almost stationary. The background consists of both high detail and low detail areas and changes as the camera is panned to follow the foreground objects.

The motion consists of two men walking up a set of stairs into the view of the camera which is mounted on the landing. Once the men reach the landing, one of them pauses as the other continues around him, at the edge of the film, and then proceeds up a second flight of stairs. Once the second man has passed out of view of the camera, there is a period of very little motion in which the man on the landing casually surveys his surroundings. This is a segment of very high correlation, often reaching 0.99. The man on the landing then turns and rapidly mounts the second flight of stairs as the camera pans to follow him, thus completing the entire film sequence.

Again these details can be observed in figure 3.3 which is a plot of the average temporal correlation at a lag of one as measured along the 300 frame film segment. The dashed line indicates the mean temporal correlation for a lag of one frame over the entire film segment.

3.5 Measured Model Accuracy

To evaluate the models, the autocorrelation functions of the experimental film subjects were computed along five directions in the field;

a) along the x spacial axis

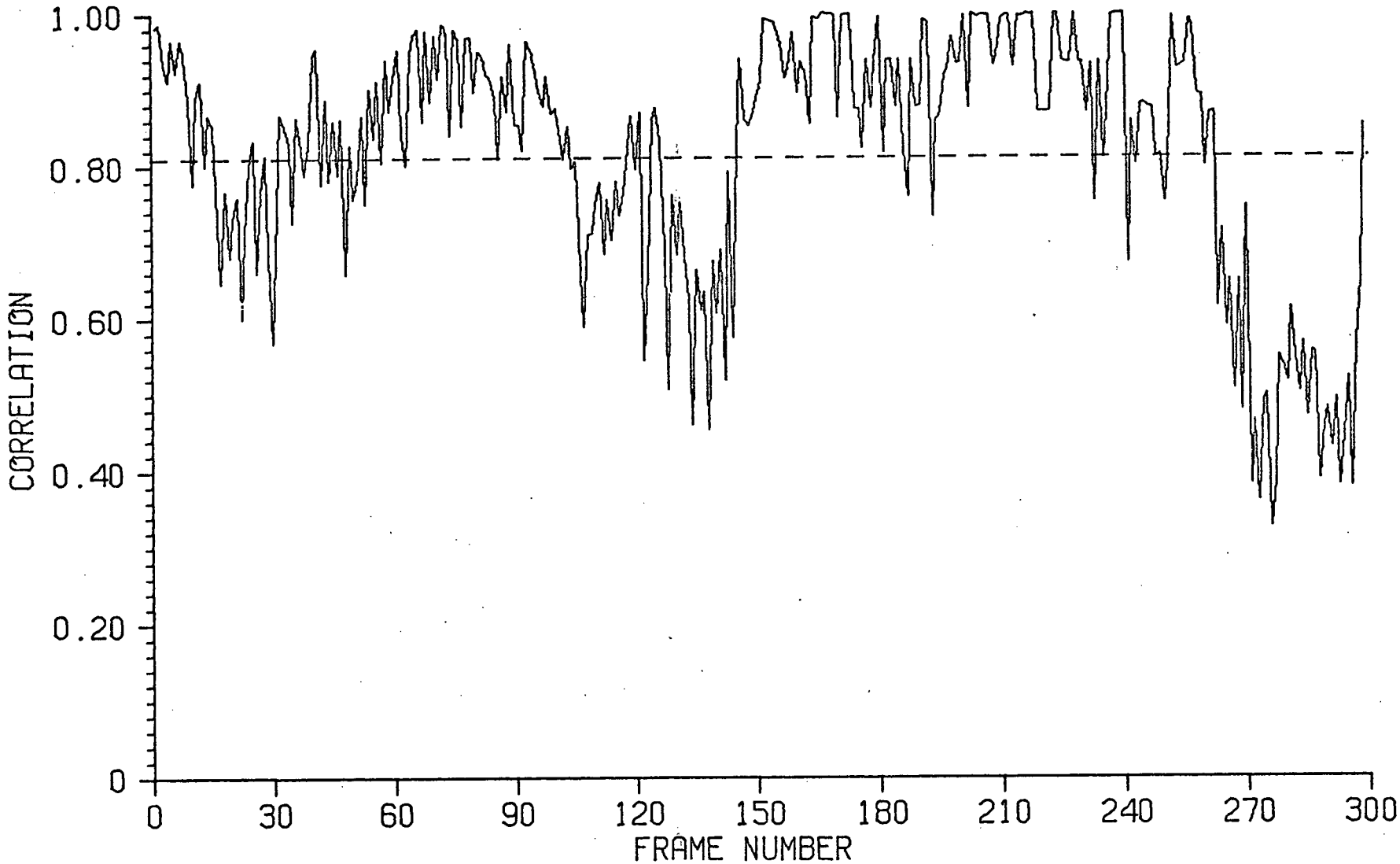


Figure 3.3 Average temporal correlation at a lag of one frame versus the frame number of the first frame for subject two.

b) along the y spacial axis

c) along the spacial diagonal

d) along the time (t) axis

e) along the diagonal in the x-t plane.

Then exponential curves were fitted, by a least squares fit method, to each of the computed correlation functions to determine α, β and γ for the models. The measurement of the autocorrelation functions was performed on the Supernova system while the least squares fit was computed on the IBM 360/67 system.

Defining the sample interval in each of the x, y and t directions of the field to be unity, the desired autocorrelation functions could be computed by evaluating

$$\rho(k) = \begin{cases} \dfrac{1}{\sigma^2}\dfrac{1}{(L-k)MN}\displaystyle\sum_{\ell=1}^{L-k}\sum_{m=1}^{M}\sum_{n=1}^{N} u'_o(\ell, m, n)\, u'_o(\ell+k, m, n) & (3.5.6a) \\ \text{for the x direction} & \\ \dfrac{1}{\sigma^2}\dfrac{1}{L(M-k)N}\displaystyle\sum_{\ell=1}^{L}\sum_{m=1}^{M-k}\sum_{n=1}^{N} u'_o(\ell, m, n)\, u'_o(\ell, m+k, n) & (3.5.6b) \\ \text{for the y direction} & \\ \dfrac{1}{\sigma^2}\dfrac{1}{(L-k)(M-k)N}\displaystyle\sum_{\ell=1}^{L-k}\sum_{m=1}^{M-k}\sum_{n=1}^{N} u'_o(\ell, m, n)\, u'_o(\ell+k, m+k, n) & (3.5.6c) \\ \text{for the spacial diagonal} & \\ \dfrac{1}{\sigma^2}\dfrac{1}{L\;M(N-k)}\displaystyle\sum_{\ell=1}^{L}\sum_{m=1}^{M}\sum_{n=1}^{N-k} u'_o(\ell, m, n)\, u'_o(\ell, m, n+k) & (3.5.6d) \\ \text{for the time direction} & \\ \dfrac{1}{\sigma^2}\dfrac{1}{(L-k)M(N-k)}\displaystyle\sum_{\ell=1}^{L-k}\sum_{m=1}^{M}\sum_{n=1}^{N-k} u'_o(\ell, m, n)\, u'_o(\ell+k, m, n+k) & (3.5.6e) \\ \text{for the x-t diagonal} & \end{cases}$$

where

$$\sigma^2 = \frac{1}{LMN} \sum_{\ell=1}^{L} \sum_{m=1}^{M} \sum_{n=1}^{N} u'_o(\ell, mn)\, u'_o(\ell, m, n) \qquad (3.5.6f)$$

and L = 256, M = 256, N = number of frames.

However, about 64 hours of continuous computing time would be required to evaluate only a single point of one of these functions for the 100 frame subject. The same evaluation performed on the 300 frame subject would take 192 hours. If fifteen points on each function in (3.5.6) were to be evaluated for both subjects, the total continuous computing time required would be about 192,000 hours or 800 days.

Since this amount of computation time is prohibitive, it was decided to compute the desired correlation data by averaging over a subset of the field. (3.5.6) was modified to reflect this fact with

$$\rho(k) = \begin{cases} \dfrac{1}{\sigma^2}\dfrac{1}{L_1 M_o N} \displaystyle\sum_{\ell=1}^{L_1} \sum_{m=1}^{M_o} \sum_{n=1}^{N} u'_o(\ell', m', n)\, u'_o(\ell'+k, m', n) & (3.5.7a) \\ \text{for the x direction} & \\ \dfrac{1}{\sigma^2}\dfrac{1}{L_o M_1 N} \displaystyle\sum_{\ell=1}^{L_o} \sum_{m=1}^{M_1} \sum_{n=1}^{N} u'_o(\ell', m', n)\, u'_o(\ell', m'+k, n) & (3.5.7b) \\ \text{for the y direction} & \\ \dfrac{1}{\sigma^2}\dfrac{1}{L_1 M_1 N} \displaystyle\sum_{\ell=1}^{L_1} \sum_{m=1}^{M_1} \sum_{n=1}^{N} u'_o(\ell', m', n)\, u'_o(\ell'+k, m'+k, n) & \\ \text{for the spacial diagonal} & (3.5.7c) \\ \dfrac{1}{\sigma^2}\dfrac{1}{L_o M_o (N-k)} \displaystyle\sum_{\ell=1}^{L_o} \sum_{m=1}^{M_o} \sum_{n=1}^{N-k} u'_o(\ell', m', n)\, u'_o(\ell', m', n+k) & \\ \text{for the time direction} & (3.5.7d) \\ \dfrac{1}{\sigma^2}\dfrac{1}{L_1 M_o (N-k)} \displaystyle\sum_{\ell=1}^{L_1} \sum_{m=1}^{M_o} \sum_{n=1}^{N-k} u'_o(\ell', m', n)\, u'_o(\ell'+k, m', n+k) & \\ \text{for the x-t diagonal} & (3.5.7e) \end{cases}$$

where

$$\sigma^2 = \frac{1}{L_o M_o N} \sum_{\ell=1}^{L_o} \sum_{m=1}^{M_o} \sum_{n=1}^{N} u'_o(\ell', m', n)\, u'_o(\ell', m', n) \qquad (3.5.7f)$$

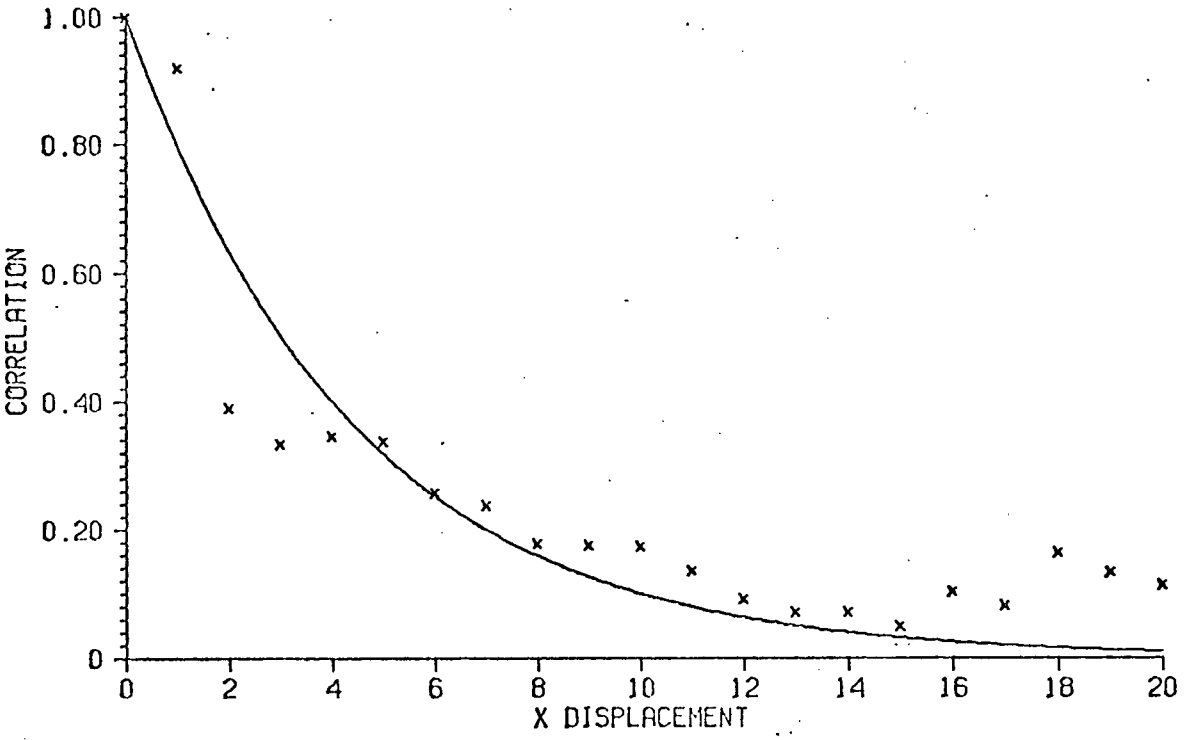
$\ell' = 8\ell - 7$, $m' = 8m - 7$, $L_o = 32$, $M_o = 32$, $L_1 = \lceil 1/8\ (256-k) \rceil$,

and $M_1 = \lceil 1/8\ (256-k) \rceil$ where $\lceil \cdot \rceil$ denotes "nearest larger integer". The computing time required to evaluate (3.5.7) is about 300 hours; a much more realistic figure.

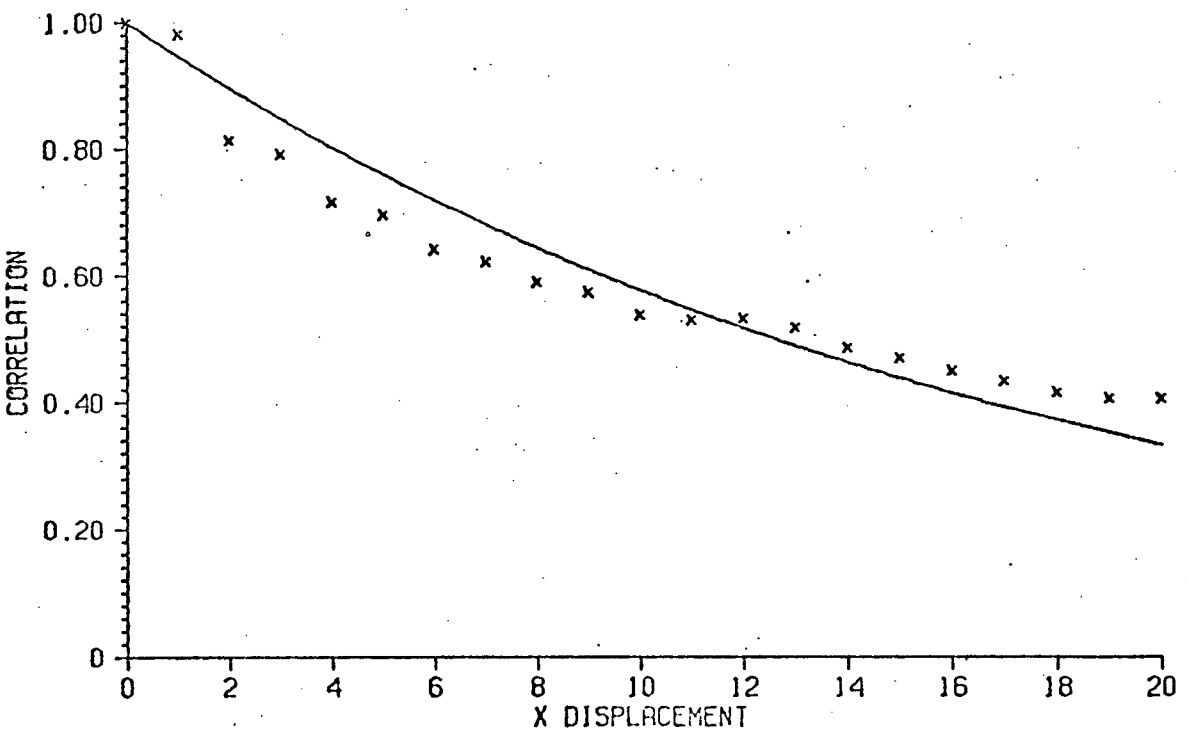
Using (3.5.7), the autocorrelation function was computed along each of the five chosen directions for both subjects. This was repeated for the x direction for subject one using two other subsets of the field, yielding results which differed numerically by less than one percent, thus verifying the soundness of this modified approach.

The computed autocorrelation functions for both subjects along each of the directions chosen are shown in figure 3.4. The x's denote the computed correlation values and the solid line is the least squares fit to those points of an exponential. Remember that in one dimension (3.2.5) and (3.2.9) reduce to the same function. The values of the exponents obtained by fitting exponentials to the data points are tabulated in table I along with the mean squared errors for these fitted curves.

It is difficult to compare these results to those obtained by other researchers due to the differences in the picture data analyzed. The exponential coefficients are a function of spacial detail and degree of motion of the image, the sampling rate in each of the dimensions, the number of levels of quantization, and the amount of noise in the digitized image. However, these results are consistent in form with previous results [1, 7, 9, 15].

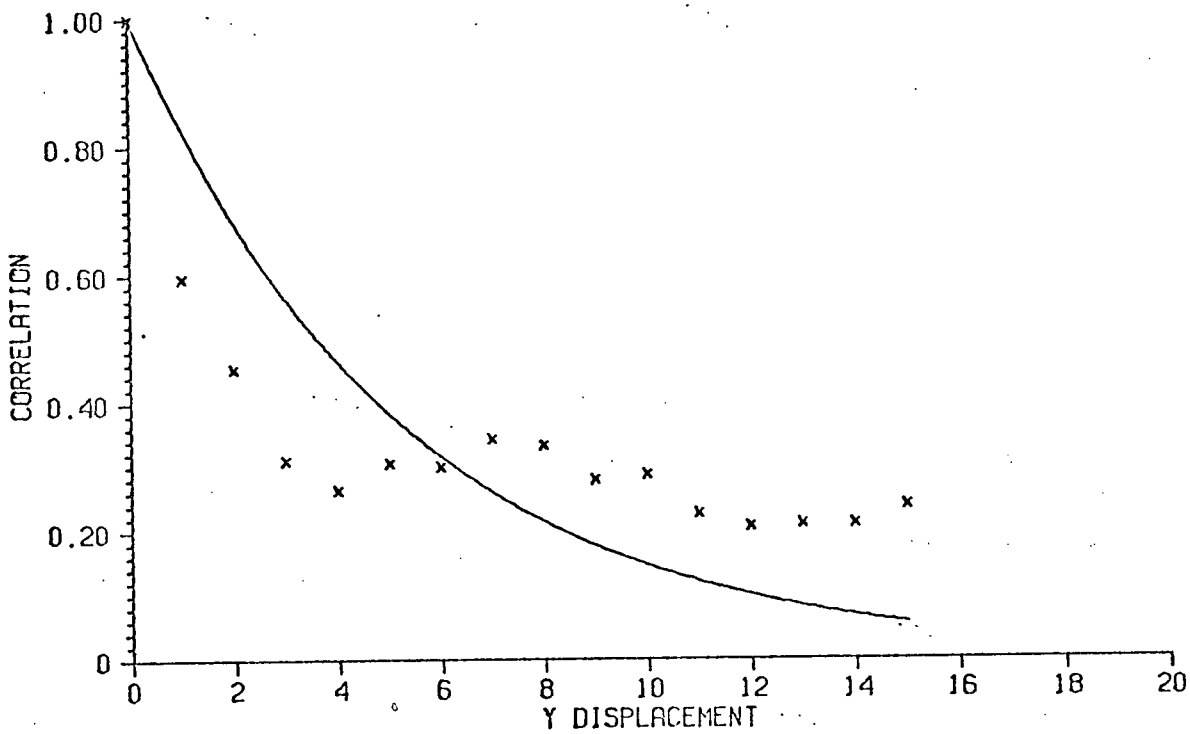


(a)

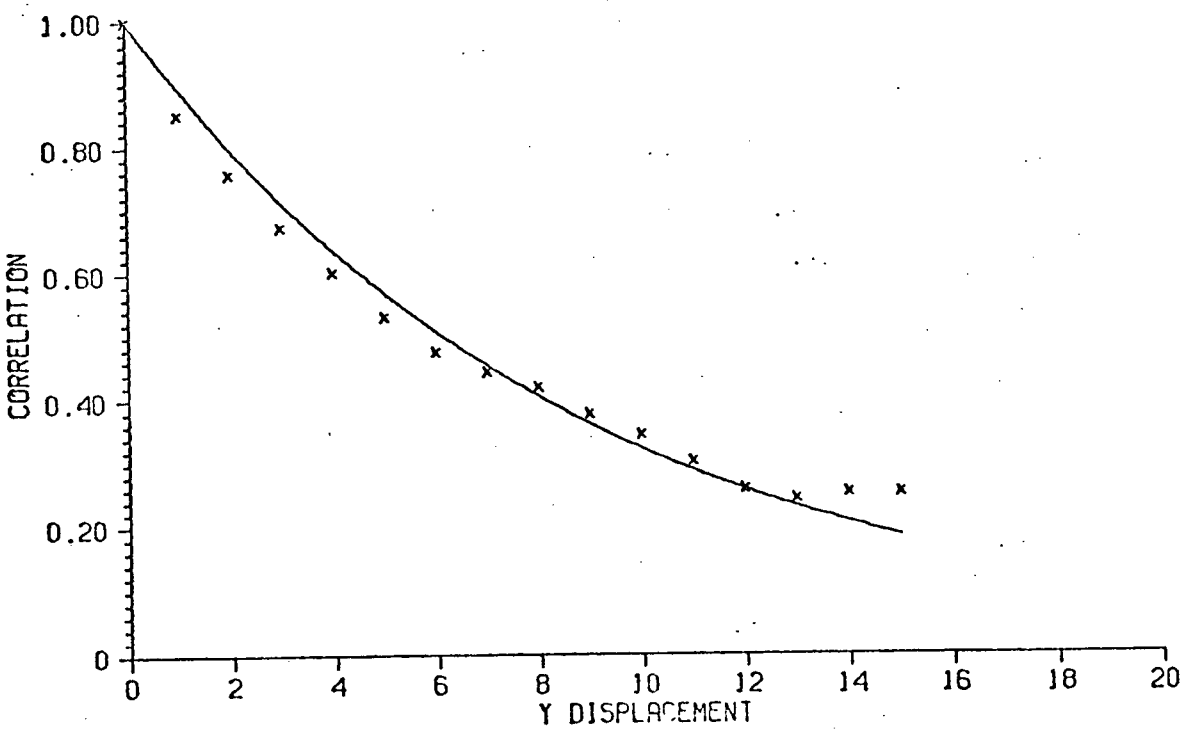


(b)

