MASTER

DIGITAL COMPUTER ANALYSIS AND DISPLAY OF
THE RADIOISOTOPE SCAN

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INTRODUCTION

One of the most rapidly expanding areas in the field of medicine is the speciality of Nuclear Medicine. This speciality is concerned with the use of radioisotopes in both diagnosis and treatment. The diagnostic procedure most frequently employed is that of radioisotope scanning, a method used to map the localized distribution of a radio-nuclide within a specific organ of a patient.

The first report of the use of radioisotope scanning was by Cassen, et al in 1951. (21) The method employed was to give the patient ^{131}I and move a scintillation detector back and forth above the thyroid, recording the intensity of ^{131}I detected at each portion of the thyroid. Display of the information thus obtained was by dot recording, each dot representing a specific number of counts detected. (8)

At the University of Colorado Medical Center Radioisotope scanning is currently used to routinely obtain bone, bone marrow, brain, cardiac, liver, lung, placenta, renal, spleen, and thyroid scans.

Radioisotope scanning is presently accomplished by giving the patient a radioactive tracer whose chemical form will assure that it will go to the organ of interest. Examples of several specific radio-nuclide pharmaceuticals and their organs of interest are: ^{131}I and the thyroid $^{99}\text{TcSO}_4$ colloid and the liver; and ^{85}Sr and bone. The goal of the radioisotope scan is to determine the size and location of any area within the organ that has a different radioisotope distribution as compared to a normal organ.

Rectilinear scanners now use several methods of recording the

the collected information. One is the teledeltos tapper which is connected to the detector by a beam and makes a black mark on special paper each time the accumulated counts reach a preset number. The most common method is to have a small light source, connected to the beam, expose a piece of x-ray film. The intensity of the light source is controlled by a rate meter activated by the detector. The resultant film is a photo-scan.

Another method is to present the information in color. For the dot scan, a multicolor ribbon is placed between the tapper and controlled by the ratemeter (35, 36, 38). The color photoscan is normally made using an oscilloscope as a light source, obtaining the position of the detector by helipots, and interposing rate meter controlled color filters between the scope and polaroid film. (1) The advantage claimed for the color display is that it leads itself to visual perception of differences in count rate as low as one standard deviation. (46)

The major problem of radioisotope scanning is the interpretation of the resultant output. The decision must be made as to whether a specific area, as shown on the output scan, is normal or not. In this department one study in 1964 showed that the correct diagnosis was made in only 21 cases out of 30 where the patient was scanned and later proved to have a space occupying lesion of the brain. (47)

Many methods have been tried in order to increase the diagnostic effectiveness of the radioisotope scan. Among these are two methods that obtain radionuclide localization data in digital form and yet do not require the detector to be moved with respect to the organ of interest. They are the scintillation camera (2, 3) and the autofluoroscope. (5, 6)

Most of the experimental energy in the direction of radioisotope scan improvement has been channeled in the direction of the rectilinear scanner. The majority of the work has been directed at the output from the scan. Beck, et al, and Mac Intyre, et al, have used large focal spots on the photoscanner in order to "smooth" the resultant output to better visualize increased or decreased uptake. (4, 23, 44) A similar method was described by Fields, et al, to smooth the resultant data from dot scans. (29)

Harris and his associates have designed equipment to "rescan" photoscans. (32, 33) By the use of this method, the scan may have the contrast enhanced or the data may be converted to color. Others have then digitally processed the data. (48)

One of the major problems with the photoscanner output is that the technician does not know until the scan is completed and developed whether the scanner settings were correct. By the time this is determined, it may be too late to repeat the scan. One method used to overcome this problem is to record the signals from the pulse height analyzer on analogue magnetic tape. (11, 25, 56) The data may then be replayed with the correct settings or to obtain additional information.

