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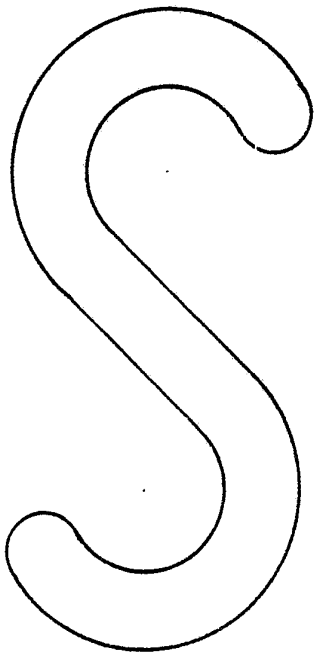
(54) Title: METHOD AND APPARATUS FOR REPRESENTATION OF A CURVE OF UNIFORM WIDTH

(57) Abstract

A graphic arts method and apparatus for representation on suitable media of curves having uniform widths. A method and apparatus of the present invention converts curve figure data into a reduced data set which defines a plurality of interconnected curve segments (44) defined by second order parametric Bezier curves (44) and straight line segments (80, 82). Each of the curve segments (44) is converted into a plurality of straight line segments (80, 82) closely approximating the shape of the associated curve segments (44). The vertices (22) of rectangles associated with each of the straight line segments (80, 82) are then determined such that the rectangles have a width substantially equal to the required width of the curve (24). The rectangle data is then presented upon suitable media (30) as an image which closely approximates that of a curve having uniform width.



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METHOD AND APPARATUS FOR REPRESENTATION OF A CURVE OF UNIFORM WIDTH

Technical Field

The present invention relates generally to the field of computer aided graphic arts. More specifically the invention relates to a method and apparatus for representation of and recreation of lines or curves having a predetermined, uniform width.

Background of the Invention

Computer aided or generated graphics systems are used in a wide range of applications, including information display, creation of images for photographic and printing applications, and computer aided design and manufacturing of a wide variety of products and components. Creation of two dimensional figures via a display media is currently accomplished in the computer aided graphic arts by storing large amounts of digitized figure coordinate data. Current systems of this type are subject to certain problems in terms of the size of memory required to store a particular figure, computation time for reconstructing the figure from the stored data, and flexibility of application in terms of ability to handle arbitrary shapes, as opposed to a limited number of predetermined shapes, and flexibility in editing and manipulating these shapes.

In these prior are systems, curve fitting or smoothing of figure data, if performed, is accomplished as a post processing step and not in real time while the figure is being created. Due to the large number of coordinates required to represent a particular figure, temporary storage of a large amount of data is necessary requiring a large amount of storage media and a

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significant amount of extra time to process the stored data.

After the digitized figure data is stored, algorithms must be used to convert the data to an acceptable format for presentation via a display medium or viewing device. The algorithms utilized for this purpose depend heavily upon the data base used to define the figures. Many display formats such as raster and run encoded, do not allow for efficient linear transformation of the digitized figure data. Polygonal approximation formats do not guarantee smooth edges when subjected to a transformation. Furthermore, transformation time is comparatively long due to the fact that all of the figure data must be individually transformed.

These limitiations of prior art computer graphic systems are especially apparent in the field of phototypesetting, where high speed operation and the ability to faithfully reproduce a wide variety of character fonts and special systems have been limited in their performance in these criteria.

In a prior application, a method and apparatus for representation of a two dimensional form on a media was disclosed which solved may of the above problems. However, there is still the problem of recreating a curve or two dimensional form of uniform width such as the border line around a two dimensional form. In addition, there is a problem of maintaining the curve width uniformity when scaling, rotating, reshaping, etc. the two dimensional form.

The present invention solves these and many other problems present in the computer aided graphic arts.

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Summary of the Invention

The present invention relates to a method in apparatus of providing a grahical representation of a curve with a uniform width. The present invention utilizes a set of data points generally lying along the curve by converting the data points into second order parametric equations which define a plurality of adjoining curve segments closely approximating the curve. The present invention further includes method and apparatus for converting the curve segments into straight line segments and defining in association with each of the straight line segments the vertices of a rectangle having a width equal to the width of the curve.

A particularly advantageous feature of the present invention is the provision of the ability to readily scale, rotate, reshape, etc. graphic presentations while present on a medium without disturbing the uniform width thereof.