Figure 3.4A Correlation in x-direction for (a) subject one (b) subject two

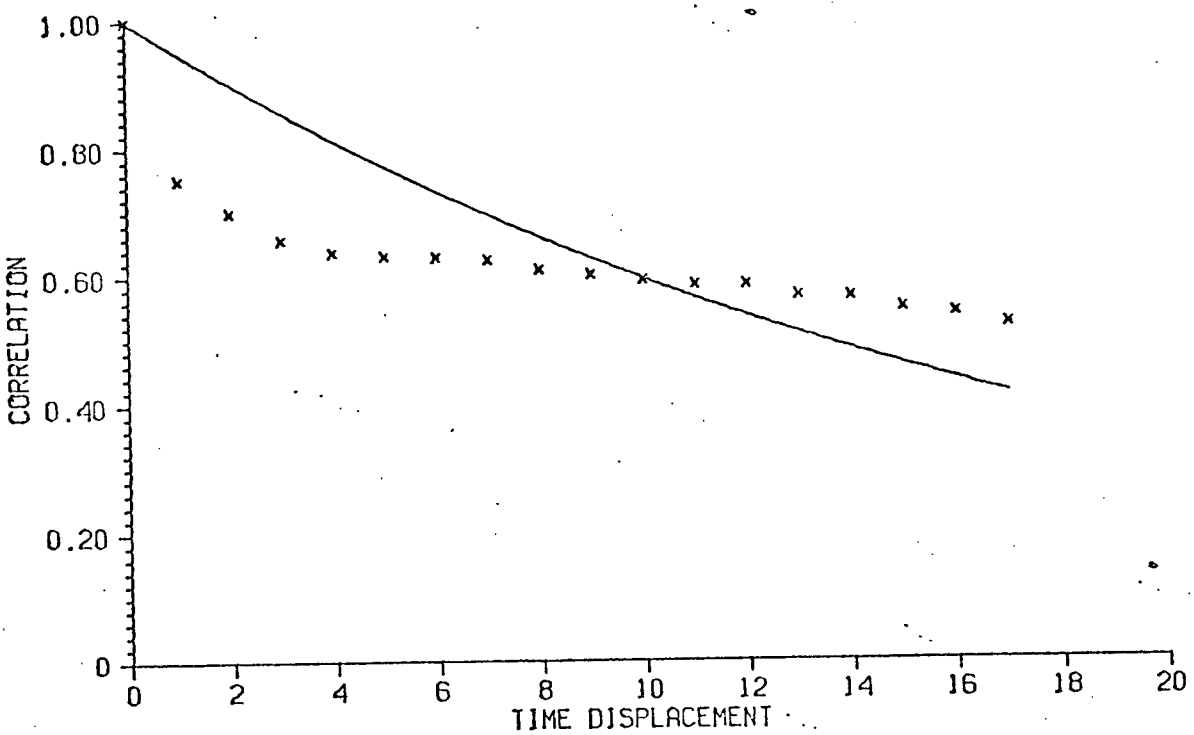


(a)

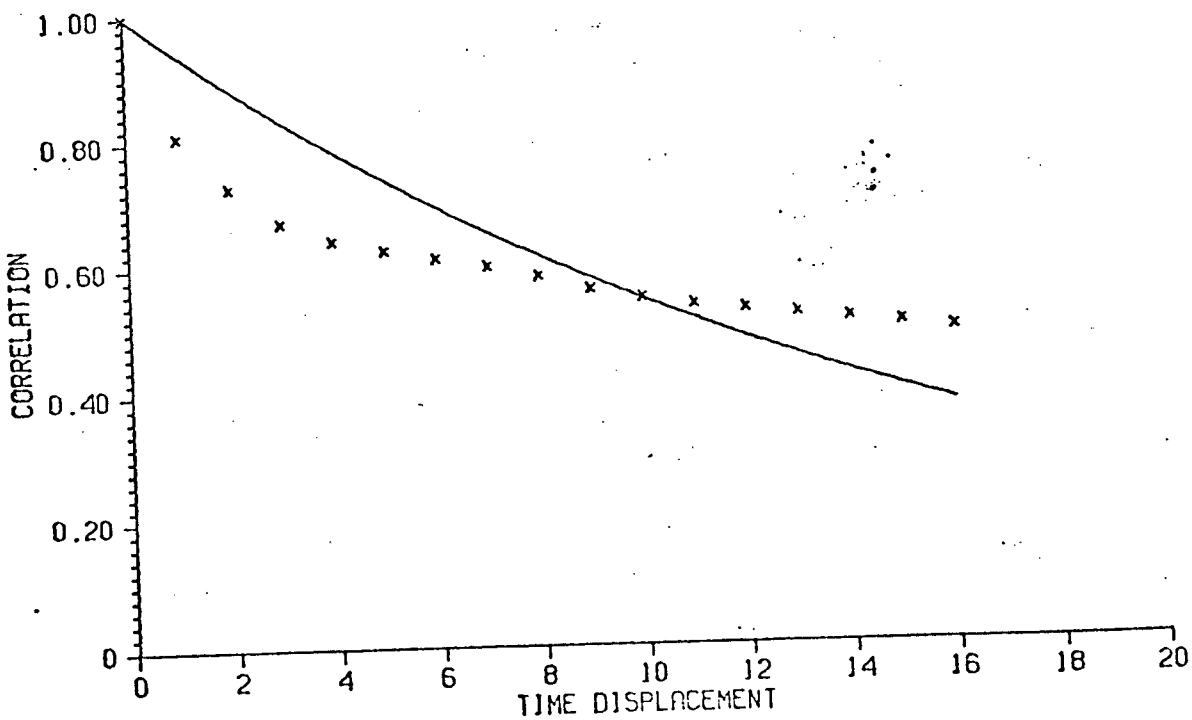


(b)

Figure 3.4B Correlation in y-direction for (a) subject one (b) subject two

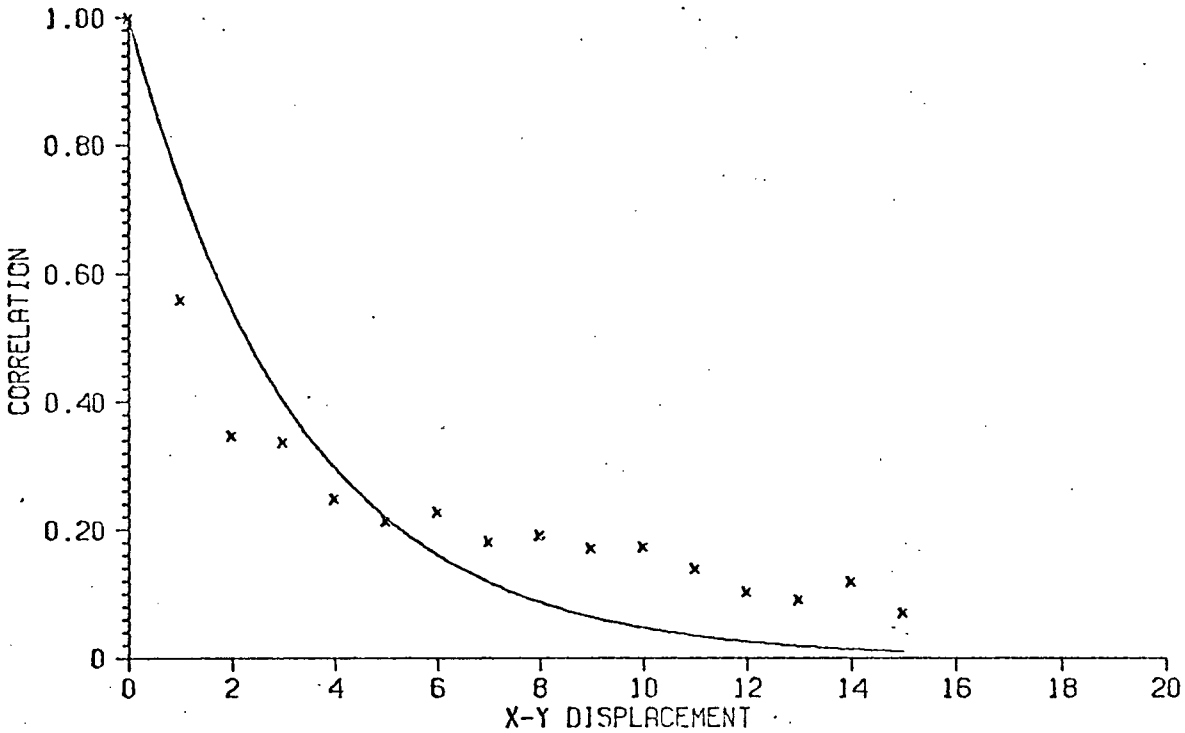


(a)

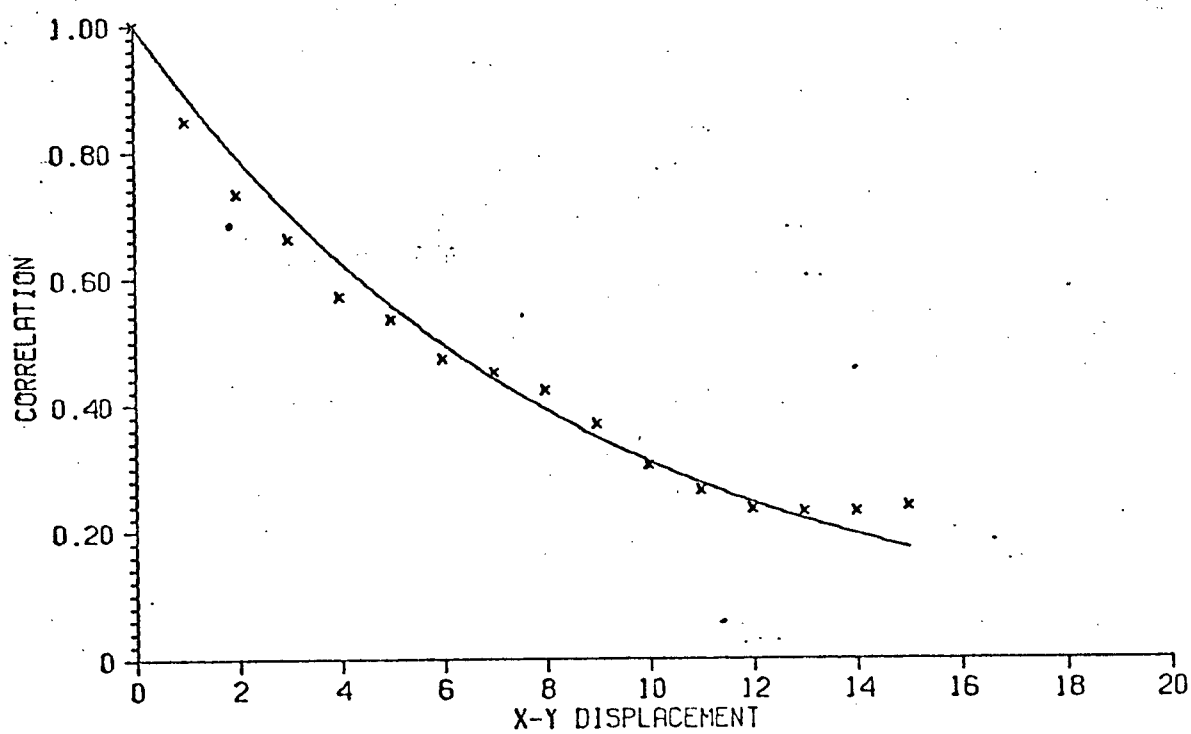


(b)

Figure 3.4C Correlation in time direction for (a) subject one (b) subject two

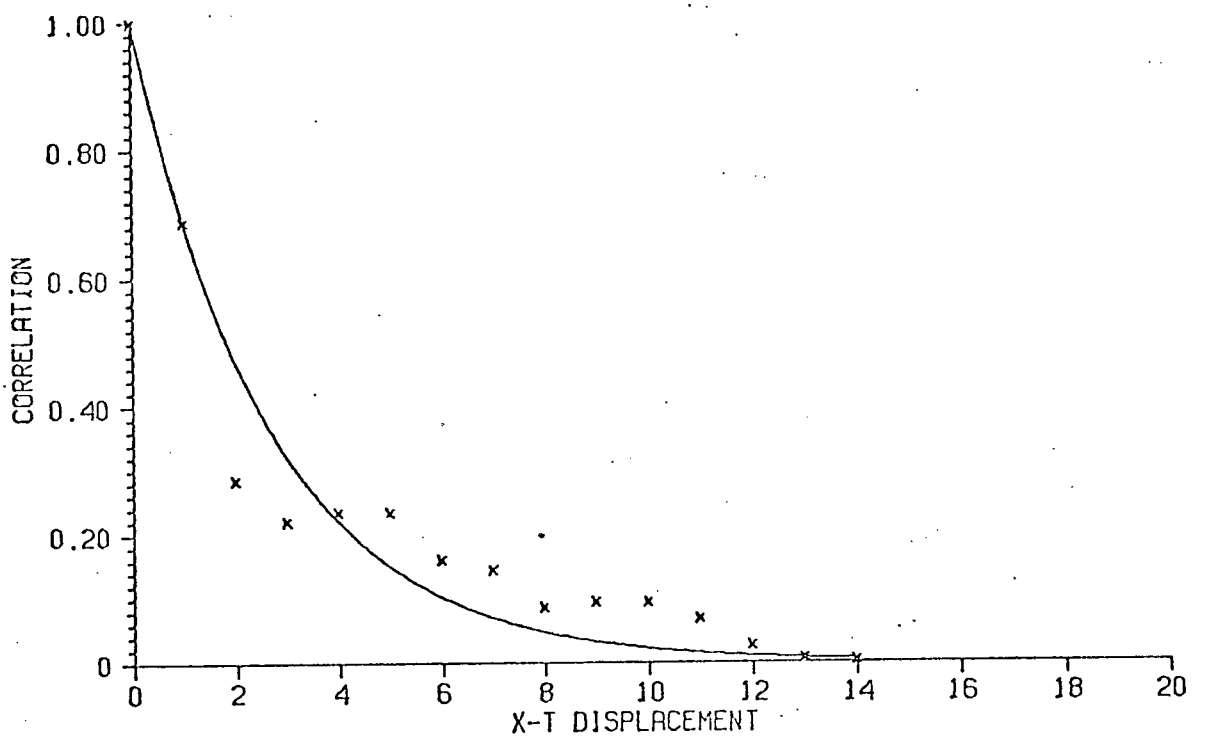


(a)

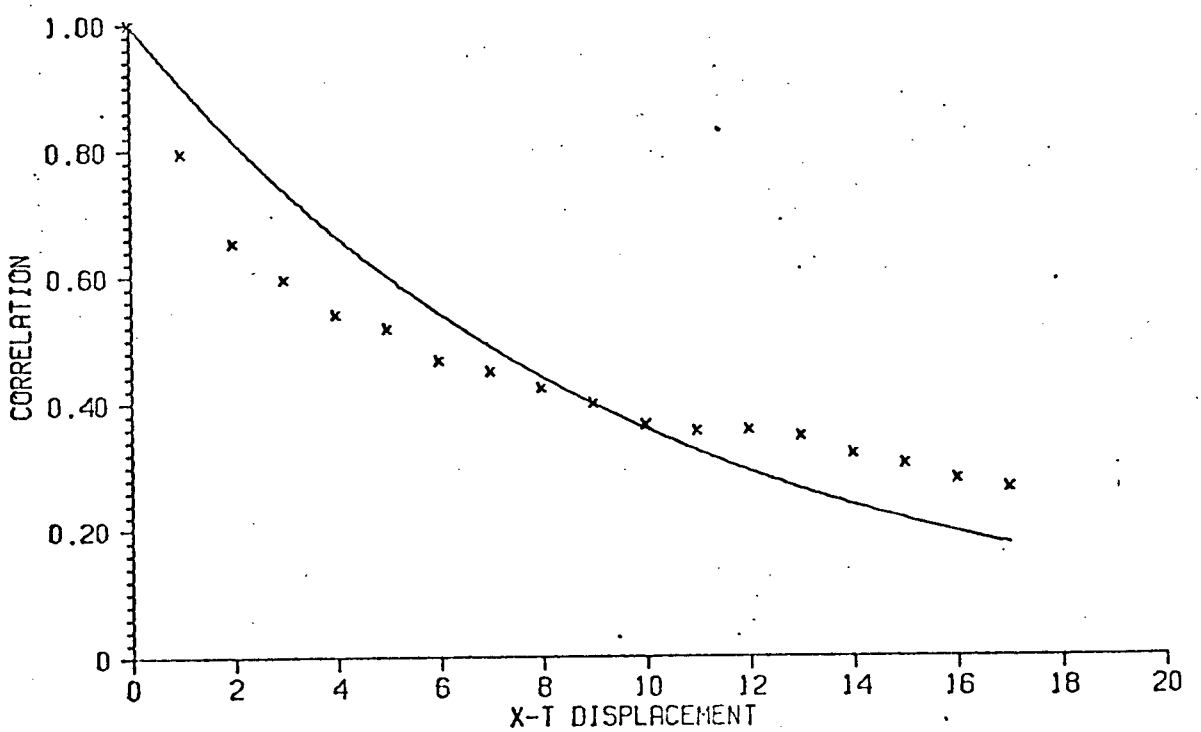


(b)

Figure 3.4D Correlation in x-y direction for (a) subject one (b) subject two



(a)



(b)

Figure 3.4E Correlation in x-t direction for (a) subject one (b) subject two

SUBJECT	DIRECTION	EXPONENT	$-10 \log_{10}$ (MSE)
Subject 1 (100 frames)	x	0.2297	20.63
	y	0.1921	16.49
	t	0.0519	18.90
	xy	0.3051	19.99
	xt	0.3793	23.09
Subject 2 (300 frames)	x	0.0551	25.89
	y	0.1128	29.73
	t	0.0610	20.57
	xy	0.1171	29.67
	xt	0.1024	21.46

TABLE I Exponential constants for least square fitted curves and the resulting error measure.

As can be seen from figure 3.4, the computed autocorrelation function initially falls off more rapidly than the fitted exponential model and less rapidly later. This difficulty in fitting an exponential to the data suggests that some model other than an exponential would be more accurate in describing pictorial data.

Having computed the autocorrelation function of the two subjects and fitted exponential curves to the computed data, it is a straightforward matter to evaluate the proposed models as to the closeness of fit to the experimental data. Using the curves fitted to the computed data along the x, y and t axes, together with the proposed models, the correlation along the x-y and x-t diagonals can be predicted. These predicted diagonal autocorrelation functions are given in figure 3.5 for both subjects along with the actual computed diagonal correlation functions. Measures of closeness of fit for the two models and both subjects are summarized in table IIa.