The problem of whether or not an area has increased or decreased activity is essentially one of statistics. (13, 27, 28) In order to analyze the data statistically, a computer is a necessity. The information is usually stored in some computer compatible form using special equipment; either punched paper tape (7,14,26,39,41,64), magnetic tape (17,22,24,39,54), or cards. (37,40) The scanner may also be connected to a storage-display device as described by Kuhl (41,42,65), who uses a

cathode ray tube display and the ability to manipulate the data and Brill, et al, (40, 50) using a 4096 channel analyzer to store data and an isometric display unit. One of the newer scanners has a digital tape recording unit, and, although it is not computer compatible, it may be used to replay the scan, (34). Spencer has used an analogue computer to analyze the scan data. (58, 59)

OBJECTIVES

The trend in scanning is in the direction of better analysis and display of the data obtained from the radioisotope scanner in order to improve its diagnostic applicability. (53,55). By the use of statistics it may be possible to state the probability of a specific area of an organ radioisotope scan containing an increased or decreased amount of activity, as compared to the remainder of the organ or a normal composite.

The objectives of the current scanning project at The University of Colorado Medical Center are twofold. The first is to store the data from the scan in digital form and then analyze this data using statistical methods. (12,14,20,30,31) Several approaches to the analysis have been explored. The first is the original method suggested by Brown (12) in which each data point is compared to its neighbors. Our current method is that described by Sprau, et al (60, 62) in which the scan is "filtered" by overlaying each data point with a small scan of a point source. Work is now underway on methods similar to that described by Iinuma, et al (37, 49) in which the scan is corrected for the detector-collimator response by an iterative procedure.

The second objective is to present the digitally analyzed radioisotope scan in a graphical form as good or better than the forms currently available. Work on this portion of the project is presented in this report.

One of the additional advantages that may be obtained is to be able to visualize overlaying organs such as the liver-pancreas by the use of multiple isotopes and the subtraction of one scan from another. (10)

Another advantage along the same line is the comparison of serial scans of the same patient for diagnostic information or therapy analysis. (20, 57)

EQUIPMENT

The equipment that has been used in this study has generally been described elsewhere. (12,14-17,19,20,30,31) Only a brief summary of the data collection and processing components will be presented here.

The original method of recording the scan data consisted of an accumulator set for a preset time connected to the pulse height analyzer of a 3" scanner. A technician would read the numbers as they appeared into a dictaphone and also announce when the scanner reached the end of a line. A secretary then transcribed the data, and it was later keypunched and computer processed.

The second data collection method provided for the use of a punch paper tape unit connected directly to the accumulator. The unit would store counts for a preset time and was automatic in operation. Additional information such as end of scan, scan parameters, and patient data could be entered manually onto the paper tape. A scanner with a 5" diameter crystal later replaced the original scanner.

The next system consisted of an accumulator, intercoupler, and magnetic tape recorder connected to the scanner. Instead of being controlled by time, the accumulator was gated by the distance that the scanner detector moved in the lateral direction; either .1 or 0.05 inches. End of line was also recorded. This system, although well designed, did not work correctly for more than one week at a time during the year and a half that it was in use.

The present system was designed for use with an on-line computer. It consists of an eight-bit accumulator and signals to inform the computer when the scanner has traversed an increment or a line. The

system was modified recently to also provide exact lateral position data as well as lateral increments of .1, .05, and .025 inch.

There have been a total of six computer systems used during this study. The first was an IBM 709 with 10 magnetic tape units and a 32K core memory. Input/output was processed on a 12K IBM 1401 with a 1402 reader-punch, two magnetic tape units, punched paper tape input, a Calcomp 30 inch plotter, and 1403 printer. This system and the following two to be described were located at the University of Colorado Graduate School Computer Center in Boulder.

The second system was an IBM 7044 with a 32K core memory, six tapes, printer, reader-punch, and a large disk file. Input/output was also handled by the 1401 mentioned previously. This system was replaced after one year by a CDC 6400 computer having a 32K (later increased to 64K) memory, 6 tape units, reader-punch, two line printers, disk files, and a microfilm plotter. This system also has the capabilities of remote batch processing from the University of Colorado Medical Center.