These and various other advantages and features of novelty which characterize the invention are pointed out with particularity in the claims annexed hereto and forming a part hereof. However, for a better understanding of the invention, its advantages, and objects obtained by its use, reference should be had to the drawings which form a further part hereof, and to the accompanying descriptive matter, in which there is illustrated and described a preferred embodiment of the invention.

Brief Description of the Drawings

In the drawings, in which like reference numerals and letters indicate corresponding parts throughout the several views,

FIGURE 1 is an illustration of the letter "s";

FIGURE 2 is a curve series representation of the letter "s";

FIGURE 3 is a diagramatic figure of a computer based graphic system;

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FIGURE 4 is a representation of the letter "s" input data received from an input device;

FIGURE 5 is a representation of three segments S1, S2, S3;

FIGURE 6 is a representation of two adjacent nodes and their associated control points;

FIGURE 7 is a representation of control line orientation;

FIGURE 8 is a representation of a Bezier curve between two adjacent nodes;

FIGURE 9 is a diagramatic representation of control points and nodes defining a letter "s";

FIGURE 10 is a diagramatic representation of Bezier curve deviation from actual input data;

FIGURE 11 is a diagramatic representation of the Bezier curve splitting process;

FIGURE 12 is a diagramatic representation of the distance computation between a portion of a Bezier curve and a corresponding polygon straight line segment approximation;

FIGURE 13 is a diagramatic representation of rectangle formation;

FIGURE 14 is a diagramatic representation of rectangle and circle formation;

FIGURE 14a, b are diagramatic representation of polygon definition for circles;

FIGURE 15 is a diagramatic representation of a closed curve;

FIGURE 16 is a diagramatic representation of flexer modification;

FIGURE 17 is a diagramatic representation of vertex modification;

FIGURE 18 is a diagramatic representation of a processing sequence of the present invention; and

FIGURES 19 through 22 are examples of curve series editing.

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Detailed Description of the Preferred Embodiment

For purposes of this application, a curve series is defined as a plurality of interconnected curves wherein the curves are defined by second order parametric Bezier curves and straight line segments. The present invention provides a computer based system for providing a curve series of substantially uniform, predetermined width.

Illustrated in FIGURE 1 is an arbitrary form which in this instance approximates the letter "s". Shown in FIGURE 2 is a curve series representation of the letter "s". Note that the curve series is defined by a series of vertices or node points 22 interconnected by a series of curves 24. In this particular example there are six curves, 24 and seven node points 22. The present invention enables the curve series of FIGURE 2 to be provided with a uniform width therealong so as to closely approximate the letter "s" as shown in FIGURE 1.

As illustrated in FIGURE 3, two dimensional figure data is normally obtained from an input device 26 such as a digitizing tablet. The figure data in turn is processed by a computer 28 in accordance with the present invention which in one embodiment of the present invention is a PDP 11/34 or PDP 11/23. The resulting data is then output to a display medium 30 for visual presentation of the figure for which the data was received and processed. Examples of the types of display media which might be utilized are raster scan frame buffer displays, film recorders, plotters, etc.

In one embodiment of the present invention, figure data is obtained from a digitizing tablet. The raw figure data represents coordinate positions 32 representative of the figure as illustrated in FIGURE 4 where the figure "s" data is illustrated. As the figure coordinate data 32 is obtained, the slope between two adjacent points is calculated. Those coordinates which are

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determined to be X maxima or minima, Y maxima or minima, inflection points, and start and end points are saved and designated as node points 22. Note that in order to determine when there is an inflection point, the slope data (S1, S2, S3) for three consecutive pairs of points 32 is saved. If either of the following conditions are met then there is an inflection point:

1) $S1 > S2 < S3$

2) $S1 < S2 > S3$

When an inflection is detected, the midpoint 33 of the middle segment having slope S2 is used as the actual inflection point and is saved as the node point 22. Illustrated in FIGURE 5 is an example of the first condition.

In FIGURE 6, a group of data points 32 two of which are node points 22 is shown. At any given time during the processing of figure data, data points 32 lying on a span between adjacent nodes 22 are saved as is one data point 32 on either side of this span. When two adjacent nodes 22 are detected, a slope control point 36 is determined by the intersection of two control lines or frames 38. Control point 36 thus lies at the vertex of a triangle 40 defined by control lines 38 connecting nodes 22 to control point 36 and a base line 42 interconnecting nodes 22.

As shown in FIGURE 7, each control line 38 has the same slope as and is parallel to the line 39 interconnecting data points 32 on either side of node 22 through which line 38 extends. The two nodes 22 and control point 36 may then be used to define a Bezier curve 44 as illustrated in FIGURE 8 which approximates that of the figure boundary between adjacent nodes 22 as defined by data points 32. Control point 36 and nodes 22 are then stored in memory and the data points 32 are discarded

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except for the data point 32 immediately preceding the last node 22 detected.