From table IIa it can be seen that the model which most closely matches the experiment data for both diagonal directions is difficult to determine. What table IIa indicates is that a compromise model between (3.2.5) and (3.2.9) is appropriate, namely

$$R_o\ (\Delta x, \Delta y, \Delta t) = \exp\ [-(\alpha^2(\Delta x)^2+\beta^2(\Delta y)^2)^{1/2}-\gamma|\Delta t|] \qquad (3.5.8)$$

Now defining

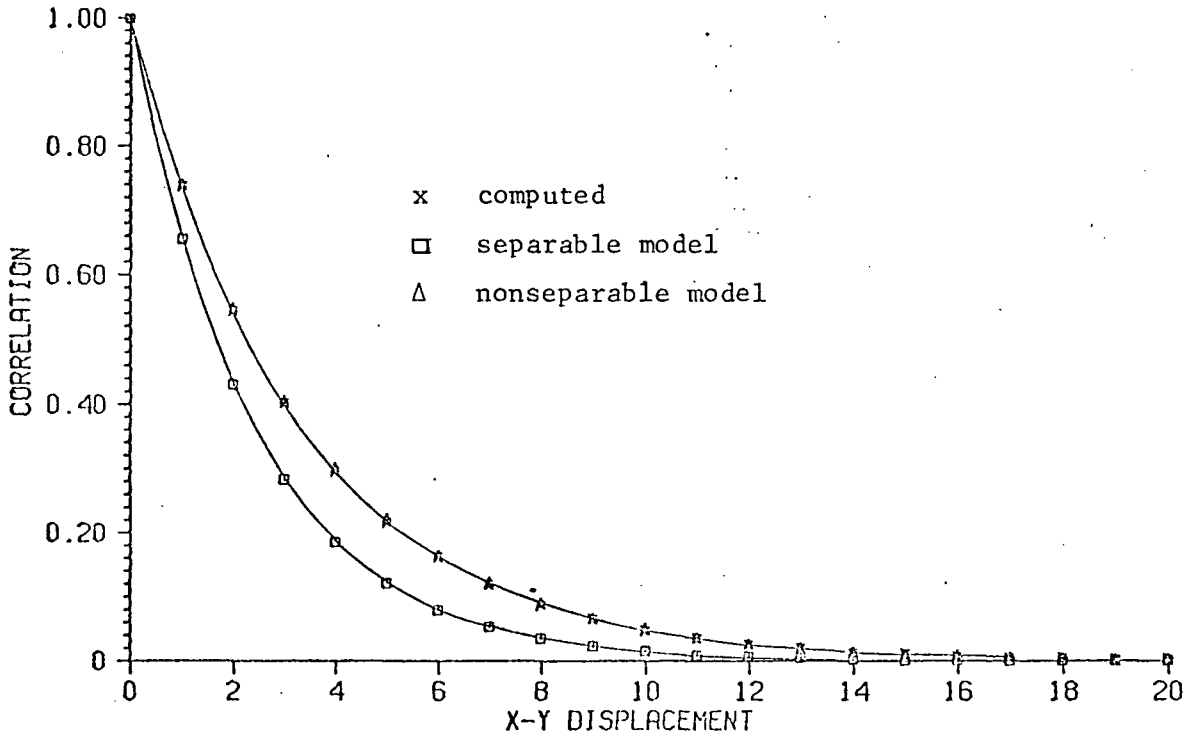
$$Rt_o\ (\Delta t) = \exp\ [-\gamma|\Delta t|] \qquad (3.5.9a)$$

$$Rx_o\ (\Delta x) = \exp\ [-\alpha|\Delta x|] \qquad (3.5.9b)$$

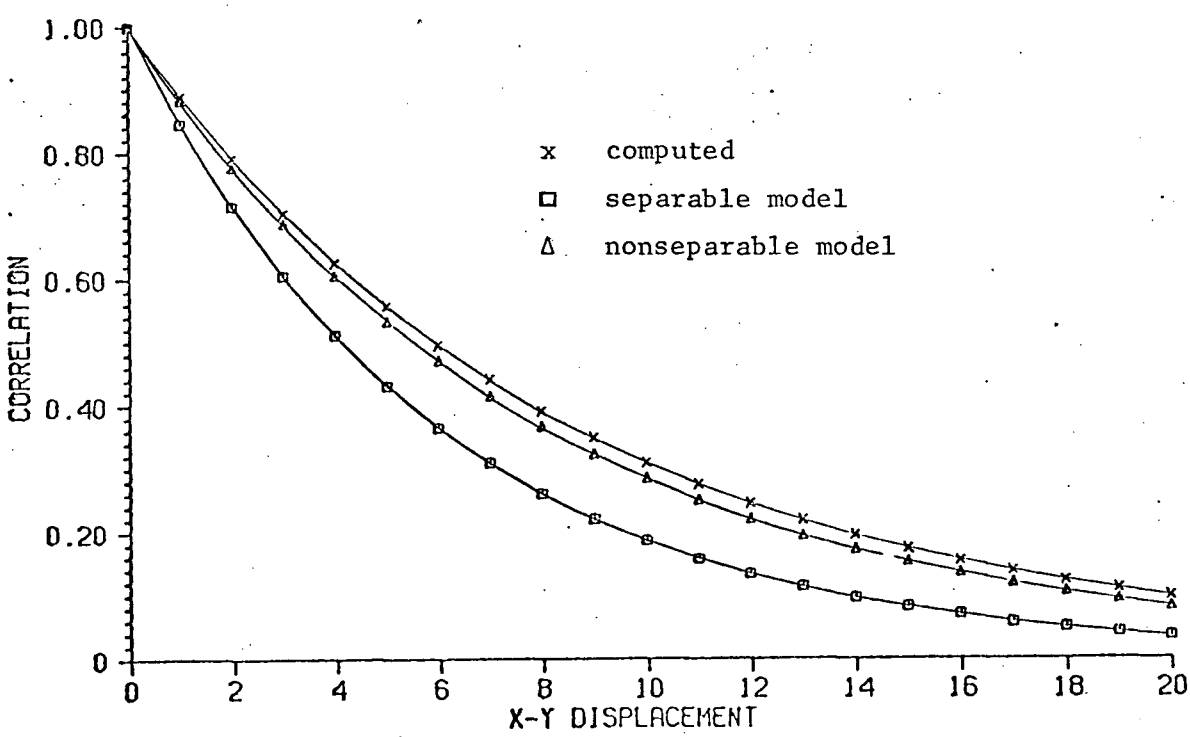
$$Ry_o\ (\Delta y) = \exp\ [-\beta\ |\Delta y|] \qquad (3.5.9c)$$

(3.5.8) can be rewritten as

$$R_o(\Delta x, \Delta y, \Delta t) = Rt_o\ (\Delta t)\ \exp\ [-([\ln(Rx_o(\Delta x))]^2 + [\ln(Ry_o(\Delta y))]^2)^{1/2}] \qquad (3.5.10)$$

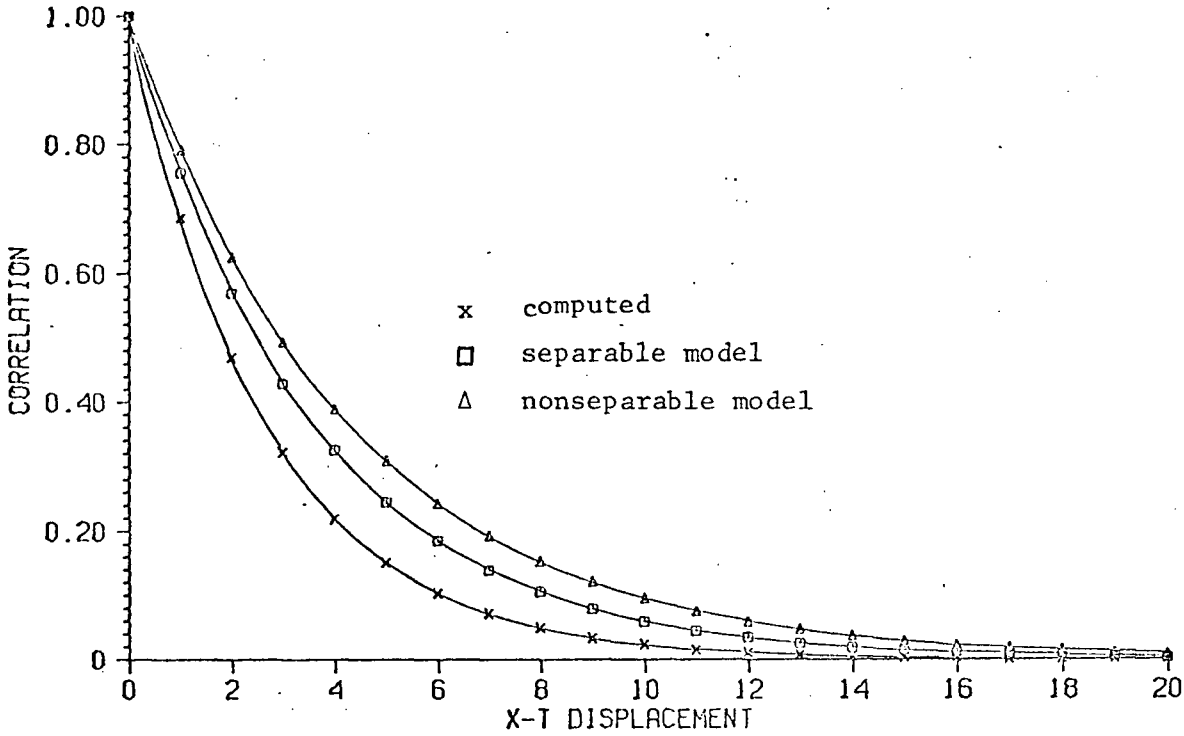


(a)

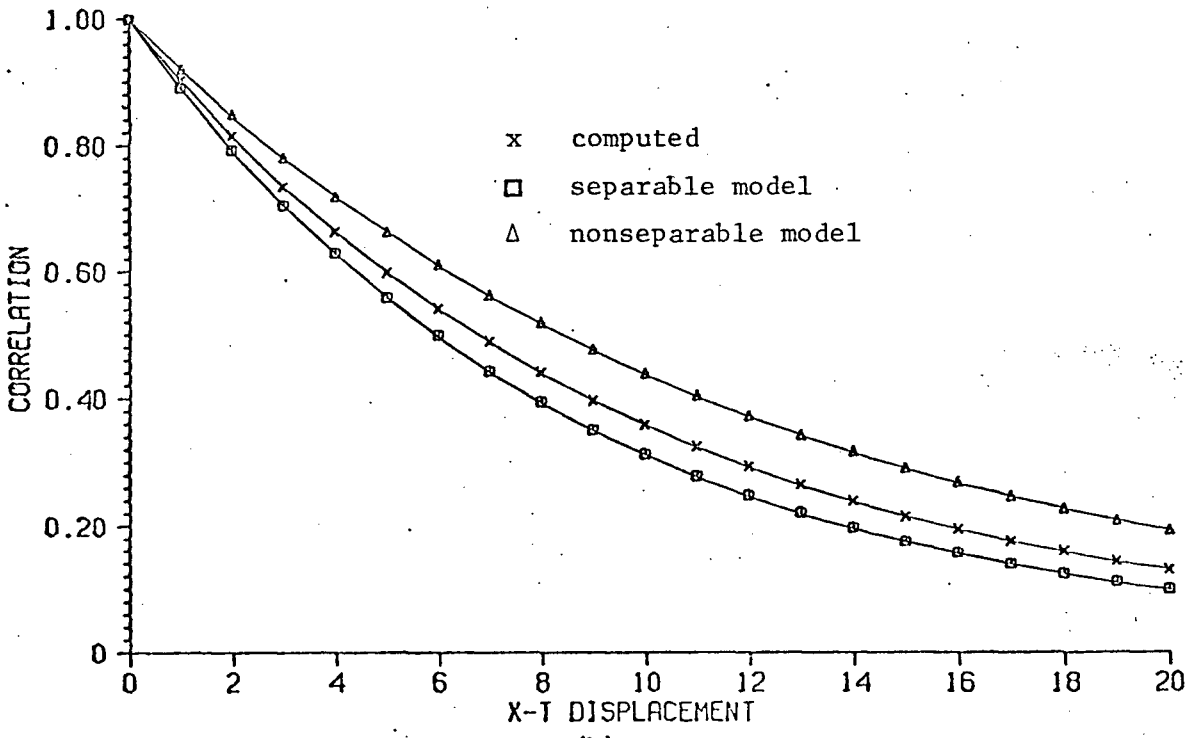


(b)

Figure 3.5A Predicted and computed diagonal autocorrelation functions for (a) Subject one (b) Subject two



(a)



(b)

Figure 3.5B Predicted and computed diagonal autocorrelation functions for (a) Subject one (b) subject two

Subject \ Dimensions \ Model		Separable	Non-Separable
Subject 1 (100 frames)	x, t	24.92	20.48
	x, y	24.61	48.55
Subject 2 (300 frames)	x, t	28.54	23.42
	x, y	19.58	33.84

(a)

Subject \ Dimensions \ Model		Separable	Non-Separable
Subject 1 (100 frames)	x, t	24.98	23.37
	x, y	18.23	24.53
Subject 2 (300 frames)	x, t	23.17	27.02
	x, y	17.82	29.07

(b)

Table II Model accuracy ($D = -10 \log_{10}$ (MSE)) in predicting diagonal autocorrelation based on (a) exponentially fitted curves (b) computed data points

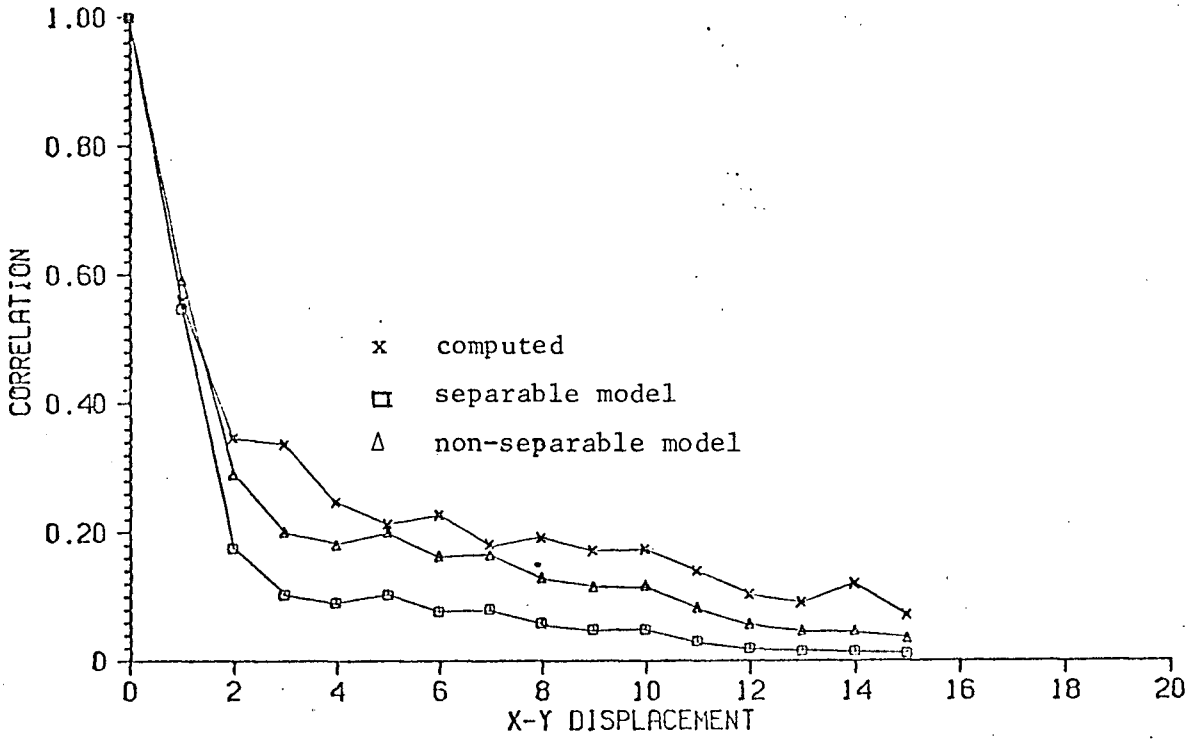
and similarly (3.2.9) and (3.2.5) can be rewritten, respectively, as

$$R_o(\Delta x, \Delta y, \Delta t) = \exp\ [-([\ln(Rx_o(\Delta x))]^2 + [\ln(Ry_o(\Delta y))]^2 + [\ln(Rt_o(\Delta t))]^2)^{1/2}] \tag{3.5.11}$$

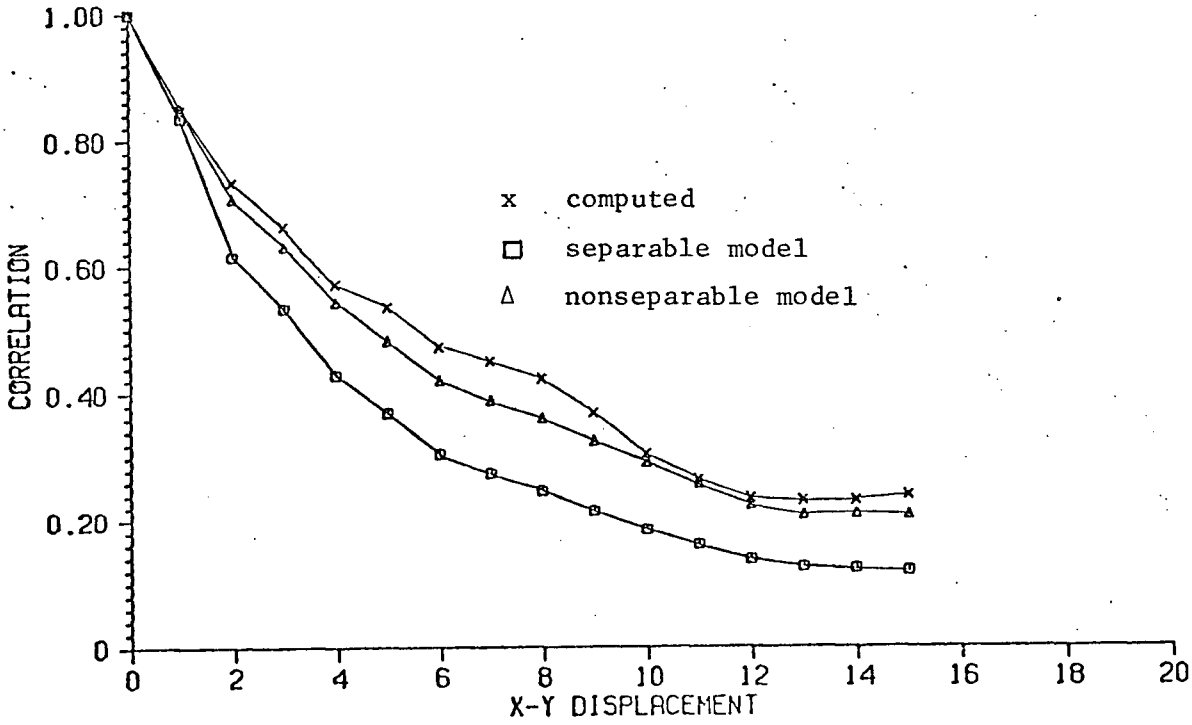
$$R_o(\Delta x, \Delta y, \Delta t) = Rx_o(\Delta x)\ Ry_o(\Delta y)\ Rt_o(\Delta t) \tag{3.5.12}$$

Now consider substituting the computed experimental values for the autocorrelation function for $Rx_o(\Delta x)$, $Ry_o(\Delta y)$ and $Rt_o(\Delta t)$ in equations (3.5.10), (3.5.11) and (3.5.12). Through this substitution and computation we determine whether or not the experimentally measured autocorrelation takes a separable or non-separable form.

Figure 3.6 is a presentation of the diagonal autocorrelation functions derived using (3.5.10), (3.5.11) and (3.5.12), and the experimentally computed autocorrelation along the two diagonal directions for both subjects. The corresponding closeness of fit measures are given in table IIb. From table IIb it can be seen that the model which most closely matches the experimental data for both diagonal directions is given by (3.5.8).