The facilities at the Colorado State University Computing Center (IBM 1401, CDC 6400) were used for several special programs due to the nature of the operating system employed. The major work done here was to rewrite magnetic tapes that had been produced using the scanner interface.

Two systems have been used at the Medical Center, the first for three months and the second for over one and a half years. An IBM 1130 with one disk and reader-punch was used to prepare programs while waiting for the second system to be installed. This computer has also been used to demonstrate computer applications at various scientific meetings.
(15, 16, 18, 19)

The present system consists of an IBM 1800 Data Acquisition and Control System. It currently has a 32K memory, two magnetic tape units, three disks, reader-punch, printer, two typewriters, two typewriter-keyboards, and a Calcomp 30 inch plotter. Data from the scanner goes directly to the computer. Storage space on the disk units (512,000 words/unit) allows data from about 100 scans to be retained. This data may then be transferred to magnetic tape for permanent storage.

TWO DIMENSIONAL PRINTER DISPLAYS

The easiest method of digital scan data presentation is to present the data via the computer printer. In general, position denotes the location of a detected amount of activity and amount is signified by the numeric value, density, or color of the character. Figure 4.1 displays data from a liver scan that has been "smoothed" and the count rates adjusted for values between 0 and 9. When printed, the zero values are suppressed. This is a normal anterior liver scan and shows slight splenic uptake. This is one of the simplest methods to present digital data and has been used in other fields. (43)

The most successful computer printer displays produced to date are those where characters of varying density are substituted for the various count rate levels. The initial character set used consisted of a blank, plus sign, asterisk, and H's overprinted with I's. (12) Character sets using four levels have been reasonably successful. An example is shown of a four level printout in Figure 4.2.

The maximum number of levels that we have worked with on scan data is ten. Figures 4.3 and 4.4 denote eight and ten level scan data displays, (20) The data in Figure 4.4 is the same as that in Figure 4.1. The character sets used are (blank, +, I, A, R, Q) and (blank, +, I, Y, A, R, Q) respectively. These figures also show the ability of the computer to enhance contrast. The data used in the upper portion is 100, 90, and 80 percent (left to right) while the lower portion denotes 70, 60, and 50 percent of the original data. This is accomplished by deleting the lower ten percent of the data for each subsequent view and distributing the levels equally among the remaining data. Figure 4.4, is data from a liver scan, reversed here, probably demonstrating cirrhosis.

Several investigators have worked with as many as 17, 20, 32, 64 and 100 levels. (51, 52, 63) There is no reason why this number of levels could not be used with the radioisotope scan data as several have done. However, the preliminary evaluation of this project tended to show that no additional information, with regards to scan diagnosis, was transmitted to the viewer by more than four levels as long as contrast enhancement and multiple printouts were used.

All of the displays discussed above used standard computer line printers with ten characters per inch and either six or eight lines per vertical inch.

Another approach that was explored was the use of special symbols. A set of characters was designed (by Dr. D. W. Brown) with the objective of providing increasing density. There are ten characters, including the blank, in this set.

While these characters were being manufactured on a special Selectric typewriter ball, an analysis of the expected optical density was performed. Each character was drawn to scale using india ink on translucent paper. The density of each character was then measured using an optical densitometer with a $\frac{1}{4}$ inch diameter field of view. Five measurements were made on each symbol and a regression line was then fitted to all of the data. The results of this analysis are shown in Figure 4.5 along with the actual characters. The characters are typed at the extremes of their densitometer measurements. As can be seen, character two was denser than any of the next three higher characters and character seven more dense than character eight.

A set of data was constructed to further examine this character set. It consists of three overlying gaussian curves denoting three points of activity. A two dimensional display of this data using the special symbols was then made. It was found that the display showed more contrast if additional sheets with carbon paper were used and one of the carbons viewed. Figure 4.6 shows one of the results of this approach. It was produced on an IBM Selectric typewriter and used the data set mentioned previously, which is shown in Figure 4.7.