Subsequent data coordinate positions 32 are then saved until a subsequent node 22 is detected at which point the processing on this set of data is performed. This processing continues for each pair of nodes 22 detected until the entire boundary of the curve series has been defined and/or terminated by the operator.

Each Bezier curve 44 is tangent to the control frames 38 at nodes 22. The Bezier curve between adjacent nodes 22 is defined by the following parametric equations:

$$X = P_0 + P_1 Z + P_2 Z^2$$

$$Y = Q_0 + Q_1 Z + Q_2 Z^2$$

Where: Z varies from 0 to 1 and where P_0, P_1, P_2, Q_0, Q_1, Q_2 are defined as follows:

$$P_0 = X(i)$$

$$P_1 = 2[Xc(i) - X(i)]$$

$$P_2 = X(i) - 2Xc(i) + X(i+1)$$

$$Q_0 = Y(i)$$

$$Q_1 = 2[Yc(i) - Y(i)]$$

$$Q_2 = Y(i) - 2Yc(i) + Y(i+1)$$

Xc(i), Yc(i) are control point coordinates between adjacent nodes whose coordinates are X(i), Y(i) and X(i+1), Y(i+1)

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As illustrated in FIGURE 9, node points 22 and control points 36 which are stored in memory define the curve series, in this case representative of the letter "s". Note that the dots illustrate the outline of the resulting Bezier curves 44.

The above described curve fitting processing is performed in real time as the figure data is received from the input device. In another embodiment of the present invention, selective figure data is obtained and saved in memory for later processing as desired.

The final data set which is saved in memory for representation of a given curve series includes all the detected nodes 22 and their associated control points 36. This requires much less memory than the storage of all figure data points 32 and minimizes delays due to the processing of such a large data set. Furthermore, the data set requiring transformation processing for display purposes is reduced and easier to operate on. In addition, a smooth figure boundary can be presented at any resolution at the display media.

In one embodiment of the present invention, when a span between nodes 22 is completed, the resulting Bezier curve 44 is compared with the corresponding figure data 32. If the deviation is greater than a specified threshold value, a node 22 will be added and the Bezier curve will be divided into two Bezier curves. The resulting Bezier curves are similarly tested in a recursive fashion until the threshold value is achieved.

To reduce the computational burden of generating the actual Bezier curve for the fitting test which is performed in real time, the properties of the Bezier polygon (triangle) are used to estimate the maximum deviation from the actual data. As indicated in FIGURE 10, a flexer point 46 of maximum displacement of Bezier curve 44 from base 42 of triangle 40 may be quickly computed

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from the triangle geometry. The point 48 of maximum figure data displacement from base 42 of triangle 40 is easily computed by checking for the intersection of a line 50 with a line 52 which extends from control point 36 to a point at the midsection of base 42 of triangle 40. Line 50 is defined by the two data points 32 closest to line 52 and on either side thereof. The distance between points 46 and 48 is then computed and compared with the predetermined threshold to see of a subdivision is necessary.

If a subdivision is required, a node 22a is inserted at point 46 and then control points 36a, b on either side are defined at the intersection point of line 50 with sides 38 of triangle 40 as illustrated in FIGURE 11. The Bezier curve math may then be performed in each of the two new Bezier curves 44a, b and compared with the predetermined threshold. Further Bezier curve splitting may be carried out in a recursive fashion until the threshold is met and the desired accuracy of fit is derived between Bezier curves 44 and data points 32.

Many display systems utilize polygons as a painting primitive. Therefore, it is necessary, in those cases, to convert the curve series data comprising vertices 22 and control points 36 to polygon data which can then be processed as the painting primitive.

One way to accomplish this is to convert the curve series data to a series of straight line segments which can then be converted to polygon data. The polygon data includes the coordinates of the polygon vertices. The coordinates of the polygon vertices are derived by substituting evenly incremented values of Z between zero and one into the Bezier curve parametric equations of each Bezier curve defining the edges of the curve series represented.

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The resultant polygon must have a sufficient number of vertices such that the polygon edges will appear smooth on the display device. However, the number of vertices needed per Bezier curve 44 between adjacent nodes 22 for a smooth appearance should be maintained at a minimum to reduce the computational time for generating the vertex list, clipping the resultant polygon, and scanline conversion of the polygon. The minimum number of vertices required to assure a smooth appearance will depend on the resolution of the viewing device, the length of the span between nodes, the radius of curvature at each point along the span, etc.