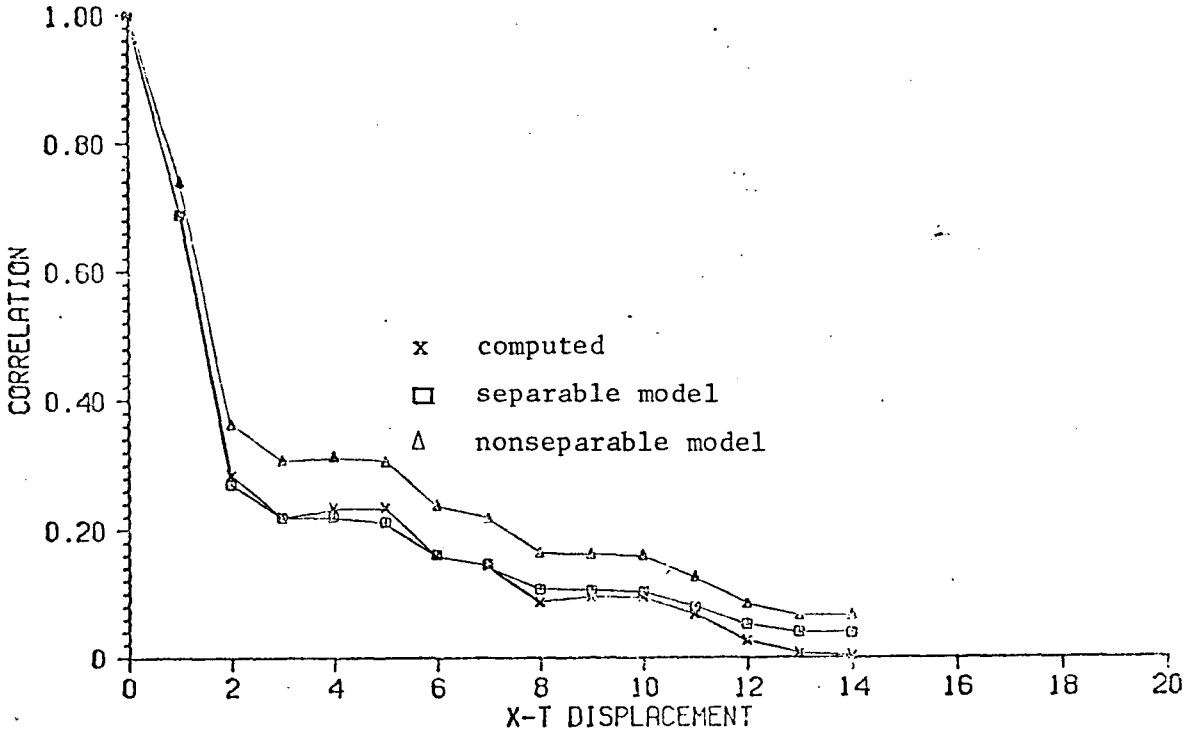


(a)

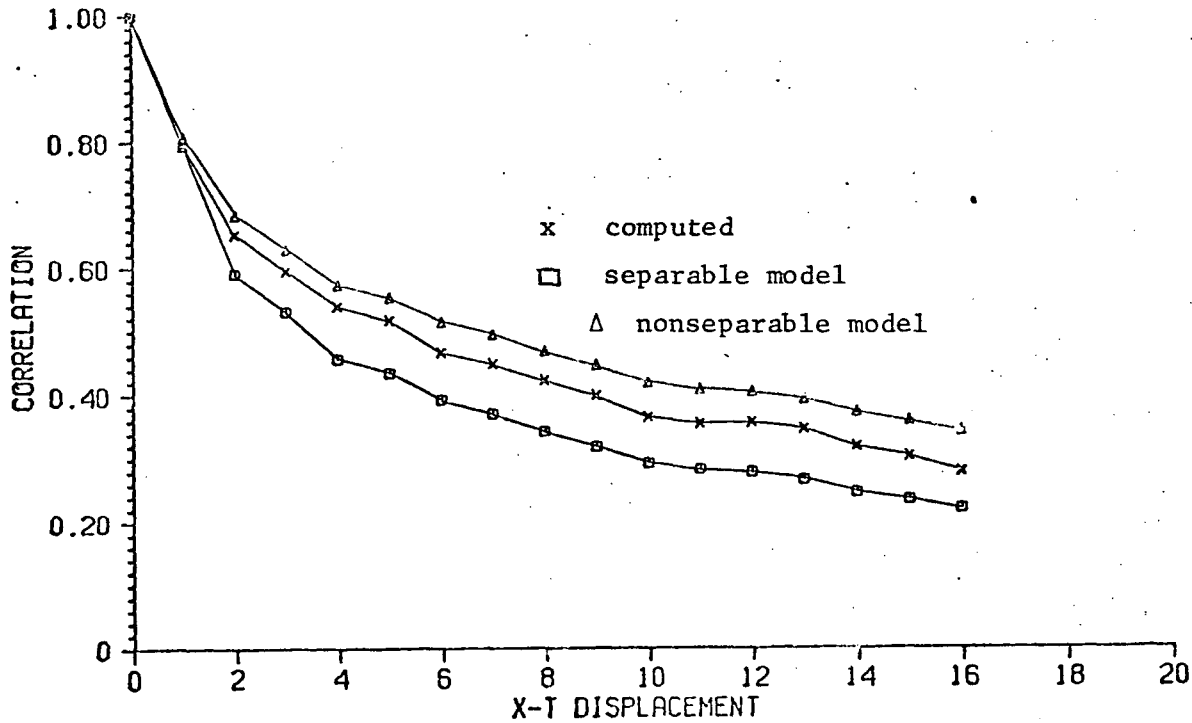


(b)

Figure 3.6A Predicted and computed diagonal autocorrelation functions for (a) subject one (b) subject two



(a)



(b)

Figure 3.6B Predicted and computed diagonal functions for (a) subject one (b) subject two

IV. THE DPCM COMMUNICATION SYSTEM

4.1 Introduction

In this chapter, we determine the effect of the error in using the Gauss-Markov model to describe the source data on estimates of the system performance for a commonly used type of communication system. Due to the assumption of stationarity of the source data, the estimate of the system performance could be poor when the source data is non-stationary. Estimates of the performance of a DPCM communication system using both the optimum, linear, one-dimensional predictor and the optimum, linear, two-dimensional predictor are obtained for selected test data. These estimates are then compared to the computed system performances for that source data.

4.2 System Model

A general model for a DPCM communication system is shown in figure 4.1. The input samples x_i are obtained by three dimensional low pass filtering, sampling, and fine quantization of a monochromatic time varying image u(x, y, t). Image sampling is performed by raster scanning successive frames of the image as described in Chapter 2. The bandwidth of the low pass filtering is determined by the width of the spot and the optics of the scanning system.

A linear predictor is used to form a predicted value z_i which is compared to the input sample x_i. The error e_i is then quantized, coded, and transmitted over the digital channel. The predicted value z_i is determined from the previous samples via an equation of the form

$$z_i = \sum_{j=1}^{N} \alpha_i \, y_{i-j} \, , \tag{4.2.1}$$

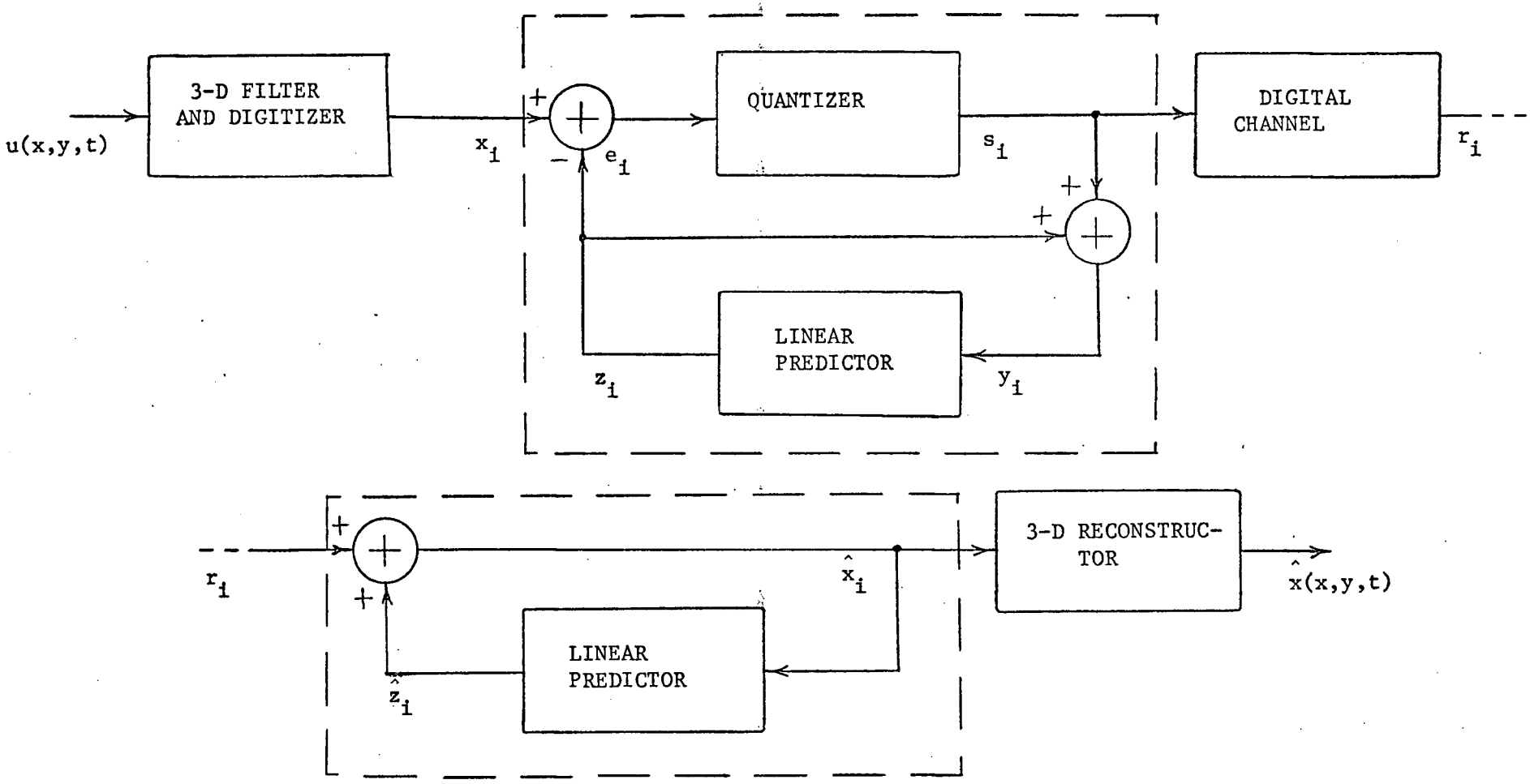


Figure 4.1 A DPCM communication system

where $y_i = x_i + q_i$ and $q_i = S_i - e_i$, the quantization error [15].

In the receiver, a similar predicted value $\hat{z}_i$ is added to the received signal to form the output sample $\hat{x}_i = r_i + \hat{z}_i$, where

$$\hat{z}_i = \sum_{j=1}^{N} \alpha_j \hat{x}_{i-j} . \tag{4.2.2}$$

In what follows, we consider two situations: optimum, one-dimensional, linear prediction based on the immediately previous sample and optimum, two-dimensional, linear prediction based on the nearest three previous samples. By optimum linear prediction is meant the minimization of $E\{e_i^2\}$ by the proper choice of the coefficients in (4.2.1). If quantization error is negligible, this criterion is equivalent to minimizing

$$\sigma e^2 = E\{(x_i - z_i)^2\} \tag{4.2.3}$$

where z_i is now given by

$$z_i = \sum_{j=1}^{N} \alpha_j x_{i-j} \tag{4.2.4}$$

σe^2 is called the prediction error variance.

A more convenient form of (4.2.3) for comparing system performance, results from normalizing by $\sigma x^2 = E\{x_i^2\}$;

$$\frac{\sigma e^2}{\sigma x^2} = \frac{E\{(x_i - z_i)^2\}}{E\{x_i^2\}} \tag{4.2.5}$$

Performance of these linear prediction schemes will be measured in terms of the signal-to-noise ratio given by

$$SNR = 10 \log_{10} \left(\frac{\sigma e^2}{\sigma x^2} \right)^{-1} \tag{4.2.6}$$

4.3 Optimum Linear One-Dimensional Prediction

If the input sequence x_i is generated from a one dimensional field, then the optimum linear predictor is found by finding the α which minimizes

$$\frac{\sigma e^2}{\sigma x^2} = \frac{E\{(x_i - \alpha x_{i-1})^2\}}{E\{(x_i)^2\}}$$

$$= (1 - 2\alpha\rho + \alpha^2) \tag{4.3.1}$$

where

$$\rho = \frac{E\{x_i\ x_{i-1}\}}{E\{x_i{}^2\}} = \frac{R(1)}{\sigma x^2} \tag{4.3.2}$$

It follows from (4.3.1) that the optimum prediction coefficient is $\alpha = \rho$, resulting in

$$\left(\frac{\sigma e^2}{\sigma x^2}\right)_{min} = (1 - \rho^2) \tag{4.3.3}$$

Although $\alpha = \rho$ yields an optimum linear predictor for one-dimensional sources, it is of interest to determine the increase in prediction error variance resulting from using a non-optimum prediction coefficient. Let this non-optimum prediction coefficient be α' and let $\Delta = \alpha' - \rho$ represent the deviation from the optimum prediction coefficient. Then the increase in prediction error variance can be shown to be

$$\left(\frac{\sigma e^2}{\sigma x^2}\right)_{\alpha = \alpha'} - \left(\frac{\sigma e^2}{\sigma x^2}\right)_{\alpha = \rho} = \Delta^2 \tag{4.3.4}$$

If $|\Delta| = 0.1$, then the ratio $(\sigma e^2/\sigma x^2)$ changes by only 0.01. This implies that the prediction error variance is relatively insensitive to variations in the prediction coefficient. This is also reflected in the flatness of the curves in figure 4.2 which plot $(\sigma e^2/\sigma x^2)$ versus the prediction

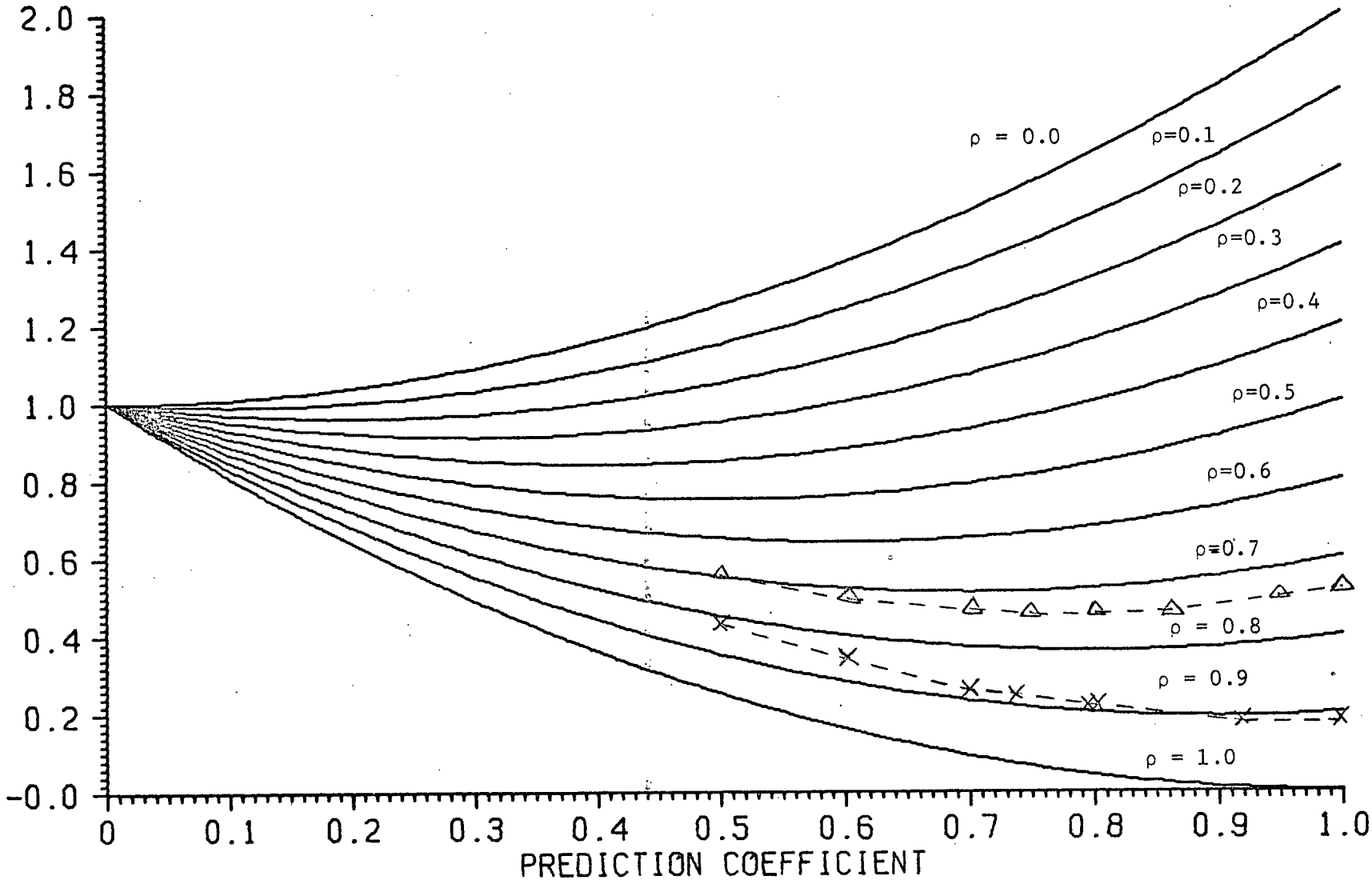


Figure 4.2 $\sigma e^2/\sigma x^2$ versus prediction coefficient for one dimensional linear prediction

coefficient.

Figure 4.3 is composed of curves relating the signal to noise ratio in decibels to α for different values of ρ. Although the flatness of the curves varies with ρ, these curves exhibit relative insensitivity to Δ near the optimum α.

The degradation in signal to noise ratio from the optimum can be shown to be

$$10 \log_{10} \left(\frac{\sigma e^2}{\sigma m^2} \right)^{-1}_{\alpha = \alpha'} - 10 \log_{10} \left(\frac{\sigma e^2}{\sigma m^2} \right)^{-1}_{\alpha = \rho}$$

$$= 10 \log_{10} \left(\frac{1 - \rho^2}{1 - \rho^2 + \Delta^2} \right) \qquad (4.3.5)$$

Figure 4.4 is a presentation of the plots of (4.3.5) for different values of ρ. We note that irrespective of ρ, the system performance is not greatly effected by using prediction coefficients in a range near the otpimum value. For example, if ρ is 0.9, then picking α in the range 0.8 to 1.0 will produce a degradation less than 0.23 decibels, or about five percent.

A previous study [15] by K.Y. Chang has examined the change in system performance when the correlation of the input data is varied while α is kept constant. However consideration should be made of the fact that the optimum performance also varies with ρ. Thus, where Chang shows a decrease of performance of 13% for $\alpha = 0.89$ and ρ decreased to 0.8, the optimum performance would also have decreased. From figure 4.4 it can be seen that the degradation from optimum performance is 0.12 decibels or about three percent.

Two sets of experiments were performed to verify the general nature of the curves shown in figures 4.2 and 4.3. As can be seen from

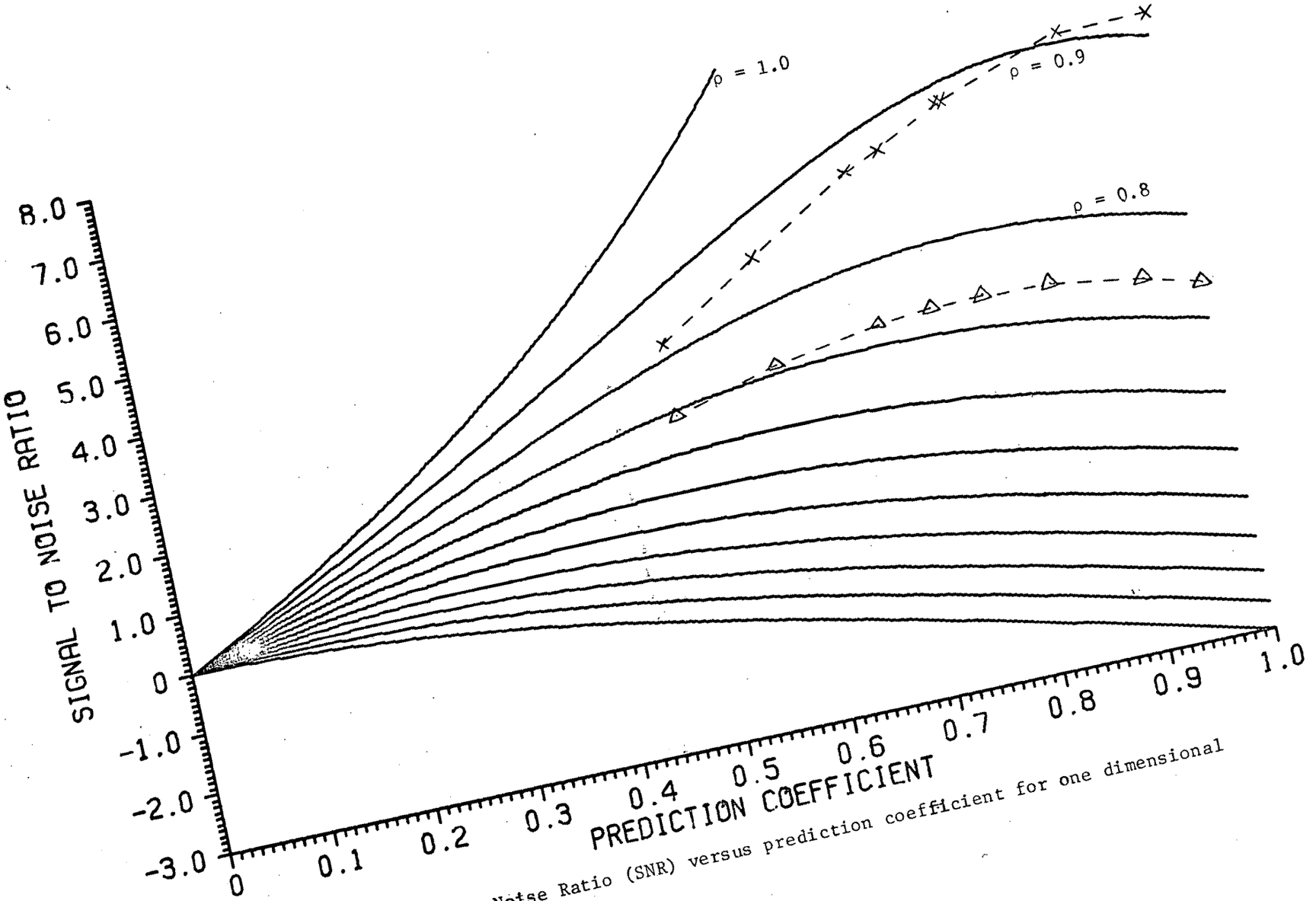


Figure 4.3 Signal to Noise Ratio (SNR) versus prediction coefficient for one dimensional linear predictor

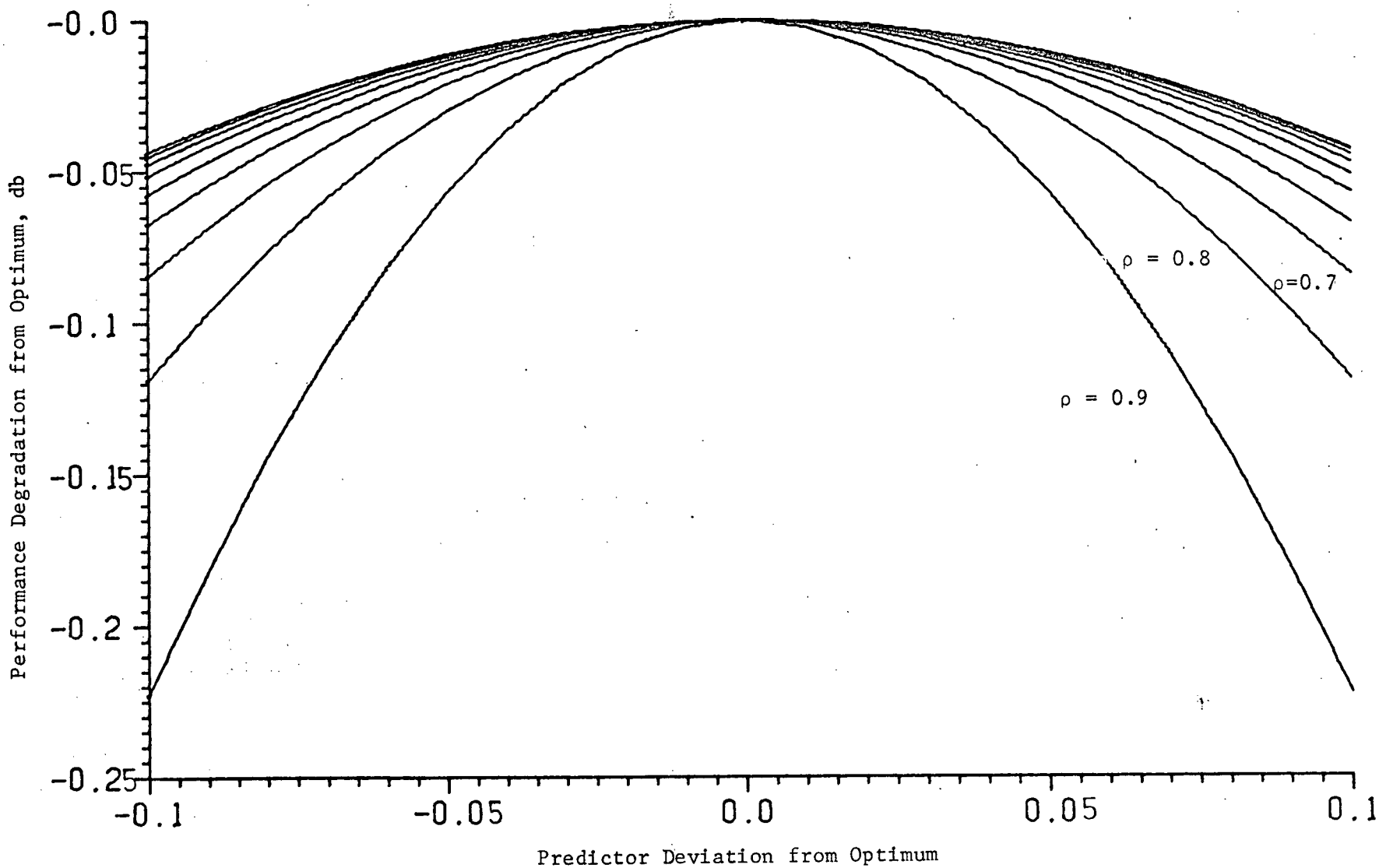


Figure 4.4 SNR degradation from optimum versus predictor coefficient deviation from optimum for linear one dimensional predictor.

these figures, there is good correspondence between the experimentally determined results and the analytic results.