Very little use of these symbols has been made to date with actual scan data. The initial problem was that after computer processing the digital data had to be typed by hand. The number of typing errors that were made caused this type of presentation to be useless for comparison with other display forms. A second attempt to assess the value of this symbol set was made by substituting the use of an IBM 1050 Remote Terminal with card reader for the Selectric typewriter. Output from the computer was in the form of cards with the correct format to operate the 1050 equipped with the special Selectric element. A sample of the output from this device is shown in Figure 4.8.

The most recent work with the special symbols has been done using one of the 1816 terminal on the IBM 1800. An attempt has been made to design a second set of characters that would have increasing density and overcome some of the problems of the first. It was decided that the character to denote the lowest range of activity would be a box drawn around eighty percent of the available typewriter character space. The densest character would have lines drawn within this box. The length of the lines for the box was .4267 inch and the total length of all lines for the densest character was 1.4370 inch. The difference was then

logarithmically divided to allow design of seven additional characters. A plotter representation of what this character set might produce is shown in Figure 4.9, using the data of three high points. More experimental work will be done along this line after the Selectric element is manufactured.

Figure 4.3

DENSITY OF SPECIAL SCANNING SYMBOLS

Fitted function $Y = 0.031 + 0.04309X$
 $r = 0.956$

Figure 4.5

Figure 4.6

DATA SET 1 THREE HIGH POINTS

ORIGINAL WITH TWO CARBONS AND BACKING SHEET
 PRESSURE 4 4/11/66

Figure 4.8

Figure 4.9

TWO DIMENSIONAL PRINTER DISPLAYS COMBINED WITH PHOTOGRAPHY

In order to gain additional contrast on the radioisotope scan data displays several methods utilizing photography were investigated.

The first experimental method required nine separate computer printout sheets for each scan view. Printout one had a symbol printed for each location where the activity was from 10 to 100 percent. A photograph of printout sheet one was then made. Next, using the same negative, the second printout sheet with a symbol at each location for 20-100 percent was placed in exact registry with the first, and photographed. This method was used to photograph all nine printout sheets on a single negative.

An example of the resultant display of this method is shown in Figure 5.1. The data used for this display consists of the gaussian curves denoting three high points of activity discussed in the previous section. As can be seen in this figure, the higher the activity at any location, the denser the symbol appears.

The equipment used for this study included a copier-enlarger using $2\frac{1}{4}$ " x $3\frac{1}{4}$ " sheet film, a lab timer for control of the copy lights or copier-enlarger, two sets of movie illumination lights each with three flood light bulbs, and a variable transformer for use with the copy lights. The lights were mounted one on each side of the copy camera and at a 45 degree angle to the material to be photographed. Light intensity was adjusted over the copy surface by the use of a photocell connected to an ohm meter. For most of the work, voltage to the copy lights was set at 35-45 volts.

Each sheet of computer printout was produced with a period printed

at each end of the top line. Registry for photography was then easily accomplished by inserting needles through the periods on each of the nine sheets. The needles were then inserted into a piece of particle board and the board adjusted until the sheets were in the correct position. Film was inserted into the copier, the lights turned out, and the shutter opened. The copy lights were then turned on, controlled by the timer. Times ranged from 1 to 15 seconds. When the copy lights went off, the top printout sheet was removed from the needles. All nine sheets would then be photographed on the same negative.

A photograph of data from a liver scan is shown in Figure 5.2. This is the same data as seen in Figure 4.2 and described in the previous section. In order to make the resulting display more closely resemble the photoscan that the radiologist is used to viewing, the negatives were printed off-focus. An off-focus print of the negative used in Figure 5.2 is shown in Figure 5.3. The vertical light and dark lines are computer printer artifacts. Figure 5.4 shows both focused and off-focused photographs of data from a lung scan. They were printed from the same negative.