In one embodiment of the present invention as illustrated in FIGURE 12, the number of vertices or straight line segments required for a given Bezier curve is determined by measuring the distance E between a point C lying on the Bezier curve 44 between two adjacent vertices V_0, V_1 and a point L lying on a polygon line segment 86 between vertices V_0, V_1. The X, Y coordinates for C and L, (Cx, Cy) and (Lx, Ly) are defined by the parametric equations defining the Bezier curve wherein the points C and L represent an incremental value of Z which is only one half that between vertices V_0, V_1:

$$Cx = \frac{P_1 Z_I}{2} + \frac{P_2 Z_I^2}{4}$$

$$Cy = \frac{Q_1 Z_I}{2} + \frac{Q_2 Z_I^2}{4}$$

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$$Lx = \frac{P_1 Z_I}{2} + \frac{P_2 Z_I^2}{2}$$

$$Ly = \frac{Q_1 Z_I}{2} + \frac{Q_2 Z_I^2}{2}$$

Z_I = Increment in parameter Z

(Note in the above, it is assumed without any loss of generality that $P_0 = Q_0 = 0$, and that the segment is the first of the sequence of segments.)

The difference in X coordinates is:

$$\frac{P_2 Z_I^2}{4}$$

The difference in Y coordinates is :

$$\frac{Q_2 Z_I^2}{4}$$

Distance E between points C and L may thus be represented as:

$$E = \sqrt{\frac{P_2^2 Z_I^4}{16} + \frac{Q_2^2 Z_I^4}{16}}$$

The above equation may be rewritten as follows:

$$E^2 = \frac{Z_I^4 (P_2^2 + Q_2^2)}{16}$$

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$$Z_I^4 = \frac{16E_2^2}{(P_2 2 + Q_2 2)}$$

$$Z_I^2 = \frac{4E}{\sqrt{(P_2^2 + Q_2^2)}}$$

$$Z_I = 2\sqrt{E}\,(P_2^2 + Q_2^2)^{-\frac{1}{4}}$$

or

$$1/Z_I = \frac{(P_2^2 + Q_2^2)^{\frac{1}{4}}}{2\sqrt{E}}$$

By selecting a value for distance E, the number of straight line segments required for a given Bezier curve may be determined as discussed above. Typically, a distance E is one half of a raster step. When distance E = 1/2, the number of straight line segments or steps is:

$$\frac{(P_2^2 + Q_2^2)^{\frac{1}{4}}}{\sqrt{2}} \quad \text{or} \quad \sqrt{\frac{\sqrt{P_2^2 + Q_2^2}}{2}}$$

If the comportation of the number of straight line segments is to be performed at the storage or page coordinates resolution, which for example might have 16 bit precision, and output is at the screen resolution, which might be 640x432, and the page to screen conversion is

Xscreen = Xpage (XSN/XSD)
Yscreen = Ypage (XSN/YSD)

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then the number of line segments will be:

CEILING [SQRT[SQRT ((XSN P2/XSD)^2 +(YSN Q2/YSD)^2) /2]] where CEILING will round a real number upward.

If only integers are used, then the number of line segments will be:

$$\text{SQRT [SQRT ((XSN P2/XSD)}^2\text{+ (YSN Q2/YSD)}^2\text{) /2]+1}$$

Based on the members of line segments (NSTEP), the increment in the parameter is easily calculated as 1/NSTEP and the vertices of the line segments calculated by inserting incremental values of Z into the parametric equation for the Bezier curve.

In an effort to speed up the computation process, a magnitude computation method illustrated below can be utilized to approximate member of line segments so as to avoid multiplications, double precision arithmetic and iterations.

$$\text{Number of segments or } 1/Z_I \approx \frac{MAG}{2} + 1$$

Where: MAG = larger of MAX or (7/8 MAX + 1/2 MIN)

MAX = larger of P_2 or Q_2

MIN = smaller of P_2 or Q_2

Newton Raphson's method may then be used to derive the number of straight line or steps. The above discussed magnitude computation method has a maximum error of approximately 3%. The computation is invariant with respect to rotation.