For the points indicated by an x in figures 4.2 and 4.3, the one-dimensional data was generated from subject one using successive points in the x-direction. The measured correlation between adjacent samples for this data is 0.9188. For the points in these figures indicated by a Δ, the one-dimensional data was generated from subject one using successive points in the time direction. The measured correlation between adjacent samples for this data is 0.7501.

4.4 The Optimum Linear Two-Dimensional Predictor

For an input sequence to the DPCM communication system consisting of samples from a two-dimensional field f(i,j), we consider the optimum linear predictor using the nearest three previous samples to predict the next sample. The coefficients in this predictor; α_1, α_2, α_3; are chosen to minimize

$$\frac{\sigma e^2}{\sigma f^2} = \frac{E\{[f(i,j) - \alpha_1 f(i-1,j) - \alpha_2 f(i,j-1) - \alpha_3 f(i-1,j-1)]^2\}}{E\{[f(i,j)]^2\}} \tag{4.4.1}$$

Defining
$$\rho_1 = \frac{E\{f(i,j)\ f(i-1,j)\}}{E\{[f(i,j)]^2\}}, \tag{4.4.2a}$$

$$\rho_2 = \frac{E\{f(i,j)\ f(i,j-1)\}}{E\{[f(i,j)]^2\}}, \tag{4.4.2b}$$

and
$$\rho_3 = \frac{E\{f(i,j)\ f(i-1,j-1)\}}{E\{[f(i,j)]^2\}}, \tag{4.4.2c}$$

(4.3.1) can be rewritten in the form

$$\frac{\sigma e^2}{\sigma f^2} = 1 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2 - 2\alpha_1\rho_1 - 2\alpha_2\rho_2 - 2\alpha_3\rho_3 + 2\alpha_1\alpha_2\rho_3 + 2\alpha_1\alpha_3\rho_2 + 2\alpha_2\alpha_3\rho_1 \tag{4.4.3}$$

It follows that the α_1, α_2 and α_3 which minimize (4.4.3) are given by

$$\alpha_1 = \frac{\rho_1^3 - \rho_1 - \rho_1\rho_2^2 + 2\rho_2\rho_3 - \rho_1\rho_3^2}{\rho_1^2 + \rho_2^2 + \rho_3^2 - 2\rho_1\rho_2\rho_3 - 1} \tag{4.4.4a}$$

$$\alpha_2 = \frac{\rho_2^2 - \rho_2 - \rho_1^2\rho_2 + 2\rho_1\rho_3 - \rho_2\rho_3^2}{\rho_1^2 + \rho_2^2 + \rho_3^2 - 2\rho_1\rho_2\rho_3 - 1} \tag{4.4.4b}$$

$$\alpha_3 = \frac{\rho_3^2 - \rho_3 - \rho_1^2\rho_3 + 2\rho_1\rho_2 - \rho_2^2\rho_3}{\rho_1^2 + \rho_2^2 + \rho_3^2 - 2\rho_1\rho_2\rho_3 - 1} \tag{4.4.4c}$$

Continuation of the analysis at this point becomes unweildly. For this reason, a further restriction is usually placed on the model; the autocorrelation function is assumed separable. With this added restriction, $\rho_3 = \rho_1\rho_2$ and (4.4.4) reduce to

$$\alpha_1 = \rho_1; \qquad \alpha_2 = \rho_2; \qquad \alpha_3 = -\rho_1\rho_2 \tag{4.4.5}$$

Substituting into equation (4.4.3), the minimized ratio becomes

$$\left(\frac{\sigma e^2}{\sigma f^2}\right)_{min} = (1 - \rho_1^2)(1 - \rho_2^2) \tag{4.4.6}$$

Now, as in section 4.2.1, we consider the effect on performance of the DPCM system when any or all of the prediction coefficients; α_1, α_2 and α_3; are not the optimum coefficients. Let the non-optimum coefficients be α'_1, α'_2 and α'_3 and define $\Delta_1 = \alpha'_1 - \rho_1$, $\Delta_2 = \alpha'_2 - \rho_2$, $\Delta_3 = \alpha'_3 + \rho_1\rho_2$ as the deviation from the optimal coefficients. The increase in prediction error variance is given by

$$\left(\frac{\sigma e^2}{\sigma f^2}\right)_{\alpha_i=\alpha'_i} - \left(\frac{\sigma e^2}{\sigma f^2}\right)_{(\alpha_i)opt.}$$

$$= \Delta_1^2 + \Delta_2^2 + \Delta_3^2 + 2\rho_1\Delta_2\Delta_3 + 2\rho_1\Delta_1\Delta_3 + 2\rho_1\rho_2\Delta_1\Delta_2 \qquad (4.4.7)$$

Note that if any two of the deviations are zero, this equation reduces to (4.3.4). However, we also note that the performance is much more sensitive to changes of the coefficients. For example, if $\rho_1 = \rho_2 = 0.9$, α_1 and α_2 are the optimum prediction coefficients, and α_3 is varied in the range 0.8 to 1.0, then the system performance will be degraded as much as 28 percent.

4.5 Signal-to-Noise Ratio Measurement

The signal-to-noise ratio for various DPCM communication systems was measured for subjects one and two using the Supernova mini-computer. In so doing, the mean values were first subtracted from the digitized samples representing the subjects. Refering to figure 4.5 which shows the seven nearest previous samples to sample x_{io}, the prediction schemes tested were.

1. Previous Sample (x_{i1})
2. Previous frame (x_{i3})
3. Nearest three previous samples in x-y plane

   (x_{i1}, x_{i2}, x_{i4})
4. Nearest three previous samples in x-t plane

   (x_{i1}, x_{i3}, x_{i6})

It has been shown [15] that, for a Gauss-Markov field, the nearest neighbor prediction schemes we are looking at are optimum for all schemes using as many previous elements as desired for prediction.

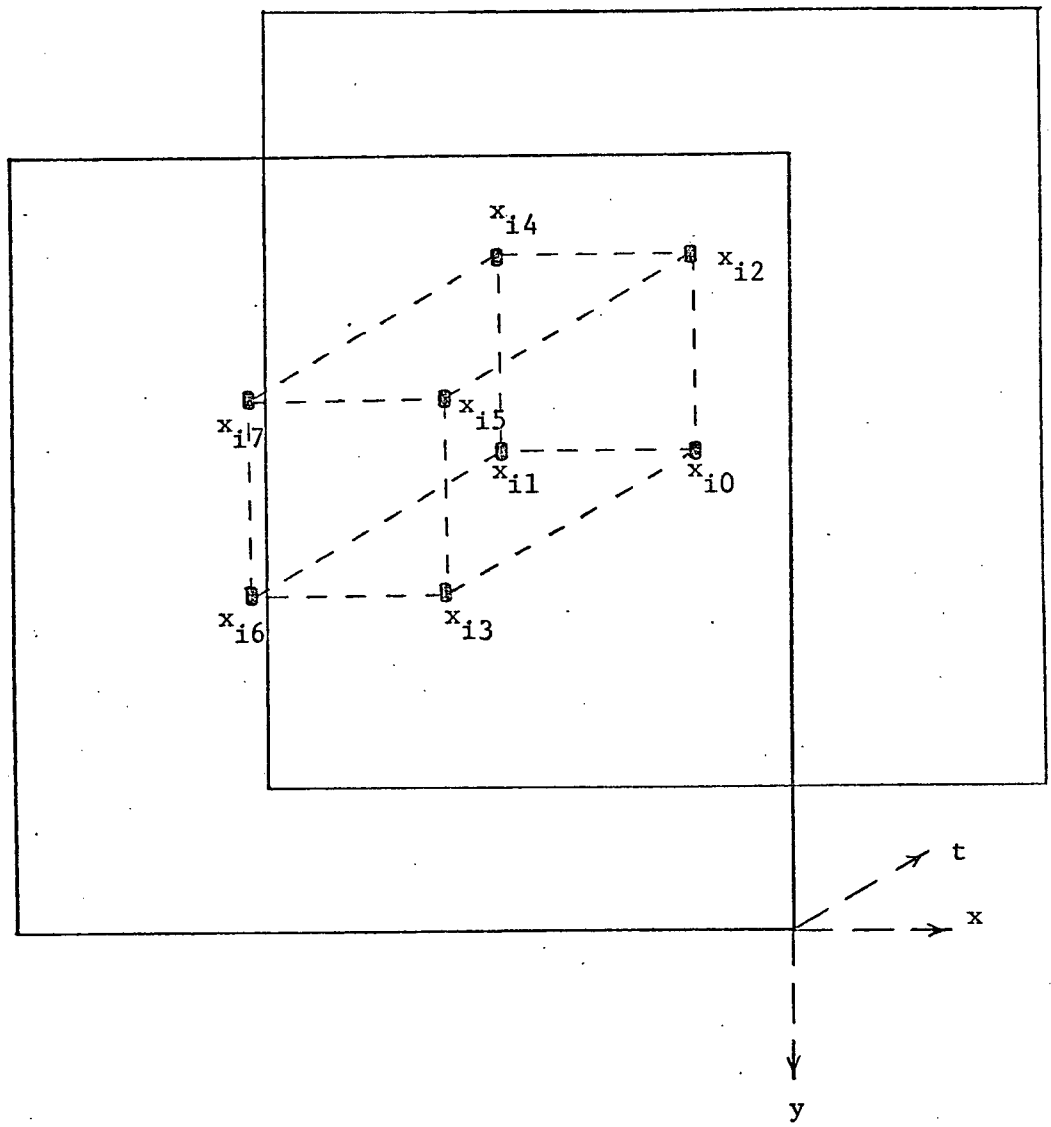


Figure 4.5 Nearest previous samples for x_{i0} used for prediction

For schemes one and two, the signal-to-noise ratio was determined by first measuring the prediction error variance

$$\sigma e^2 = \frac{1}{N} \sum_{i=1}^{N} (x_{io} - \alpha x_{ij})^2 \tag{4.5.1}$$

where N is the number of image samples involved and

$$x_{ij} = \begin{cases} x_{i1} & \text{for scheme one} \\ x_{i3} & \text{for scheme two} \end{cases}$$

The optimum prediction coefficient results when $\alpha = \rho$, where ρ is the average correlation between two adjacent samples. We can determine ρ either by direct measurement or from the exponential model, i.e.

$$\rho = \exp\,[\varepsilon] \tag{4.5.2}$$

where $\varepsilon = \alpha$ for scheme one and $\varepsilon = \gamma$ for scheme two. Measurements were made using both prediction coefficients based on the measurement of ρ and on (4.5.2). The signal-to-noise ratio was then determined for each case as

$$SNR = -10 \log_{10} (\sigma e^2/\sigma^2), \tag{4.5.3}$$

where

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} (x_{io})^2. \tag{4.5.4}$$

The results of these measurements are summarized in table III. Included in the table is the predicted signal-to-noise ratio computed as

$$SNR_p = -10 \log_{10} (1 - \rho^2), \tag{4.5.5}$$

where ρ again takes on a value obtained from direct measurement and from (4.5.2). Comparison of the results for schemes one and two leads to the following conclusion: the correspondence between predicted and measured

Subject	ρ	σe^2 \ Prediction scheme	scheme 1 (x_{i1})	scheme 2 (x_{i2})	scheme 3 (x_{i1}, x_{i2}, x_{i4})	scheme 4 (x_{i1}, x_{i3}, x_{i6})
Subject 1 (100 frames)	from (4.5.2)	predicted	4.34	10.04	9.28	14.38
		measured	6.66	3.08	9.51	12.84
	measured	predicted	8.10	3.59	10.01	11.69
		measured	7.40	3.34	10.55	14.01
Subject 2 (100 frames)	from (4.5.2)	predicted	9.87	9.39	16.80	19.26
		measured	13.54	4.41	16.88	14.65
	measured	predicted	14.20	4.62	18.09	18.82
		measured	13.89	4.61	17.01	15.26

TABLE III Signal-to-noise ratios predicted from model and measured for DPCM communication systems operating on subjects one and two

signal-to-noise ratios is poor when the least-squares fitted model is used to determine ρ, whereas the correspondence is very good when the measured correlation is used. The poor correspondence can be attributed to the poor fit of the exponential model to the first point of the autocorrelation function curve (see figure 3.4). From (4.5.5) it can be seen that a small variation in ρ will cause a large change in predicted signal to noise ratio. The system performance, however, is improved only slightly be using the measured correlation coefficient instead of the model correlation coefficient. This is consistent with the analysis of section 4.3.

For prediction schemes three and four, the experimental prediction error variance can be determined by evaluating

$$\sigma e^2 = \frac{1}{N} \sum_{i=1}^{N} (x_{io} - \alpha_1 x_{i1} - \alpha_2 x_{ik} - \alpha_3 x_{i\ell})^2, \qquad (4.5.6)$$

where

$$x_{ik} = \begin{cases} x_{i2} & \text{for scheme three} \\ x_{i3} & \text{for scheme four} \end{cases}$$

$$x_{i\ell} = \begin{cases} x_{i4} & \text{for scheme three} \\ x_{i6} & \text{for scheme four} \end{cases}$$

Assuming a separable autocorrelation function, the optimum predictor results when $\alpha_1 = \rho_1$, $\alpha_2 = \rho_2$ and $\alpha_3 = -\rho_1\rho_2$ where ρ_1 is the correlation coefficient in the x-direction and ρ_2 is the correlation coefficient in the y-direction for scheme three and the time direction for scheme four. As before, ρ_1 and ρ_2 can be obtained both by direct measurement and from the exponential model.

The measured signal-to-noise ratios are summarized in table III as well, along with the predicted signal-to-noise ratio determined as

$$SNR_p = -10 \log_{10} (1 - \rho_1^2) (1 - \rho_2^2) \tag{4.5.7}$$

It can be seen that using the measured correlation coefficients again produces the best results. There is good correspondence between the predicted and measured signal-to-noise ratios even when the correlation coefficients were determined from least-squares fitted models. This is due to a compensating effect. As can be seen from figure 3.4, the measured x-direction correlation coefficient is greater than the value determined from the exponential model whereas this situation is reversed for both the y-direction and the time-dimension correlation coefficients. This means that the first term in parenthesis in (4.5.7) is decreased while the second term is increased, producing the mentioned compensation.

Theoretical analysis based on the model of a Gauss-Markov field shows that the signal to noise ratio for two-dimensional prediction is the sum of the signal-to-noise ratios for one-dimensional prediction in each of the two orthogonal directions. From table III it can be seen that, for subject one, the measured signal to noise ratio for two-dimensional prediction was about three decibels greater than the sum of the measured signal-to-noise ratios for one-dimensional predictions in the two orthogonal directions. For subject two this two-dimensional prediction performance was three decibels lower than the sum. This is probably due to the fact that the Gauss-Markov model poorly describes subject two in the x-t plane, whereas the model more closely matches the data for subject one.

Table IV is a summary of the exponential coefficients and the measured correlations for the two subjects used in this study.

SUBJECT	DIRECTION	ε	ρ
Subject 1 (100 frames)	x	0.2297	0.9188
	y	0.1921	0.5960
	t	0.0519	0.7501
	xy	0.3051	0.5587
	xt	0.3793	0.6891
Subject 2 (300 frames)	x	0.0551	0.9811
	y	0.1128	0.8516
	t	0.0610	0.8094
	xy	0.1171	0.8498
	xt	0.1024	0.7955

TABLE IV Summary of exponential coefficients and measured correlations used in this study

V. CONCLUSION

The results obtained from this study are summarized in the following.

1) A system has been designed and implemented which can be used to process and study time varying images

2) Using this system, experimental images have been digitized and stored on computer magnetic tape. This data has been stored on tape compatable with that used by larger computing installations making this data relatively installation independent and therefore readily available for further experiments.

3) Statistics for two motion picture images were computed and compared to the statistics predicted by previously used models. For these images it was found that an autocorrelation function of the form

$$R(\Delta x, \Delta y, \Delta t) = \exp[-(\alpha^2(\Delta x)^2 + \beta^2(\Delta y)^2)^{1/2} - \gamma|\Delta t|]$$

was most accurate in predicting these statistics.

4) The effect of using the Gauss-Markov model in designing a DPCM communication system on the performance of that system in terms of signal-to-noise ratio was determined by comparing predicted and measured signal-to-noise ratios for the system.

APPENDIX

Supernova Support Routines for Digitizer

The following subroutines are used to digitize picture images located on 35 mm film using the system described in Chapter Two. In order to use them, the main routine SCANN must be called from a fortran routine as follows:

```
CALL SCANN
STOP
END
```

This will ensure porper initialization of the fortran calling sequence.