Another method of printing these negatives was by the use of a piece of ground glass in contact with the printing paper. This method seemed to accentuate the dense areas and eliminate the lighter. A print of the previous lung scan is shown in Figure 5.5. The liver scan negative used to produce Figures 5.2 and 5.3 was also printed by this method and is shown in Figure 5.6.

The final experimental method of printing that was used was to print the negative through a screen consisting of a fine mesh of clear dots. The data from Figure 5.4, a lung scan, is shown printed by this

method in Figure 5.7. As can be seen, a great deal of detail is lost and the contrast is not enhanced. The goal of this method was to remove all traces of the character or characters used to computer print the data.

This method, the use of photography and computer output, has the advantage of providing contrast by the use of the same character. Also contrast may be easily adjusted by varying the length of exposure for each sheet, or holding the exposure time constant, varying the intensity of light used.

Another advantage is that this method, especially when off-focus printing is used, presents the data in nearly the same form as a regular photoscan. This helps in comparing the original data with the computer processed and statistically analyzed output.

The disadvantages are several; lack of contrast, uneven intensity across the whole photograph, vertical printout artifacts, length of time required to produce a single scan view, and cost.

Although high contrast film and developer was used, contrast still was not as good as it could be. Additional work along this line would certainly improve the contrast.

The best method for copy lights would probably consist of fluorescent lights, although they were not tried in this study. The problem with the six-light system employed was that no matter how these lights were arranged, there were still areas that were lighter or darker than the average as shown by the photocell-ohm meter and seen on the accompanying figures of this section. Back lighting, with the use of a

light box, was tried, but was not successful.

Each set of scan data usually requires several photographic sessions to obtain good contrast and intensity. The procedure varies greatly depending on how dense the printer characters were and type and color of computer paper used.

Fig 5.1

The image consists of two large, dark, irregular shapes positioned side-by-side, resembling silhouettes of people or large objects. These shapes are composed of many small, dark, rectangular blocks, giving them a pixelated or segmented appearance. The background is white. The shapes are roughly triangular or trapezoidal in overall form, with the right shape being slightly taller and more complex in its internal structure than the left one. The overall effect is that of a high-contrast, black-and-white scan or a stylized graphic representation.

Figure

Figure 5.5

Figure 5.6

Figure 1

ISOMETRIC PRINTER DISPLAYS

Several methods of using an isometric display of the scan data and the computer printer were tried and are discussed in this section. An isometric display of an object is one in which the frontal plane is viewed directly but the other planes are seen at an angle. This requires that the object to be visualized must have three dimensions. For the data used in these experiments, two dimensions were the lateral and longitudinal positions. The third dimension was taken to be the activity at each specific location.

The isometric visualization of the data that contains three high points is shown in Figure 6.1. (20) The data are first constructed as a two dimensional isometric plane. Each point is then raised above this base plane an amount proportionate to the activity at this point. The base plane visualization is shown as Figure 6.2. The symbol corresponding to the activity is then printed at this location above the base plane.

An easier way to visualize the activity planes in an isometric display is to outline then darken the area below the plane as if there was illumination from above the object. Figures 6.3 and 6.4 demonstrate this method of display. The disadvantage here is, of course, the time required to outline the planes. The computer could be programmed to perform this function, but it would still require a long time. Figure 6.3 is data from a liver scan and Figure 6.4 is a pancreas scan. Both of these sets of data have been previously displayed and discussed.

The isometric may also be constructed with one character by using the photographic method described in the previous section. Figures 6.5

and 6.6 show isometric views of the same lung scan. The latter was printed off-focus with the same negative. Again a screen may also be used with off-focused printing. Both a two-dimensional and isometric view printed through a fine dot screen are shown in Figure 6.7. The liver scan previously discussed is shown in Figure 6.8 and 6.9. (20)

Another method that was only demonstrated and not experimented with beside the single display shown in Figure 6.10 is to slice the isometric view in half before output. This figure shows the same lung scan as in the previous example but only the upper portion is processed by the computer. This method allows easy visualization of the activity at any cross-section location in an organ while still presenting data on the rest of the organ localization.