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Once the curve series data including the vertices or nodes 22 and the control points 36, has been converted to the line segments 86, the present invention provides for the line segments 86 to be expanded such that the individual curves of the curve series are provided with a predetermined width. As illustrated in FIGURE 13, based on a predetermined width (W) selected by an operator or automatically predetermined, the present invention provides for the definition of a rectangle 100 having the width (W) along each of the line segments 86 of the Bezier curves 44. The line segments 86 divide their associated rectangles 100 into two equal portions each having a width of 1/2 W and intersect the ends 102 of the rectangles 100 at a 90° angle so as to be perpendicular thereto. The determination of the four corner vertices of each of the rectangles 100 is as follows:

Given: (XS, YS) = starting point of the line segment
(XE, YE) = ending point of the line segment
W = line width of the line segment

The four points of the rectangle:

XR(1), YR(1)
XR(2), YR(2)
XR(3), YR(3)
XR(4), YR(4)

The four points of the associated rectangle are computed as follows:

$$\theta = \tan^{-1}\left(\frac{YE-YS}{XE-XS}\right)$$

$$dy = \frac{W}{2}\cos\theta$$

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$$dx = \frac{W}{2} \sin \theta$$

$$YR(1) = XS + dx$$
$$YR(1) = YS - dy$$

$$XR(1) = XE + dx$$
$$YR(2) = YE - dy$$

$$XR(3) = XE - dx$$
$$XR(3) = YE + dy$$

$$XR(4) = XS - dx$$
$$YR(4) = YS + dy$$

Next, if so requested by the operator, the ends of each of the rectangles 100 are smoothed and rounded such that the adjacent rectangles 100 aligned end for end form a curve of predetermined width (W). This is accomplish by determining vertices of polygons representing the circumference of circles 104 having a radius of W/2 and centered at each of the vertices V0, V1, V2, V3 as illustrated in FIGURE 14.

The polygons representative of the circles 104 can then be displayed utilizing a scan conversion algorithm. The polygon determination is made as follows:

Given: (Xc, Yc) = coordinator of the circle center
R = radius of the circle

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Let: XP(1), YP(1) = first vertex of the polygon (see Figure 14a)

XP(n), YP(n) = n th vertex of the polygon

n = vertex count of the polygon

Computation of n (vertex count):

$$\delta\theta = 2\cos^{-1}\left(\frac{2R - 1}{2R}\right)$$

$$n = \left\lceil \frac{2\pi}{\delta\theta} \right\rceil$$

Note: n must be an integer, so round result upward.

The derivation of above equation is as follows (see Figure 14b):

$$e = R - d$$

$$e = R - R\cos\left(\frac{\delta\theta}{2}\right)$$

$$e = R\left[1 - \cos\left(\frac{\delta\theta}{2}\right)\right]$$

Let e = ½ (½ is pixel error on the output device resolution).

$$\tfrac{1}{2} = R\left[1 - \cos\left(\frac{\delta\theta}{2}\right)\right]$$

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$$\frac{1}{2R} - 1 = -\cos\left(\frac{\delta\theta}{2}\right)$$

$$\cos\frac{\delta\theta}{2} = \frac{2R - 1}{2R}$$

$$\delta\theta = 2\cos^{-1}\left(\frac{2R - 1}{2R}\right)$$

The XP(i), YP(i) are computed as follows:

$$\Delta\theta = \frac{2\pi}{n}$$

$$\theta i = (i - 1)\Delta\theta$$

$$XP(i) = XC + R\cos\theta i$$

$$XP(i) = YC + R\sin\theta i$$

Where: i = 1, ..., n

Accordingly, a curve series may be converted into a curve of predetermined width providing a graphic representation of a two dimensional form; for example, the curve series of FIGURE 2 may be accordingly made to appear as the character "s" of FIGURE 1.

The operator may also request the curve series be closed and not opened as in FIGURE 13. As illustrated in FIGURE 15, if a closed curve series is requested, the present invention will connect the first and last vertices V0, V3 of FIGURE 15 with a straight line 106 and its associated rectangle and round the corners if so requested by the operator.

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In the preferred embodiment of the present invention, when beginning a prompting sequence, the operator may select the following parameters:

1. Color of are series presentation.
2. Curve series width.
3. Opened or closed curve series.
4. Point or stream input
5. Curve or straight section.

The first four parameters have previously been discussed. The fifth parameter indicates whether the Bezier curves are to be determined or the individual data connected by straight lines. If point input mode is selected, then the operator manually marks each location at the input device which is to be utilized in determining the Bezier curves of the figure. In the stream input mode, figure data is periodically input to the processing unit.