All subroutines are compiled and assembled separately. Once the above fortran program has been compiled and assembled, it must be loaded along with the following subroutines and the fortran library FORT.LB using the supernova relocatable loader.

```
0001  ACOUT
                                ; THIS SUBROUTINE IS DESIGNED TO OUTPUT
                                ; A 16 BIT WORD IN OCTAL FORMAT ON THE TT
                                ;
                                ; AC2 MUST CONTAIN THE WORD TO BE
                                ; DISPLAYED
                                ;
                        .TITL   ACOUT
                        .ENT    ACOUT
                        .NREL
00000'054437 ACOUT:     STA     3,RTN     ; SAVE RETURN
00001'048437            STA     0,AC0     ; SAVE AC'S
00002'044437            STA     1,AC1
00003'050437            STA     2,AC2
00004'020437            LDA     0,C6
00005'040437            STA     0,RP1
00006'020437            LDA     0,C60     ; FIRST BIT
00007'151122            MOVZL   2,2,SZC
00010'101400            INC     0,0
00011'000411            JMP     ENTER
00012'020434 LOOP1:     LDA     0,C3      ; SUBSEQUENT THREE BIT
00013'040434            STA     0,RP2     ;        GROUPS
00014'020427            LDA     0,C6
00015'101120 LOOP2:     MOVZL   0,0       ; EACH BIT
00016'151122            MOVZL   2,2,SZC
00017'101400            INC     0,0
00020'014427            DSZ     RP2
00021'000774            JMP     LOOP2
00022'006002 ENTER:     .SYSTM            ; OUTPUT CHARACTER
00023'070000            .PCHAR
00024'000400            JMP     .
00025'014417            DSZ     RP1
00026'000764            JMP     LOOP1
00027'020421            LDA     0,C40     ; BLANK CHARACTER
00030'006002            .SYSTM
00031'070000            .PCHAR
00032'000400            JMP     .
00033'020405            LDA     0,AC0     ; RESTORE AC'S
00034'024405            LDA     1,AC1
00035'030405            LDA     2,AC2
00036'002401            JMP     @RTN      ; RETURN

                                ; CONSTANTS

00037'000000 RTN:       0
00040'000000 AC0:       0
00041'000000 AC1:       0
00042'000000 AC2:       0
00043'000006 C6:        6
00044'000000 RP1:       0
00045'000060 C60:       60
00046'000003 C3:        3
00047'000000 RP2:       0
00050'000040 C40:       40
                        .END
```

```
0001  BRGHT
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; ADJUST THE BRIGHTNESS OF THE SPOT
                                  ; ON THE FLYING SPOT SCANNER
                                  ;
                                  ; A CALL TO BRSTA SETS THE INDEX
                                  ; LOCATION OF THE PERFORATION (EDGE1)
                                  ;
                                  ; INTNS IS CALLED TO DETERMINE THE
                                  ; SPOT BRIGHNESS IN THE PERFORATION
                                  ; LOCATED BY 'EDGE1'
                                  ;
                                  ;
                                  ;
                                  ;
                                  ;
                         .TITL    BRGHT
                         .ENT     BRGHT,BRSTA
                         .EXTN    INTNS
                         .EXTD    .FCAL
                         .NREL

00000'040452 BRSTA:      STA      0,EDGE1 ; STORE EDGE1
00001'001400             JMP      0,3     ; RETURN

00002'040443 BRGHT:      STA      0,AC0   ; SAVE AC'S
00003'044443             STA      1,AC1
00004'050443             STA      2,AC2
00005'054437             STA      3,RTN   ; SAVE RETURN
00006'020442             LDA      0,C346  ; DESIRED INTENSITY = 346
00007'006001$LOOP:       JSR      @.FCAL  ; OBTAIN ACTUAL INTENSITY
00010'177777             INTNS
00011'000002             2
00012'000052'            EDGE1
00013'000051'            BRT
00014'024435             LDA      1,BRT
00015'125220             MOVZR    1,1     ; DIVIDE BY 8
00016'125220             MOVZR    1,1
00017'125220             MOVZR    1,1
00020'106415             SUB#     0,1,SNR ; EQUAL ?
00021'000417             JMP      DONE    ; YES
00022'106513             SUBL#    0,1,SNC ; TOO LOW ?
00023'000410             JMP      HIGH    ; NO
00024'024427             LDA      1,BRT1  ; DECREASE CONTROL
00025'124400             NEG      1,1
00026'125400             INC      1,1
00027'124400             NEG      1,1
00030'044423             STA      1,BRT1
00031'066045             DOB      1,45    ; ISSUE CONTROL
00032'000755             JMP      LOOP
00033'024420 HIGH:       LDA      1,BRT1  ; INCREASE CONTROL
00034'125400             INC      1,1
00035'044416             STA      1,BRT1
00036'066045             DOB      1,45    ; ISSUE CONTROL
00037'000750             JMP      LOOP
00040'020405 DONE:       LDA      0,AC0   ; RESTORE AC'S
00041'024405             LDA      1,AC1
00042'030405             LDA      2,AC2
00043'002401             JMP      @RTN    ; RETURN
```

```
0002  BRGHT
                                        ; CONSTANTS

 00044'000000 RTN:     0
 00045'000000 AC0:     0
 00046'000000 AC1:     0
 00047'000000 AC2:     0
 00050'000346 C346:    346
 00051'000000 ART:     0
 00052'000000 IDCE1:   0
 00053'000600 ART1:    600

                       .END
```

```
0001  CHWRT
                                ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                ; CHECK THE STATUS OF A WRITE COMMAND
                                ; HAVING BEEN ISSUED TO THE MAGNETIC
                                ; TAPE UNIT.
                                ;
                                ; ALL ERRORS ARE CHECKED AND WHERE
                                ; POSSIBLE, REWRITE ATTEMPTS ARE MADE.
                                ;
                                ; AC0 MUST CONTAIN THE ADDRESS OF THE
                                ; BUFFER TO BE WRITTEN
                                ; AC1 MUST CONTAIN THE WORD SIZE OF
                                ; THE BUFFER
                                ;
                                ;
                                ;
                        .TITL   CHWRT
                        .ENT    CHWRT
                        .EXTN   CSKIP,ACOUT,WRITE
                        .NREL
      000001            .TXTM   1

00000'040461 CHWRT:     STA     0,AC0    ; SAVE AC'S
00001'044461            STA     1,AC1
00002'050461            STA     2,AC2
00003'054461            STA     3,RTN    ; SAVE RETURN
00004'152400            SUB     2,2      ; RETRY=ERASE=0
00005'050460            STA     2,RETRY
00006'050460            STA     2,ERASE
00007'063622 WAIT:      SKPDN   MTA      ; WAIT FOR TAPE
00010'000777            JMP     .-1
00011'070422            DIA     2,MTA    ; OBTAIN STATUS
00012'060222            NIOC    MTA
00013'060177            INTEN
00014'151112            MOVL#   2,2,SZC  ; ERROR?
00015'000405            JMP     .+5      ; YES
00016'020443            LDA     0,AC0    ; NO - RESTORE AC'S
00017'024443            LDA     1,AC1
00020'030443            LDA     2,AC2
00021'002443            JMP     @RTN     ; RETURN
00022'020433            LDA     0,C15    ; OUTPUT STATUS
00023'006002            .SYSTM
00024'070000            .PCHAR
00025'000400            JMP     .
00026'020426            LDA     0,C12
00027'006002            .SYSTM
00030'070000            .PCHAR
00031'000400            JMP
00032'006426            JSR     @ACOUT
00033'151120            MOVZL   2,2
00034'151122            MOVZL   2,2,SZC  ; DATA LATE?
00035'000464            JMP     LATE     ; YES
00036'153122            ADDZL   2,2,SZC  ; ILLEGAL?
00037'000513            JMP     LEGAL    ; YES
00040'153122            ADDZL   2,2,SZC  ; PARITY ERROR?
00041'000460            JMP     LATE     ;YES
00042'151122            MOVZL   2,2,SZC  ; END OF TAPE?
00043'000521            JMP     EOT      ; YES
00044'151300            MOVS    2,2      ; ODD CHARACTERS?
00045'151222            MOVZR   2,2,SZC  ;
```

```
0002  CHWRT
 00046'000453          JMP      LATE     ; YES
 00047'020420          LDA      0,TXT1   ; UNKNOWN ERROR
 00050'006407 STOP:    JSR      @AWRT
 00051'000002          .SYSTM
 00052'064400          .RTN
 00053'000400          JMP

                                ;CONSTANTS

 00054'000012 C12:     12
 00055'000015 C15:     15
 00056'000105 CE:      105
 00057'177777 AWRT:    WRITE
 00060'177777 ACOUT:   ACOUT
 00061'000000 AC0:     0
 00062'000000 AC1:     0
 00063'000000 AC2:     0
 00064'000000 RTN:     0
 00065'000000 RETRY:   0
 00066'000000 ERASE:   0
 00067'000070'TXT1:    .+1
                       .TXT     /<15><12>UNKNOWN TAPE WRITE ERROR - EXECUT
 00070'006412
 00071'052516
 00072'045516
 00073'047527
 00074'047040
 00075'052101
 00076'050105
 00077'020127
 00100'051111
 00101'052105
 00102'020105
 00103'051122
 00104'047522
 00105'020055
 00106'020105
 00107'054103
 00110'041525
 00111'052111
 00112'047516
 00113'020124
 00114'042522
 00115'046511
 00116'047101
 00117'052105
 00120'042000

 00121'024427 LATE:    LDA      1,CM1    ; SPACE REVERSE
 00122'060277          INTDS
 00123'067022          DOC      1,MTA
 00124'030425          LDA      2,C40
 00125'071122          DOAS     2,MTA
 00126'063622          SKPDN    MTA      ; WAIT FOR TAPE
 00127'000777          JMP      .-1
 00130'060222          NIOC     MTA
 00131'060177          INTEN
 00132'020733          LDA      0,RETRY  ; RETRY = 8?
 00133'024417          LDA      1,C10
```

```
0003  CAWRT
 00134'106403          SUB     0,1,SNR
 00135'000433          JMP     RUB       ; YES
 00136'101400          INC     0,0       ; RETRY = RETRY + 1
 00137'040726          STA     0,RETRY
 00140'060277 RITE:    INTDS
 00141'020730          LDA     0,AC0
 00142'063022          DOB     0,MTA
 00143'020717          LDA     0,AC1
 00144'063022          DOC     0,MTA
 00145'020406          LDA     0,C50
 00146'061122          DOAS    0,MTA
 00147'000640          JMP     WAIT

                                ; CONSTANTS

 00150'177777 CM1:     -1
 00151'000040 C40:     40
 00152'000010 C10:     10
 00153'000050 C50:     50

 00154'020445 LEGAL:   LDA     0,TXT2    ; TAPE FILE PROTECTED
 00155'006702          JSR     @AWRT
 00156'020470 CANC:    LDA     0,TXT3    ; CANCEL OR RESTART
 00157'024440          LDA     1,A1
 00160'000436          JSR     @ASKIP
 00161'006062          .SYSTM
 00162'064400          .RTN
 00163'000400          JMP     .

 00164'020513 EOT:     LDA     0,TXT4    ; END OF TAPE
 00165'006672          JSR     @AWRT
 00166'000770          JMP     CANC.

 00167'020677 RUB:     LDA     0,ERASE   ; ERASE = 8?
 00170'024762          LDA     1,C10
 00171'106404          SUB     0,1,SZR
 00172'000403          JMP     .+3       ; NO
 00173'020537          LDA     0,TXT5    ; YES
 00174'000654          JMP     STOP
 00175'101400          INC     0,0       ; ERASE = ERASE + 1
 00176'040670          STA     0,ERASE
 00177'102400          SUB     0,0       ; RETRY = 0
 00200'040665          STA     0,RETRY
 00201'060277          INTDS
 00202'020416          LDA     0,C70     ; ERASE A SECTION
 00203'061122          DOAS    0,MTA
 00204'063622          SKPDN   MTA       ; WAIT FOR TAPE
 00205'000777          JMP     .-1
 00206'020742          LDA     0,CM1     ; SPACE REVERSE
 00207'063022          DOC     0,MTA
 00210'020741          LDA     0,C40
 00211'061122          DOAS    0,MTA
 00212'063622          SKPDN   MTA       ; WAIT FOR TAPE
 00213'000777          JMP     .-1
 00214'060177          INTEN
 00215'000723          JMP     RITE

                                ; CONSTANTS
```

```
0004  CHWRT
 00216'177777 ASKIP:  CSKIP
 00217'000140'A1:     RITE
 00220'000070 C70:    70
 00221'000222'TXT2:   .+1
                      .TXT    /<15><12>    TAPE FILE PROTECTED - CORRECT
 00222'006412
 00223'020040
 00224'020040
 00225'052101
 00226'050105
 00227'020105
 00230'044514
 00231'042440
 00232'050122
 00233'047524
 00234'042503
 00235'052105
 00236'042040
 00237'026440
 00240'041517
 00241'051122
 00242'042503
 00243'052040
 00244'040516
 00245'042000
 00246'000247'TXT3:   .+1
                      .TXT    /<15><12>    TYPE 'Y' TO CONTINUE OR 'N' T
 00247'006412
 00250'020040
 00251'020040
 00252'052131
 00253'050105
 00254'020047
 00255'054447
 00256'020124
 00257'047440
 00260'041517
 00261'047124
 00262'044516
 00263'052505
 00264'020117
 00265'051040
 00266'023516
 00267'023440
 00270'052117
 00271'020110
 00272'040514
 00273'052040
 00274'020040
 00275'020040
 00276'000000
 00277'000300'TXT4:   .+1
                      .TXT    /<15><12>    END OF TAPE ENCOUNTERED - MOL
 00300'006412
 00301'020040
 00302'020040
 00303'042516
 00304'042040
 00305'047506
```

```
0005  CHWRT
 00306'020124
 00307'040520
 00310'042440
 00311'042516
 00312'041517
 00313'052516
 00314'052105
 00315'051105
 00316'042040
 00317'026440
 00320'046517
 00321'052516
 00322'052040
 00323'047105
 00324'053440
 00325'052101
 00326'050105
 00327'020101
 00330'047104
 00331'000000
 00332'000333'TXT5:    .+1
                       TXT     /<15><12>UNABLE TO WRITE ON TAPE - EXECUTI
 00333'006412
 00334'052516
 00335'040502
 00336'046105
 00337'020124
 00340'047440
 00341'053522
 00342'044524
 00343'042440
 00344'047516
 00345'020124
 00346'040520
 00347'042440
 00350'026440
 00351'042530
 00352'042503
 00353'052524
 00354'044517
 00355'047040
 00356'052105
 00357'051115
 00360'044516
 00361'040524
 00362'042504
 00363'000000

                       .END
```

```
0001  CSKIP
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; BUILD A SKIP CHAIN VIA USER
                                  ; INTERROGATION
                                  ;
                                  ; AC0 MUST CONTAIN A  POINTER TO
                                  ; THE DESIRED PROMPT
                                  ; AC1 MUST CONTAIN A JUMP LOCATION TO
                                  ; BE TAKEN ON AN AFFIRMATIVE RESPONSE
                                  ; THIS MAY BE A SUBROUTINE ADDRESS
                                  ; AS THE RETURN FOR THIS ROUTINE WILL
                                  ; BE PASSED ON
                                  ;
                                  ;
                                  ;
                        .TITL     CSKIP
                        .ENT      CSKIP
                        .EXTN     WRITE
                        .NREL
00000'054434 CSKIP:     STA       3,RTN     ;SAVE RETURN
00001'040434            STA       0,AC0     ; SAVE AC'S
00002'044434            STA       1,AC1
00003'050434            STA       2,AC2
00004'006436 AGAIN:     JSR       @AWRT     ; WRITE MESSAGE
00005'006002            .SYSTM              ; GET RESPONSE
00006'067400            .GCHAR
00007'000400            JMP       .
00010'006002            .SYSTM
00011'070000            .PCHAR
00012'000400            JMP       .
00013'024425            LDA       1,CY      ; AFFIRMATIVE?
00014'106404            SUB       0,1,SZR
00015'000406            JMP       NO
00016'020417            LDA       0,AC0     ; RESTORE AC'S
00017'024417            LDA       1,AC1
00020'030417            LDA       2,AC2
00021'034413            LDA       3,RTN
00022'002414            JMP       @AC1      ; JUMP OUT
00023'024416 NO:        LDA       1,CN      ; NEGATIVE?
00024'106404            SUB       0,1,SZR
00025'000405            JMP       BACK
00026'020407            LDA       0,AC0     ; RESTORE AC'S
00027'024407            LDA       1,AC1
00030'030407            LDA       2,AC2
00031'002403            JMP       @RTN      ; RETURN
00032'020403 BACK:      LDA       0,AC0
00033'000751            JMP       AGAIN

                                  ; CONSTANTS

00034'000000 RTN:       0
00035'000000 AC0:       0
00036'000000 AC1:       0
00037'000000 AC2:       0
00040'000131 CY:        131
00041'000116 CN:        116
00042'177777 AWRT:      WRITE

                        .END
```

```
C       THIS SUBROUTINE HAS BEEN DESIGNED TO DETECT
C       THE LOCATION OF THE EDGE OF A PERFORATION
C       OF THE 35 MM FILM
C
C       CALLED FROM ASSEMBLER BY:
C                 JSR    @.FCAL
C                 EDGE
C                 2
C                 EDGE1
C                 EDGED
C
C            WHERE EDGE1 IS THE INDEX LOCATION
C            AND EDGED IS THE DIFFERENCE BETWEEN
C            THE INDEX AND ACTUAL LOCATIONS
C
C            IF EDGE1 IS ZERO ON CALL TO THIS ROUTINE
C            EDGE1 WILL BE SET EQUAL TO THE PRESENT
C            LOCATION OF THE EDGE
C
C            IF EDGE1 IS NONZERO , EDGED WILL BE SET
C            EQUAL TO THE DIFFERENCE BETWEEN EDGE1 AND
C            THE PRESENT LOCATION OF THE PERFORATION
C            EDGE
C
C            DUE TO THE DYNAMIC STORAGE ALLOCATION USED
C            BY THE SUPERNOVA FORTRAN , VARIABLES DO NOT
C            RETAIN THEIR VALUES FOR SUBSEQUENT CALLS TO
C            A ROUTINE . FOR THIS REASON THE PARAMETER
C            EDGE1 MUST BE STORED IN AN ASSEMBLER ROUTINE
C            OR IN THE COMMON AREA .
C
C       LINEP IS CALLED TO SCAN THE PERFORATIONS
C       FILLING THE ARRAY IYB
C
C
C
      SUBROUTINE EDGE (IEDG1,IEDGD)
      DIMENSION IYB(1024)
C
C *** SCAN PERFORATIONS
C
      CALL LINEP (IYB)
C
C *** SET THREASHOLD AT MEAN
C
      S=0.0
      DO 200 I=1,1024
      S=S+IYB(I)
  200 CONTINUE
      ITHR=S/1024.00
C
C *** FIND LEADING EDGE OF PERFORATION
C
      DO 201 I=1,1024
      J=I
      IF (IYB(I).GE.ITHR) GO TO 202
  201 CONTINUE
      STOP 'NO EDGE FOUND'
C
C *** FIND TRAILING EDGE OF PERFORATION
C
C
  202 DO 203 I=J,1024
```

```
      J=I
      IF (IYB(I).LT.ITHR) GO TO 204
  203 CONTINUE
      STOP 'NO EDGE FOUND'
  204 IF (IEDG1.EQ.0) GO TO 205
C
C *** SET EDGED TO DIFFERENCE
C
      IEDGD=J-IEDG1
      RETURN
C
C *** SET EDGE1 TO EDGE LOCATION
C
  205 IEDG1=J
      RETURN
```

```
0001  FIPOS
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; POSITION 35 MM FILM
                                  ;
                                  ;
                                  ;
                        .TITL     FIPOS
                        .ENT      FIPOS
                        .EXTN     GTNUM,FSTEP,FMPOS,WRITE,CSKIP,FMSTA,EDGE,
                        .EXTD     .FCAL
                        .NWEL
        000001          .TXTN     1

00000'054466 FIPOS:     STA       3,RTN    ; SAVE RETURN
00001'043406            STA       0,AC0    ; SAVE AC'S
00002'044466            STA       1,AC1
00003'050466            STA       2,AC2
00004'020536            LDA       0,TXT1   ; MESSAGE- FILM POSITIONING
00005'006000            JSR       @AWRT
00006'020521 MORE:      LDA       0,TXT2   ; MESSAGE- ENTER COMMAND
00007'006476            JSR       @AWRT
00010'020535            LDA       0,TXT3   ; MESSAGE- COMMAND CHOICES
00011'006474            JSR       @AWRT
00012'006470            JSR       @AGNUM   ; GET COMMAND
00013'102400            SUB       0,0      ; CHECK FOR BAD
00014'142405            SUB       2,0,SNR  ;     RESPONSE
00015'000771            JMP       MORE     ; BAD- REINITIALIZE
00016'020455            LDA       0,C3     ; CHECK FOR BAD
00017'112513            SUBL#     0,2,SNC  ;       RESPONSE
00020'000766            JMP       MORE
00021'050451            STA       2,CMND   ; STORE IT
00022'020553 FIPO1:     LDA       0,TXT4   ; MESSAGE- HOW MANY TIMES?
00023'006462            JSR       @AWRT
00024'006456            JSR       @AGNUM   ; GET RESPONSE
00025'102400            SUB       0,0      ; CHECK FOR BAD
00026'142405            SUB       2,0,SNR  ;       RESPONSE
00027'000773            JMP       FIPO1    ; BAD- REINITIALIZE
00030'050445            STA       2,TIMES  ; STORE IT
00031'030441            LDA       2,CMND   ; GET COMMAND
00032'020442            LDA       0,C2     ; IS IT A
00033'112415            SUB#      0,2,SNR  ;       TWO?
00034'000404            JMP       MOVE     ; YES- GO TO MOVE
00035'024440            LDA       1,TIMES  ; NO-CALL STEP ROUTINE
00036'006446            JSR       @AFST