The two general disadvantages of the printer isometric display are that the display is hard to interpret and increases or decreases in activity over small areas are difficult to see especially if they are in the "back" of the display. Both of these disadvantages are absent when the isometric is presented by a plotter as will be discussed in the next section.

ORIGINAL WITH ONE CARBON
AND BACKING SHEET

DATA SET 1 THREE HIGH POINTS
POINT RAISED TWO SPACES FOR EACH INCREASE
IN ACTIVITY. PRESSURE 4, 4/13/66

Figure 6.1

BACKGROUND ARRAY FOR TYPEWRITER DISPLAY _ 80 x 40 MATRIX

Figure 6.2

Figure 6.3

PANCREAS SCAN 193 MICROCURIES OF SE-75
26050 17-6-65 1.66 45.0 0.42 9.5
4 34 -4 14

Figure 6.4

Fig 5.6

Figure 6.8

Figure 6.9

Figure 6.10

PLOTTER DISPLAYS

Both two dimensional and isometric displays may be produced by a plotter connected directly to the computer. The two dimensional display was not programmed during this study because it was felt that the printer display was adequate for this type of presentation. However, several other investigators have presented two dimensional isodose plot displays (4, 23, 26, 54, 64).

All of the work discussed here concerns isometric displays although other types of displays will be mentioned later. The display shown in Figure 7.1 is of the three high points data. The isometric angle is thirty degrees and all lines of the figure are shown. Although all of the information is shown, it is extremely difficult to interpret, especially the information on the "back" of the display. If the display is conceived of as a solid figure, it may then be plotted showing only those lines that would normally be seen in viewing a figure of this type. This method is shown in Figure 7.2, using the same data, a sixty degree isometric angle ten percent background cutoff (the lowest ten percent is not plotted), and horizontal only line plotting. Additionally the maximum activity is raised only one-third as high as compared to Figure 7.1.

An isometric plot of the liver data previously described is presented in Figure 7.3. (20) The data consists of the activity ranking (integers 0 to 9) as did the data for the previous two figures. This is what gives the display the "stepped" appearance. If the original data is plotted, the display has a much smoother appearance. Hidden lines are plotted, but the height for the maximum activity above the base plane and the isometric angle, sixty degrees, have been chosen so that almost all of the detail is visualized as can be seen by comparing this

figure with previous displays of the same data.

In general, the additional plotting time required to connect points along the same row as well as the same column did not seem to be justified. Figures 7.4 and 7.5 are plotted from the same data, a scan of a one millimeter diameter point source of ^{131}I . The hidden lines have been removed and the lines connected by methods to be described in a later section.

Data from a normal lung scan are shown in Figure 7.6. The isometric was plotted with a sixty degree angle with maximum activity raised one inch above the base plane. A background cut-off of five percent was used. Figure 7.7 was plotted using the same data and parameters except the height of maximum activity was doubled. Note how much better the apices are visualized in Figure 7.6. No data smoothing or filtering was used on this data or the following two displays.

Figures 7.8 and 7.9 are isometric plots of another lung scan. The first has the hidden lines removed while the second has a ten percent background cut-off and all lines are plotted. As may be noted hidden lines are not a problem as long as isometric angles and maximum height above the base plane are chosen correctly.

Work with phantoms is becoming a major portion of this project in order to help statistically analyze the scan data. One phantom in use consists of a point source that may be covered by a varying amount of radioactive or non-radioactive solution. Figure 7.10 shows an isometric display of data from this phantom. The amount of activity present in the pool in the lower left is approximately five times

that in the point source. The pool extends with decreasing amounts to the right and the upper left.

The isometric display has been one of the best to be analyzed during this study. It allows examination of activity levels without regard to contrast restrictions. By correct choice of the several parameters (isometric angle, background cut-off, plotting directions, suppression of hidden lines, and maximum height above the base plane) any or all of the detail of the scan may be easily visualized. Although not displayed here, the scan may be rotated so that any side desired may be shown at the front. (45)

The only major disadvantage of the isometric display is the amount of time required to plot it. This will range from ten minutes to several hours depending on the amount of data present and plot size required. There are several possible methods that could overcome this problem. One is the use of a microfilm plotter connected to the computer. An example of an isometric display of a normal thyroid scan is shown in Figure 7.11. The thyroid is shown visualized as if one were looking at it from the head down.

Another method that has been proposed but not yet investigated, is the use of a storage oscilloscope or television display connected to the computer. The purpose for this method would be to allow the viewer to adjust the previously discussed parameters for the best scan detail visualization. Additionally the scan data might easily be rotated.

Figure 7.1

40 BY 80 ARRAY WITH THREE HIGH POINTS.

Figure 7.2

Figure 7.3

Figure 7.4

Figure 7.5

IBM-MAYO DATA SCAN 1

Figure 7.6

IBM-MAYO DATA SCAN 1

Figure 7.7

Figure 7.8

IBM-MAYO DATA SCAN 2

Figure 7.9

IBM-MAYO DATA SCAN 2

Figure 7.10

Figure 7.11

DATA "SMOOTHING"

As more work was done with isometric data displays it was evident that a method of smoothly connecting adjacent data points would be helpful. The initial work was done by connecting points as shown by the solid line in Figure 8.1. A better presentation would be made if the points were connected as shown by the dotted line.

Instead of using standard smoothing techniques which generate smoothing functions that do not pass through all (or may not pass through and) of the data points, a technique was developed which passed through all the data points and yet has the appearance of a smooth curve.

First the points used must meet the following criteria:

- 1) The X distance between points must be the same for all points.
- 2) All X and Y values must be positive.
- 3) The number of data points in a row must be ≤ 4 .

The procedure for generating a connector line between any two points, n and $n + 1$, of a row of m points is as follows. A function of the type $Y = A + BX + CX^2 + DX^3$ is fitted to the data points $n-1$, n , $n + 1$, and $n + 2$. Since the function contains four unknowns and four data points are used, there is a unique solution. Using this equation, a line is plotted between points n and $n + 1$. The same procedure is then used to connect $n + 1$ and $n + 2$, using points n , $n + 1$, $n + 2$ and $n + 3$. This method is used to connect points 2 through $m - 1$. To include the first and last points, the first function obtained is used to connect points 1 to 2 and 2 to 3, and the last used to connect points $m - 2$ to $m - 1$ and $m - 1$ to m .

By making the x distance between points the same in all cases, it

is necessary to solve only four equations for the four unknown coefficients. The equations are shown below for assumed x values of 0, 1, 3, and 3 for Y(1), Y(2), Y(3), and Y(4), respectively.

$$A = Y(1)$$

$$B = -1.833 Y(1) + 3 Y(2) - 1.5 Y(3) + 0.33333 Y(4)$$

$$C = Y(1) - 2.5 Y(2) + 2 Y(3) - 0.5 Y(4)$$

$$D = 0.16667 Y(1) + .5 Y(2) - .5 Y(3) + 0.16667 Y(4)$$

The curve may then be plotted between the two points Y(1) and Y(2).

HIDDEN LINES

Hidden lines have been removed from some of the isometric plots of scan data by a simple but costly (computer memory-wise) method called rising horizon. This method divides the total X distance of the graph into a number of increments. Plotting then starts at the first line of the scan and proceeds in a positive X direction as shown in Figure 9.1.

A vector consisting of the highest y value for each x increment is kept in the computer memory. Before the pen is moved to the next x increment, the y value for that x position is compared to the y value stored for position. If the new value is greater than the stored value, the new value is stored and plotting is accomplished. If it is lower than the stored value, plotting is suppressed.

When plotting in both horizontal and vertical directions is desired, the plotting pattern is as shown in Figure 9.2.

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