00037'000420            JMP       END      ; GO TO END
00040'102400 MOVE:      SUB       0,0      ; SET FLAG TO FIND EDGE1
00041'040437            STA       0,EDGE1
00042'006446            JSR       @ADRST   ; SET EDGE1 TO ADJUST INTENSITY
00043'006446            JSR       @ABRT    ; ADJUST BRIGHTNESS
00044'006001$           JSR       @.FCAL   ; CALL EDGE
00045'177777            EDGE
00046'000002            2
00047'000100'           EDGE1
00050'000077'           DUN
00051'020427            LDA       0,EDGE1  ; SET EDGE1 IN FMPOS
00052'006427            JSR       @AFSTA
00053'006435            JSR       @ABRST   ; SET EDGE1 IN BRGHT
00054'006427 MOVE1:     JSR       @AFMPO   ; CALL FRAME ROUTINE
00055'014428            DSZ       TIMES    ; ENOUGH FRAMES?
00056'000776            JMP       MOVE1    ; NO- CONTINUE
```

```
0002  FIPOS
 00047'020516 END:     LDA     0,TXT5   ; MESSAGE- ANY MORE?
 00050'020107          LDA     1,ANORE
 00051'000475          JSR     SASKIP
 00052'020105          LDA     0,AC0    ; RESTORE AC'S
 00053'020105          LDA     1,AC1
 00054'020105          LDA     2,AC2
 00055'000401          JMP     SRTN     ; RETURN

                       ;CONSTANTS

 00056'000000 RTN:     0
 00057'000000 AC0:     0
 00060'000000 AC1:     0
 00061'000000 AC2:     0
 00062'000000 CMND:    0
 00063'000003 C3:      3
 00064'000002 C2:      2
 00065'000000 TIMES:   0
 00066'000116 CN:      116
 00067'000000 NUM:     0
 00100'000000 EDGE1:   0
 00101'177777 AFSTA:   FMSTA
 00102'177777 AGNUM:   GTNUM
 00103'177777 AFMPO:   FMPOS
 00104'177777 AFST:    FSTEP
 00105'177777 AWRT:    WRITE
 00106'177777 ASKIP:   CSKIP
 00107'000036'ANORE:   MORE
 00110'177777 ABRST:   SRSTA
 00111'177777 ABRT:    SRGHT

 00112'000113'TXT1:    .+1
                       .TXT    /<15><12>    FILM POSITIONING/
 00113'006412
 00114'020040
 00115'020040
 00116'043111
 00117'043115
 00120'020120
 00121'047523
 00122'044524
 00123'044517
 00124'047111
 00125'047107
 00126'000000
 00127'000130'TXT2:    .+1
                       .TXT    /<15><12>        ENTER COMMANDS/
 00130'006412
 00131'020040
 00132'020040
 00133'020040
 00134'020040
 00135'042515
 00136'052105
 00137'051040
 00140'041517
 00141'046515
 00142'040516
 00143'042123
```

```
0003  FIPOS
 00144'000000
 00145'000146'TXT3:    .+1
                       .TXT     /<15><12>        1(SINGLE STEP), 2(SINGLE
 00146'006412
 00147'020040
 00150'020040
 00151'020040
 00152'020040
 00153'030450
 00154'051511
 00155'047147
 00156'046105
 00157'020123
 00160'052105
 00161'050051
 00162'020040
 00163'031050
 00164'051511
 00165'047107
 00166'046105
 00167'020106
 00170'051101
 00171'046505
 00172'024445
 00173'020040
 00174'020040
 00175'000176'TXT4:    .+1
                       .TXT     /<15><12>        HOW MANY TIMES?
 00176'006412
 00177'020040
 00200'020040
 00201'020040
 00202'020040
 00203'044117
 00204'053443
 00205'046501
 00206'047131
 00207'020124
 00210'044515
 00211'042523
 00212'037443
 00213'020040
 00214'020040
 00215'020040
 00216'020040
 00217'020040
 00220'020040
 00221'020040
 00222'020040
 00223'020040
 00224'020000
 00225'000226'TXT5:    .+1
                       .TXT     /<15><12>        POSITIONING DONE. ANY MOR...
 00226'006412
 00227'020040
 00230'020040
 00231'020040
 00232'020040
 00233'050117
```

```
0004  F1P08
 00234'051511
 00235'052111
 00236'047016
 00237'044015
 00238'043146
 00241'043117
 00242'047105
 00243'027045
 00244'048515
 00245'054443
 00246'046017
 00247'051107
 00250'027443
 00251'020040
 00252'020040
 00253'020040
 00254'020000

                    .END
```

```
0001  FMPOS
                                ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                ; ADVANCE 35 MM FILM BY ONE FRAME
                                ;
                                ; A CALL TO FMSTA SETS EDGE1 TO THE
                                ; INDEX LOCATION OF THE EDGE OF THE
                                ; PERFORATIONS
                                ;
                                ; A CALL TO FMPOS ADVANCES THE FILM
                                ; TO THE NEXT FRAME
                                ;
                                ; FSTEP IS CALLED TO ADD CORRECTION
                                ; STEPS DUE TO POSITIONAL ERROR
                                ;
                                ; EDGE IS CALLED TO DETERMINE THE ERROR
                                ; IN POSITION BY DETECTING THE LOCATION
                                ; OF THE PERFORATIONS AND COMPARING THIS
                                ; TO THE INDEX LOCATION 'EDGE1'
                                ;
                                ; BRGHT IS CALLED TO ADJUST THE
                                ; BRIGHTNESS OF THE FLYING SPOT SCANNER
                                ;
                                ;
                                ;
                                ;
                        .TITL   FMPOS
                        .ENT    FMPOS,FMSTA
                        .EXTN   FSTEP,EDGE,BRGHT
                        .EXTD   .FCAL
                        .NREL

00000'040510 FMSTA:     STA     0,EDGE1
00001'001400            JMP     0,3

00002'054510 FMPOS:     STA     3,RTN    ; SAVE RETURN
00003'040510            STA     0,AC0    ; SAVE AC'S
00004'044510            STA     1,AC1
00005'050510            STA     2,AC2
00006'020475            LDA     0,C12    ; OUTPUT AN 'S'
00007'006002            .SYSTM           ;       TO DENOTE END OF SCAN
00010'070000            .PCHAR
00011'000400            JMP     .
00012'020472            LDA     0,C15
00013'006002            .SYSTM
00014'070000            .PCHAR
00015'000400            JMP     .
00016'020467            LDA     0,CS
00017'006002            .SYSTM
00020'070000            .PCHAR
00021'000400            JMP     .
00022'020474            LDA     0,ACNT   ; PUT PULSE
00023'024474            LDA     1,ADELY  ;       COUNT AND
00024'030474            LDA     2,C1     ;       DELAY ADDRESSES
00025'142400            SUB     2,0      ;       IN AUTO-
00026'146400            SUB     2,1      ;       INCREMENT
00027'040023            STA     0,23     ;       LOCATIONS
00030'044024            STA     1,24     ;
00031'020471            LDA     0,COUNT  ; INITIALIZE
00032'040471            STA     0,TCNT   ;       COUNTER
00033'024472            LDA     1,DELAY  ; INITIALIZE DELAY
```

```
0002  FMPOS
 00034'060247          NIOC    47
 00035'022023 LOOP1:   LDA     0,023    ; INITIALIZE PULSE
 00036'040465          STA     0,PCNT   ;        COUNT AND
 00037'022024          LDA     0,024    ;        DELAY
 00040'060347 LOOP2:   NIOP    47       ; ISSUE PULSE
 00041'106400          SUB     0,1      ; INITIALIZE
 00042'044464          STA     1,DELA   ;        DELAY
 00043'014463          DSZ     DELA     ; DELAY
 00044'000777          JMP     .-1      ;        LOOP
 00045'014457          DSZ     PCNT     ; LAST PULSE?
 00046'000772          JMP     LOOP2    ; NO- CONTINUE
 00047'014454          DSZ     TCNT     ; FRAME IN POSITION?
 00050'000765          JMP     LOOP1    ; NO- CONTINUE
 00051'060447          DIA     0,47     ; OBTAIN PULSE COUNT
 00052'024455          LDA     1,NPLS   ; ANY ERRORS ?
 00053'106400          SUB     0,1
 00054'125113          MOVL#   1,1,SNC
 00055'006434          JSR     @AFST    ; YES - GO CORRECT
 00056'006001#LOOP3:   JSR     @.FCAL   ; DETERMINE EDGE DIFFERENCE
 00057'177777          EDGE
 00060'000002          2
 00061'000110'         EDGE1
 00062'000121'         EDGED
 00063'024436          LDA     1,EDGED  ; NEGATIVE ?
 00064'125112          MOVL#   1,1,SZC
 00065'000405          JMP     DONE     ; YES
 00066'125005          MOV     1,1,SNR  ; ZERO ?
 00067'000403          JMP     DONE     ; YES
 00070'006421          JSR     @AFST    ; GO CORRECT
 00071'000765          JMP     LOOP3    ; RECHECK POSITION
 00072'020414 DONE:    LDA     0,CM     ; OUTPUT AN 'M'
 00073'006002          .SYSTM           ;        TO DENOTE END OF MOVE
 00074'070000          .PCHAR
 00075'000400          JMP     .
 00076'006411          JSR     @ABRT    ; ADJUST BRIGHTNESS
 00077'020414          LDA     0,AC0    ; RESTORE AC'S
 00100'024414          LDA     1,AC1
 00101'030414          LDA     2,AC2
 00102'002410          JMP     @RTN     ; RETURN

                                ; CONSTANTS

 00103'000012 C12:     12
 00104'000015 C15:     15
 00105'000123 CS:      123
 00106'000115 CM:      115
 00107'177777 ABRT:    BRGHT
 00110'000000 EDGE1:   0
 00111'177777 AFST:    FSTEP
 00112'000000 RTN:     0
 00113'000000 AC0:     0
 00114'000000 AC1:     0
 00115'000000 AC2:     0
 00116'000130'ACNT:    CNT
 00117'000151'ADELY:   DLAY
 00120'000001 C1:      1
 00121'000000 EDGED:   0
 00122'000021 COUNT:   21
 00123'000000 TCNT:    0
```

```
0003  PMPOS
 00124'000000 PCNT:    0
 00125'044630 DELAY:   44630
 00126'000000 DELA:    0
 00127'005360 NPLS:    5360
 00130'000024 CNT:     24
 00131'000050          50
 00132'000074          74
 00133'000121          121
 00134'000151          151
 00135'000225          225
 00136'000250          250
 00137'000727          727
 00140'001130          1130
 00141'000727          727
 00142'000250          250
 00143'000225          225
 00144'000151          151
 00145'000121          121
 00146'000074          74
 00147'000050          50
 00150'000024          24
 00151'000727 DLAY:    727
 00152'000116          116
 00153'000032          32
 00154'000014          14
 00155'000006          6
 00156'000003          3
 00157'000002          2
 00160'000001          1
 00161'000000          0
 00162'177777          -1
 00163'177776          -2
 00164'177775          -3
 00165'177772          -6
 00166'177764          -14
 00167'177746          -32
 00170'177662          -116
 00171'177051          -727

                       .END
```

```
0001  FSTEP
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; ADVANCE THE 35 MM TRANSPORT BY A GIVEN
                                  ; NUMBER OF STEPS
                                  ;
                                  ; THE DESIRED NUMBER MUST BE IN AC1
                                  ;
                                  ;
                                  ;
                          .TITL   FSTEP
                          .ENT    FSTEP
                          .NREL

00000'054432 FSTEP:       STA     3,RTN    ; SAVE RETURN
00001'040432              STA     0,AC0    ; SAVE AC'S
00002'044432              STA     1,AC1
00003'050432              STA     2,AC2
00004'125112 LOOPA:       MOVL#   1,1,SZC  ; NEGATIVE ?
00005'000403              JMP     DONE     ; YES
00006'125004              MOV     1,1,SZR  ; ZERO ?
00007'000405              JMP     START    ; NO
00010'020423 DONE:        LDA     0,AC0    ; RESTORE AC'S
00011'024423              LDA     1,AC1
00012'030423              LDA     2,AC2
00013'002417              JMP     @RTN     ; RETURN
00014'044422 START:       STA     1,STEPS
00015'124400              NEG     1,1      ; NEG. STEP COUNTER
00016'060247              NIOC    47       ; CLEAR COUNTER
00017'060347 LOOP:        NIOP    47       ; ISSUE PULSE
00020'020417              LDA     0,DELAY
00021'100400              NEG     0,0
00022'101404              INC     0,0,SZR  ; DELAY LOOP
00023'000777              JMP     .-1
00024'125404              INC     1,1,SZR  ; ENOUGH PULSES?
00025'000772              JMP     LOOP     ; NO
00026'060447              DIA     0,47     ; OBTAIN COUNT
00027'024407              LDA     1,STEPS
00030'106400              SUB     0,1      ; NEW COUNT
00031'000753              JMP     LOOPA    ; BACK AGAIN

                                  ; CONSTANTS

00032'000000 RTN:         0
00033'000000 AC0:         0
00034'000000 AC1:         0
00035'000000 AC2:         0
00036'000000 STEPS:       0
00037'040000 DELAY:       40000

                          .END
```

```
0001  GTNUM
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; ACCEPT MULTIPLE DIGIT DECIMAL
                                  ; INTEGERS FROM TT AND CONVERT TO
                                  ; BINARY INTEGERS
                                  ;
                                  ; INPUT IS TERMINATED ON RECOGNITION
                                  ; OF A NON-NUMERIC CHARACTER
                                  ;
                                  ; ANY NUMBER LARGER THAN 16 BINARY
                                  ; BITS WILL BE TRUNCATED ON THE
                                  ; LEFT
                                  ;
                                  ; NEGATIVE NUMBERS HAVE NOT BEEN CONSIDERE
                                  ;
                                  ; RETURNS THE BINARY VALUE IN AC2
                                  ;
                                  ;
                          .TITL*  GTNUM
                          .ENT    GTNUM
                          .NREL
00000'054436 GTNUM:       STA     3,RTN    ; SAVE RETURN
00001'040432              STA     0,AC0
00002'044432              STA     1,AC1
00003'050432              STA     2,AC2
00004'152400              SUB     2,2
00005'006002 LOOP:        .SYSTM           ; OBTAIN DIGIT
00006'067400              .GCHAR
00007'000400              JMP     .
00010'006002              .SYSTM
00011'070000              .PCHAR
00012'000400              JMP     .
00013'024424              LDA     1,C57    ; ABOVE LOWER LIMIT?
00014'106513              SUBL#   0,1,SNC
00015'000413              JMP     DONE     ; NO-RETURN
00016'024422              LDA     1,C72    ; BELOW UPPER LIMIT?
00017'122513              SUBL#   1,0,SNC
00020'000410              JMP     DONE     ; NO-RETURN
00021'024420              LDA     1,C17    ; ASCII TO BINARY
00022'123400              AND     1,0
00023'145000              MOV     2,1      ; MULTIPLY NUMBER BY TEN
00024'153120              ADDZL   2,2
00025'133120              ADDZL   1,2
00026'113000              ADD     0,2      ; ADD DIGIT
00027'000756              JMP     LOOP
00030'020403 DONE:        LDA     0,AC0
00031'024403              LDA     1,AC1
00032'002404              JMP     @RTN

                                  ; CONSTANTS

00033'000000 AC0:         0
00034'000000 AC1:         0
00035'000000 AC2:         0
00036'000000 RTN:         0
00037'000057 C57:         57
00040'000072 C72:         72
00041'000017 C17:         17

                          .END
```

```
C       THIS SUBROUTINE HAS BEEN DESIGNED TO
C       DETERMINE THE AVERAGE SPOT BRIGHTNESS
C       OF THE FLYING SPOT SCANNER
C
C       LINEP IS CALLED TO SCAN THE PERFORATIONS
C
C       THE INTENSITY IS MEASURED THROUGH THE
C       FILM PERFORATIONS WHEN POSSIBLE
C
C       IF THERE IS INSUFFICIENT PERFORATION
C       AVAILABLE TO MAKE THIS MEASUREMENT ,
C       THE INTENSITY IS MEASURED ON THE
C       FIRST 40 POINTS OF THE PERFORATION SCAN
C
C       THE METHOD USED WILL BE INVARIANT
C       TROUGHOUT THE SET OF FRAMES SCANNED
C       SINCE THE PERFORATION IS MOVED TO
C       THE SAME LOCATION WITH EVERY ADVANCE
C
C       CALLED FROM ASSEMBLER BY :
C               JSR     @.FCAL
C               INTNS
C               2
C               IEDG1
C               INTS
C
C           WHERE EDGE1 IS THE INDEX LOCATION
C           OF THE FILM PERFORATION AND INTNS
C           IS THE AVERAGE INTENSITY MEASURED
C
C           DUE TO THE DYNAMIC STORAGE ALLOCATION
C           USED BY THE SUPERNOVA FORTRAN ,
C           VARIABLES DO NOT RETAIN THEIR VALUES
C           FOR SUBSEQUENT SUBROUTINE CALLS .
C           THEREFORE IEDG1 MUST BE STORED IN
C           AN ASSEMBLER ROUTINE OR IN THE COMMON
C           AREA
C
C
C
      SUBROUTINE INTNS (IEDG1,INTS)
      DIMENSION IYB(1024)
      CALL LINEP (IYB)
      S=0.0
      J=IEDG1-60
      K=IEDG1-20
C
      IF (J.LE.0) GO TO 201
C
      DO 200 I=J,K
      S=S+IYB(I)
  200 CONTINUE
C
      GO TO 203
C
  201 DO 202 I=1,41
      S=S+IYB(I)
  202 CONTINUE
C
  203 INTS=S/40.00
      RETURN
      END
```

```
0001  LINEP
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; SCAN THE PERFORATIONS ON THE FILM
                                  ;
                                  ; THIS IS A PARTIAL SCAN OF THE FILM
                                  ; WIDTH AT A VERY HIGH DENSITY
                                  ;
                                  ; CALLED BY :
                                  ;                CALL LINEP (ARRAY)
                                  ;.       WHERE ARRAY = BUFFER FOR SCAN
                                  ;
                                  ; REQUIRES HARDWARE INTEFACE ON DEVICE 44
                                  ;
                                  ;
                                  ;
                        .TITL     LINEP
                        .ENT      LINEP
                        .EXTD     .CPYL,.FRET
                        .NREL

       177611           X=-167
       000001           FS.=1

00000'000001            FS.
00001'006001$LINEP:     JSR       @.CPYL   ; ENTRY
00002'020432            LDA       0,C3777
00003'062044            DOB       0,44     ; ISSUE Y TO SCANNER
00004'063044            DOC       0,44     ; ISSUE Z TO SCANNER
00005'035611            LDA       3,X,3    ; BUFFER ADDRESS
00006'020431            LDA       0,PPLIN  ; INITIALIZE POINT
00007'100400            NEG       0,0      ;        COUNTER
00010'024425            LDA       1,C777   ; X-COORDINATE
00011'044425            STA       1,XX
00012'060277            INTDS
00013'065144 CONT:      DOAS      1,44     ; ISSUE X COORDINATE
00014'063644            SKPDN     44       ; WAIT FOR
00015'000777            JMP       .-1      ;        SCANNER
00016'070444            DIA       2,44     ; OBTAIN VALUE
00017'024415            LDA       1,C3777  ; MASK TO
00020'133400            AND       1,2      ;        ELEVEN BITS
00021'051400            STA       2,0,3    ; STORE VALUE
00022'175400            INC       3,3
00023'024413            LDA       1,XX     ;INCREMENT X
00024'030414            LDA       2,INCX   ;        COORDINATE
00025'147000            ADD       2,1      ;        AND
00026'044410            STA       1,XX     ;        STORE
00027'101404            INC       0,0,SZR  ; DONE LINE ?
00030'000763            JMP       CONT     ; NO- CONTINNUE
00031'060244            NIOC      44
00032'060177            INTEN
00033'006002$           JSR       @.FRET   ; RETURN


                                  ; CONSTANTS

00034'003777 C3777:     3777
00035'000777 C777:      777
00036'000000 XX:        0
00037'002000 PPLIN:     2000
00040'177777 INCX:      -1
```

```
0002  LINEP
                    .END
```

```
0001  SCAN
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; SCAN A SEQUENCE OF FRAMES
                                  ;
                                  ; REQUIRES HARDWARE INTERFACE ON DEVICE 44
                                  ;
                          .TITL   SCAN
                          .ENT    SCAN
                          .EXTN   GTNUM,FMPOS,CHWRT,WRITE,EDGE,FMSTA,BRGHT,B
                          .EXTD   .FCAL
                          .NREL
        000001            .TXTM   1

                                  ; CONSTANTS

00000'000227'ARTN:        RTN
00001'000230'AAC0:        AC0
00002'000231'AAC1:        AC1
00003'000232'AAC2:        AC2
00004'000267'T1:          TXT1
00005'000304'T2:          TXT2
00006'000327'T3:          TXT3
00007'177777 AGNUM:       GTNUM
00010'000000 DUM:         0
00011'000000 EDGE1:       0
00012'177777 AFSTA:       FMSTA
00013'177777 ABRT:        BRGHT
00014'177777 ABRST:       BRSTA

00015'056763 SCAN:        STA     3,@ARTN ; SAVE RETURN
00016'042763              STA     0,@AAC0 ;SAVE AC'S
00017'046763              STA     1,@AAC1
00020'052763              STA     2,@AAC2
00021'102400              SUB     0,0     ; SET FLAG TO DETERMINE
00022'040767              STA     0,EDGE1 ;       EDGE1
00023'006771              JSR     @ABRST  ; SET EDGE1 TO ADJUST INTENSITY
00024'006767              JSR     @ABRT   ; ADJUST BRIGHTNESS
00025'006001$             JSR     @.FCAL  ; CALL EDGE
00026'177777              EDGE
00027'000002              2
00030'000011'             EDGE1
00031'000010'             DUM
00032'020757              LDA     0,EDGE1 ; SET EDGE1 IN FMPOS
00033'006757              JSR     @AFSTA
00034'006760              JSR     @ABRST  ; SET EDGE1 IN BRGHT
00035'006756              JSR     @ABRT   ; ADJUST BRIGHTNESS
00036'020746              LDA     0,T1    ;MESSAGE- SCAN INITIALIZATION
00037'006567              JSR     @AWRT
00040'020745 SCAN1:       LDA     0,T2    ; MESSAGE- HOW MANY FRAMES?
00041'006565              JSR     @AWRT
00042'006745              JSR     @AGNUM  ; GET RESPONSE
00043'102400              SUB     0,0     ; CHECK FOR
00044'142405              SUB     2,0,SNR ;       BAD RESPONSE
00045'000773              JMP     SCAN1   ; BAD- RE-ENTER
00046'050565              STA     2,FRAME ; STORE IT
00047'020737              LDA     0,T3    ; MESSAGE- SCAN BEGINS
00050'006556              JSR     @AWRT
00051'020563              LDA     0,Z     ; ISSUE Z TO
00052'063044              DOC     0,44    ;       SCANNER
00053'060277 STFRM:       INTDS
```

```
0002  SCAN
 00054'020561          LDA     0,C60    ; WRITE END
 00055'061132          DOAS    0,MTA    ;        OF FILE
 00056'102400          SUB     0,0      ; FIRST = 1
 00057'101400          INC     0,0
 00060'040556          STA     0,FIRST
 00061'020556          LDA     0,ASUFF  ; SET UP
 00062'024556          LDA     1,BSUFF  ;        BUFFER
 00063'044556          STA     1,BUFF   ;        POINTERS
 00064'030556          LDA     2,WHLIN  ; SET UP LINE
 00065'050556          STA     2,HLIN   ;        COUNTER
 00066'030556          LDA     2,Y0     ; INITIALIZE Y
 00067'050556          STA     2,Y      ;        COORDINATE
 00070'034556          LDA     3,C20    ; BUFFER COUNTER
 00071'054556          STA     3,BUFLL
 00072'034564          LDA     3,C1     ; PRODUCE AUTO INCR.
 00073'162400          SUB     3,0      ;        ADDRESS
 00074'040021          STA     0,21
 00075'163000          ADD     3,0
 00076'072044 STLNE:   DOB     2,44     ; ISSUE Y COORDINATE
 00077'126400          SUB     1,1      ; CLEAR AC1
 00100'030550          LDA     2,C2     ; INITIALIZE BYTE
 00101'050550          STA     2,TWO    ;        COUNTER
 00102'030550          LDA     2,X0     ; INITIALIZE X
 00103'050550          STA     2,X      ;        COORDINATE
 00104'034550          LDA     3,PPLIN  ; INITIALIZE POINT
 00105'054550          STA     3,PLIN   ;        COUNTER
 00106'071144 CONT:    DOAS    2,44     ; ISSUE X COORDINATE
 00107'063644          SKPDN   44       ; WAIT FOR
 00110'000777          JMP     .-1      ;        SCANNER
 00111'070444          DIA     2,44     ; OBTAIN VALUE
 00112'034545          LDA     3,MASK   ; MASK TO
 00113'173400          AND     3,2      ;        ELEVEN BITS
 00114'151220          MOVZR   2,2      ; CONVERT TO
 00115'151220          MOVZR   2,2      ;        EIGHT
 00116'151220          MOVZR   2,2      ;        BITS
 00117'147300          ADDS    2,1      ; INSERT AND SWAP
 00120'014531          DSZ     TWO      ; FIRST OR LAST BYTE?
 00121'000406          JMP     .+6      ; FIRST- NO STORE
 00122'125300          MOVS    1,1      ; LAST- SWAP HALVES
 00123'046021          STA     1,@21    ;        AND STORE
 00124'126400          SUB     1,1      ; CLEAR AC1
 00125'030523          LDA     2,C2     ; RESTORE BYTE
 00126'050523          STA     2,TWO    ;        COUNTER
 00127'030524          LDA     2,X      ;INCREMENT X
 00130'034530          LDA     3,INCX   ;        COORDINATE
 00131'173000          ADD     3,2      ;        AND
 00132'050521          STA     2,X      ;        STORE
 00133'014522          DSZ     PLIN     ; LAST POINT IN LINE?
 00134'000752          JMP     CONT     ; NO- CONTINNUE
 00135'030510          LDA     2,Y      ; INCREMENT Y COORDINATE
 00136'034523          LDA     3,INCY
 00137'173000          ADD     3,2
 00140'050505          STA     2,Y
 00141'014506          DSZ     BUFLL
 00142'000444          JMP     SBFLL
 00143'024473          LDA     1,FIRST
 00144'125004          MOV     1,1,SZR  ; FIRST = 1?
 00145'000413          JMP     YES      ; YES
 00146'024473          LDA     1,BUFF   ; NO - SWAP POINTERS
```

```
0003  SCAN
 00147'040472          STA     0,BUFF
 00150'121000          MOV     1,0
 00151'024511          LDA     1,WDCNT
 00152'060244          NIOC    44
 00153'006510          JSR     @ACWRT   ; CHECK WRITE
 00154'024465          LDA     1,BUFF   ; SWAP POINTERS
 00155'040464          STA     0,BUFF
 00156'121000          MOV     1,0
 00157'000410          JMP     RITE
 00160'063622 YES:     SKPDN   MTA      ; WAIT FOR EOF WRITE
 00161'000777          JMP     .-1
 00162'126400          SUB     1,1      ;FIRST = 0
 00163'044453          STA     1,FIRST
 00164'060222          NIOC    MTA
 00165'060244          NIOC    44
 00166'060177          INTEN
 00167'060277 RITE:    INTDS
 00170'062022          DOB     0,MTA    ; ISSUE START LOCATION
 00171'024471          LDA     1,WDCNT  ; ISSUE WORD COUNT
 00172'067022          DOC     1,MTA    ;        TO MTA
 00173'024471          LDA     1,C50    ; ISSUE WRITE
 00174'065122          DOAS    1,MTA    ;        COMMAND
 00175'024444          LDA     1,BUFF   ; SWAP
 00176'040443          STA     0,BUFF   ;        BUFFER
 00177'121000          MOV     1,0      ;        POINTERS
 00200'024446          LDA     1,C20    ; BUFFER COUNTER
 00201'044445          STA     1,BUFLL
 00202'034454          LDA     3,C1     ; PRODUCE AUTO INCR.
 00203'152400          SUB     3,0      ;        ADDRESS
 00204'040021          STA     0,21
 00205'163000          ADD     3,0
 00206'014435 SBFLL:   DSZ     NLIN     ; LAST LINE?
 00207'000067          JMP     STLNE    ; NO- CONTINUE
 00210'060244          NIOC    44       ; YES - CHECK WRITE
 00211'020430          LDA     0,BUFF
 00212'024450          LDA     1,WDCNT
 00213'006450          JSR     @ACWRT
 00214'014417          DSZ     FRAME    ; LAST FRAME?
 00215'000407          JMP     .+7      ; NO- MOVE TO NEXT
 00216'020447          LDA     0,T4     ; DONE MESSAGE
 00217'006407          JSR     @AWRT
 00220'020410          LDA     0,AC0    ; RESTORE AC'S
 00221'024410          LDA     1,AC1
 00222'030410          LDA     2,AC2
 00223'002404          JMP     @RTN     ; YES- RETURN
 00224'006442          JSR     @AFMPS   ; MOVE FILM
 00225'000626          JMP     STFRM    ; RESTART SCANNING

                                        ; CONSTANTS

 00226'177777 AWRT:    WRITE
 00227'000000 RTN:     0
 00230'000000 AC0:     0
 00231'000000 AC1:     0
 00232'000000 AC2:     0
 00233 000000 FRAME:   0
 00234'003777 C:       3777
 00235'000060 C20:     60
```

```
0004  SCAN
 00236'000000 FIRST:   0
 00237'006357'wBUFF:   BUFF1
 00240'004357'BBUFF:   BUFF2
 00241'000000 BUFF:    0
 00242'000400 NNLIN:   400
 00243'000000 NLIN:    0
 00244'002400 Y0:      2400
 00245'000000 Y:       0
 00246'000020 C20:     20
 00247'000000 NUFLL:   0
 00250'000002 C2:      2
 00251'000000 TWO:     0
 00252'175400 X0:      -2400
 00253'000000 X:       0
 00254'000400 PPLIN:   400
 00255'000000 PLIN:    0
 00256'000001 C1:      1
 00257'003777 MASK:    3777
 00260'000012 INCX:    12
 00261'177735 INCY:    -12
 00262'174000 WDCNT:   -4000
 00263'177777 ACWRT:   CHWRT
 00264'000050 C50:     50
 00265'000342'T4:      TXT4
 00266'177777 AFMPS:   FMPOS

                                  ; MESSAGES

                TXT1:    .TXT     /<15><12>    SCAN INITIALIZATION/
 00267'006412
 00270'020040
 00271'020040
 00272'051503
 00273'040516
 00274'020111
 00275'047111
 00276'052111
 00277'040514
 00300'044532
 00301'040524
 00302'044517
 00303'047000
                TXT2:    .TXT     /<15><12>        HOW MANY FRAMES?
 00304'006412
 00305'020040
 00306'020040
 00307'020040
 00310'020040
 00311'044117
 00312'053440
 00313'046501
 00314'047131
 00315'020106
 00316'051101
 00317'046505
 00320'051477
 00321'020040
 00322'020040
 00323'020040
```

```
0005  SCAN
 00321'020040
 00322'020040
 00323'020000
                TXT3:    .TXT     /<15><12>         SCAN BEGINS/
 00327'006412
 00330'020040
 00331'020040
 00332'020040
 00333'020040
 00334'051503
 00335'040516
 00336'020102
 00337'042507
 00340'044516
 00341'051400
                TXT4:    .TXT     /<15><12>         SCAN DONE<7><7><7><7><7><
 00342'006412
 00343'020040
 00344'020040
 00345'020040
 00346'020040
 00347'051503
 00350'040516
 00351'020104
 00352'047516
 00353'042407
 00354'003407
 00355'003407
 00356'003400

       004000 BUFF1:   .BLK     4000
       004000 BUFF2:   .BLK     4000
                       .END
```

```
0001  SCANN
                                  ; MAIN PROGRAM FOR SCANNING FILM
                                  ;
                                  ; CALLED FROM A FORTRAN PROGRAM BY :
                                  ;        CALL SCANN
                                  ;
                                  ;
                                  ;
                          .TITL   SCANNER
                          .ENT    SCANN
                          .EXTN   TAPOS,CSKIP,FIPOS,SCAN
                          .EXTD   .CPYL,.FRET
                          .NREL
        000001            .TXTM   1

        000000            FS.=0

  00000'000000            FS.
  00001'006001$SCANN:     JSR     @.CPYL   ; ENTRY.
  00002'020422 BEGIN:     LDA     0,QUES1  ; TAPE POSITIONING?
  00003'024414            LDA     1,ATAPE
  00004'006414            JSR     @ASKIP
  00005'020443            LDA     0,QUES2  ; FILM POSITIONING?
  00006'024413            LDA     1,AFILM
  00007'006411            JSR     @ASKIP
  00010'020464            LDA     0,QUES3  ; SCANNING?
  00011'024411            LDA     1,ASCAN
  00012'006406            JSR     @ASKIP
  00013'020505            LDA     0,QUES4  ; MORE TO DO?
  00014'024407            LDA     1,ASTRT
  00015'006403            JSR     @ASKIP
  00016'006002$           JSR     @.FRET   ; RETURN

                                  ; CONSTANTS

  00017'177777 ATAPE:     TAPOS
  00020'177777 ASKIP:     CSKIP
  00021'177777 AFILM:     FIPOS
  00022'177777 ASCAN:     SCAN
  00023'000002'ASTRT:     BEGIN

  00024'000025'QUES1:     .+1
                          .TXT    /<15><12> IS TAPE POSITIONING DESIRED?
  00025'006412
  00026'020111
  00027'051440
  00030'052101
  00031'050105
  00032'020120
  00033'047523
  00034'044524
  00035'044517
  00036'047111
  00037'047107
  00040'020104
  00041'042523
  00042'044522
  00043'042504
  00044'037440
  00045'020040
```

```
0002  SCANN
 00046'020040
 00047'020000
 00050'000051'QUES2:   .+1
                       .TXT    /<15><12> IS FILM POSITIONING DESIRED?
 00051'006412
 00052'020111
 00053'051440
 00054'043111
 00055'046115
 00056'020120
 00057'047523
 00060'044524
 00061'044517
 00062'047111
 00063'047107
 00064'020104
 00065'042523
 00066'044522
 00067'042504
 00070'037440
 00071'020040
 00072'020040
 00073'020000
 00074'000075'QUES3:   .+1
                       .TXT    /<15><12> IS SCANNING DESIRED?
 00075'006412
 00076'020111
 00077'051440
 00100'051503
 00101'040516
 00102'047111
 00103'047107
 00104'020104
 00105'042523
 00106'044522
 00107'042504
 00110'037440
 00111'020040
 00112'020040
 00113'020040
 00114'020040
 00115'020040
 00116'020040
 00117'020000
 00120'000121'QUES4:   .+1
                       .TXT    /<15><12> DO YOU WISH TO CONTINUE?
 00121'006412
 00122'020104
 00123'047440
 00124'054517
 00125'052440
 00126'053511
 00127'051510
 00130'020124
 00131'047440
 00132'041517
 00133'047124
 00134'044516
 00135'052505
```

```
0003  SCANN
 00136'037440
 00137'020040
 00140'020040
 00141'020040
 00142'020040
 00143'020000

                    .END
```

```
0001  TAPOS
                                ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                ; POSITION THE MAGNETIC TAPE
                                ;
                                ; IF USED IN CONJUNCTION WITH DOS, THE
                                ; FILE DIRECTORY DATA WILL NOT CORRESPOND
                                ; WITH THE PRESENT TAPE POSITION
                                ;
                                ;
                        .TITL   TAPOS
                        .ENT    TAPOS
                        .EXTN   GTNUM,WRITE,CSKIP
                        .NREL
      000001            .TXTM   1
00000'054465 TAPOS:     STA     3,RTN    ; SAVE RETURN
00001'040465            STA     0,AC0    ; SAVE AC'S
00002'044465            STA     1,AC1
00003'050465            STA     2,AC2
00004'020477            LDA     0,TXT1   ; MESSAGE- TAPE POSITIONING
00005'006473            JSR     @AWRT
00006'020512 MORE:      LDA     0,TXT2   ; MESSAGE- ENTER COMMAND
00007'006471            JSR     @AWRT
00010'020530            LDA     0,TXT3   ; MESSAGE- (COMMAND CHOICES)
00011'006467            JSR     @AWRT
00012'006465            JSR     @AGNUM   ; GET COMMAND
00013'102400            SUB     0,0      ; CHECK FOR BAD
00014'142405            SUB     2,0,SNR  ;       RESPONSE
00015'000771            JMP     MORE     ; BAD- RE-ENTER
00016'020455            LDA     0,C4     ; CHECK FOR BAD
00017'142512            SUBL#   2,0,SZC  ;       RESPONSE
00020'000766            JMP     MORE     ; BAD- RE-ENTER
00021'050450            STA     2,CMND   ; STORE IT
00022'020450            LDA     0,C2     ; IS IT A
00023'112415            SUB#    0,2,SNR  ;       TWO?
00024'000435            JMP     RETRN    ; YES- RETURN
00025'020447            LDA     0,C1     ; NO- IS IT A
00026'040447            STA     0,TIMES  ;       ONE? (ALSO
00027'112415            SUB#    0,2,SNR  ;       SET TIMES=1)
00030'000410            JMP     MOVE     ; YES- DO MOVE
00031'020537 TAPO1:     LDA     0,TXT4   ; NO- MESSAGE- HOW MANY TIMES?
00032'006446            JSR     @AWRT
00033'006444            JSR     @AGNUM   ; GET NUMBER
00034'102400            SUB     0,0      ; CHECK FOR
00035'142405            SUB     2,0,SNR  ;       BAD RESPONSE
00036'000773            JMP     TAPO1    ; BAD- RE-ENTER
00037'050436            STA     2,TIMES  ; STORE IT
00040'020431 MOVE:      LDA     0,CMND   ; SHIFT COMMAND
00041'103120            ADDZL   0,0      ;       LEFT THREE
00042'101120            MOVZL   0,0      ;       BITS
00043'126400            SUB     1,1      ; ZERO AC1
00044'060277            INTDS
00045'067022 LOOP:      DOC     1,MTA    ; ISSUE ZERO WORD COUNT
00046'061122            DOAS    0,MTA    ; ISSUE COMMAND AND START
00047'070422            DIA     2,MTA    ; CHECK IF TAPE
00050'151203            MOVR    2,2,SNC  ;       READY
00051'000776            JMP     .-2      ; NO- WAIT
00052'014423            DSZ     TIMES    ; YES- DO IT AGAIN?
00053'000772            JMP     LOOP     ; YES- GO BACK AGAIN
00054'060222            NIOC    MTA      ; NO- CLEAR FLAGS
00055'060177            INTEN
```

```
0002  TAPOS
 00056'020542          LDA     0,TXT5   ; MESSAGE- ANY MORE?
 00057'024423          LDA     1,AMORE
 00060'005421          JSR     @ASKIP
 00061'020405 RETRN:   LDA     0,AC0    ; RESTORE AC'S
 00062'024405          LDA     1,AC1
 00063'030405          LDA     2,AC2
 00064'002401          JMP     @RTN     ; YES- RETURN

                                ; CONSTANTS
 00065'000000 RTN:     0
 00066'000020 AC0:     0
 00067'000000 AC1:     0
 00070'000000 AC2:     0
 00071'000000 CMND:    0
 00072'000002 C2:      2
 00073'000004 C4:      4
 00074'000001 C1:      1
 00075'000000 TIMES:   0
 00076'000116 CN:      116
 00077'177777 AGNUM:   GTNUM
 00100'177777 AWRT:    WRITE
 00101'177777 ASKIP:   CSKIP
 00102'000006'AMORE:   MORE

                                ; MESSAGES
 00103'000104'TXT1:    .+1
                       .TXT     /<15><12>    TAPE POSITIONING/
 00104'006412
 00105'020040
 00106'020040
 00107'052101
 00110'050105
 00111'020120
 00112'047523
 00113'044524
 00114'044517
 00115'047111
 00116'047107
 00117'000000
 00120'000121'TXT2:    .+1
                       .TXT     /<15><12>        ENTER TAPE COMMAND:/
 00121'006412
 00122'020040
 00123'020040
 00124'020040
 00125'020040
 00126'042516
 00127'052105
 00130'051040
 00131'052101
 00132'050105
 00133'020103
 00134'047515
 00135'046501
 00136'047104
 00137'035000
 00140'000141'TXT3:    .+1
                       .TXT     /<15><12>        1(RWD), 2(NONE), 3(FSF),
 00141'006412
```

```
0003  TAPOS
 00142'020040
 00143'020040
 00144'020040
 00145'020040
 00146'030450
 00147'051127
 00150'042051
 00151'026040
 00152'031050
 00153'047117
 00154'047105
 00155'024454
 00156'020063
 00157'024106
 00160'051506
 00161'024454
 00162'020064
 00163'024122
 00164'051506
 00165'024440
 00166'020040
 00167'020000
 00170'000171'TXT4:    .+1
                       .TXT    /<15><12>        HOW MANY TIMES?
 00171'006412
 00172'020040
 00173'020040
 00174'020040
 00175'020040
 00176'044117
 00177'053440
 00200'046501
 00201'047131
 00202'020124
 00203'044515
 00204'042523
 00205'037440
 00206'020040
 00207'020040
 00210'020040
 00211'020040
 00212'020040
 00213'020040
 00214'020040
 00215'020040
 00216'020040
 00217'020000
 00220'000221'TXT5:    .+1
                       .TXT    /<15><12>        POSITIONING DONE. ANY MOR
 00221'006412
 00222'020040
 00223'020040
 00224'020040
 00225'020040
 00226'050117
 00227'051511
 00230'052111
 00231'047516
 00232'044516
```

```
0004  TAPOS
 00233'042440
 00234'042117
 00235'047105
 00236'027040
 00237'040515
 00240'054440
 00241'046517
 00242'051105
 00243'057440
 00244'020040
 00245'020040
 00246'020040
 00247'020000
                    ..END
```

```
0001  WRITE
                                  ; THIS SUBROUTINE HAS BEEN DESIGNED TO
                                  ; OUTPUT A LINE OF TEXT TO THE TELETYPE
                                  ; USING THE PCHAR INSTRUCTION
                                  ;
                                  ; AC0 MUST CONTAIN THE LOCATION OF
                                  ; THE LINE TO BE WRITTEN
                                  ;
                                  ; THE LINE MUST BE WRITTEN IN TXTM 1
                                  ; FORMAT
                                  ;
                                  ;
                          .TITLE  WRITE
                          .ENT    WRITE
                          .NREL

00000'054430 WRITE:       STA     3,RTN    ; SAVE RETURN
00001'040430              STA     0,AC0    ; SAVE AC'S
00002'044430              STA     1,AC1
00003'050430              STA     2,AC2
00004'040431              STA     0,DDR    ; STORE ADDRESS
00005'022430 LOOP:        LDA     0,@DDR   ; OBTAIN TWO CHARACTERS
00006'010427              ISZ     DDR      ; INCREMENT ADDRESS
00007'024425              LDA     1,C177   ; MASK
00010'107400              AND     0,1      ; SECOND IN AC1
00011'122705              SUBS    1,0,SNR  ; FIRST IN AC0-ZERO?
00012'000412              JMP     END      ; YES
00013'006002              .SYSTM           ; NO-OUTPUT FIRST
00014'070000              .PCHAR
00015'000400              JMP     .
00016'121005              MOV     1,0,SNR  ; SECOND ZERO?
00017'000405              JMP     END      ; YES
00020'006002              .SYSTM           ; NO-OUTPUT SECOND
00021'070000              .PCHAR
00022'000400              JMP     .
00023'000762              JMP     LOOP     ; NEXT TWO
00024'020405 END:         LDA     0,AC0    ; RESTORE AC'S
00025'024405              LDA     1,AC1
00026'030405              LDA     2,AC2
00027'002401              JMP     @RTN     ; RETURN

                                  ; CONSTANTS

00030'000000 RTN:         0
00031'000030 AC0:         0
00032'000000 AC1:         0
00033'000000 AC2:         0
00034'000177 C177:        177
00035'000000 DDR:         0

                          .END
```

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