The present invention further provides for a graphic representation of a figure to be moved or translated on the display media by preforming translation or transformation on the vertices 22 and control points 36 as follows:

$$X_{new} = X + TX$$

$$Y_{new} = Y + TY$$

Where TX and TY are the translation factors of the X and Y coordinates. Furthermore, scaling transformation may be preformed in all vertices and control points of the curve series as follows:

$$X_{new} = X\ SX$$

$$Y_{new} = Y\ SY$$

Where SX and SY are the scaling factors of the X and Y coordinates.

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The curve series may also be rotated about a reference point XR, YR, through an angle A by preforming a rotation on all vertices and control points as follows:

$$X_{new} = XR + (X - Xr) \cos A + (Y - Yr) \sin A$$
$$Y_{new} = YR - (X - Xr) \sin A + (Y - Yr) \cos A$$

The preferred embodiment to the present invention further enables an operator to select a curve series on a display. The operator indicates a coordinate position on the screen by, for example, the use of cursor. The curve series data for each curve series of the display is converted into rectangle and partial circle data reflecting a curve series of predetermined width. A check is then made to ascertain in which a rectangle or partial circle in a coordinate position was contained. The operator than able to preform whenever operation are necessary on the selected curve series are selected.

Furthermore, the preferred embodiment of the present invention enables an operator to modify a curve series figure by either modifying the flexer points 46 or the vertices 22. As illustrated in Figure 16 and 17 modification of the flexer points 46 and the vertices 22 has varying results on the curve series. This is accomplished by the operator moving a cursor along the vertices 22 and flexers 46 of a curve series. When the cursor is positioned over the appropriate flexer or vertex, the operator than moves the cursor to the desired new location and enters the coordinate position of the cursor. The flexer or vertex selected is than moved to the designated location resulting in a modification of the curve series as illustrated in the example of FIGURE 16 and 17.

Illustrated in FIGURE 18 is an example of the processing sequence from curve series vertices 22 and control points 36 determination through imaging of a

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figure on a graphic device. As shown by step 60, the curve series description data must first be determined as previously discussed. Next at step 62, transformations are performed such as scaling, translation, perspectives, rotation, etc. using well known transformation routines. It is important to note that significant reduction in processing is achieved by performing the transformations with curve series data which is a minimum data set before conversion of the data set to a polygon data set which is an expanded data set. Next as illustrated in step 64 a transformation to screen coordinates is performed. This may be accomplished by any one of several well known conversion techniques. In steps 65, the Bezier curves 44 are converted to line segments and in step 66, the associated rectangles and pies or circles are calculated. In step 67, the data is converted and expanded to polygon data as described above. Once the polygon data has been established, at step 68 well known clipping algorithms can be used to clip portions of the polygon data which will not be displayed on the viewing device. Finally, at step 70, a scanline conversion of the polygon data is performed. At step 72 the figure representation is next displayed on the graphic device.

In yet another embodiment of the present invention there is included a feature which allows insertion, deletion, and modification of Bezier curves 44 whereby the overall shape of a curve series can be edited. This feature provides for the smoothing of the junction between two adjacent Bezier curves 44. As illustrated in FIGURES 22 through 25, four types of junctions are curve-curve, curve-line, line-curve, and line-line.

As illustrated in FIGURE 22, two new Bezier curves 44a are defined by moving control points 36 in along control frame 38 to define new control points 36a. New control points 36a are at the intersection of a line 82a which passes through node 22a and control frame 38 and

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is parallel to line 82 between control points 36. New curves 44a are thus the resulting Bezier curves defined by each set of nodes 22 and 22a and their associated control point 36a. In FIGURE 23, a new curve 44a is defined by moving control point 36 in along control frame 38 to define a new control point 36a at the intersection of line 80 and control frame 38. The same process is performed in FIGURE 24 where there is a line 80 and Bezier curve 44 junction. In FIGURE 25, node 22a which is the junction of two lines 80 is used as the new control point for a new curve 44a. The above described feature thus enables modification of a curve series so as to more accurately represent the form desired.

Accordingly, the present invention provides a method and apparatus for graphic representation of a curve or two dimensional figure having a predetermined, uniform width. Furthermore, the present invention provides for scaling, rotation, reshaping, etc. of the two dimensional form while maintaining the uniform width. Additionally, the present invention provides for the graphic representation of a two dimensional form of uniform width and having a relatively smooth boundary.

It is to be understood, however, that even though numerous characteristics and advantages of the invention have been setforth in the foregoing description, together with details of the structure and function of the invention, the disclosure is illustrative only, and changes may be made in detail, especially in matters of shape, size and arrangement of parts within the principle of the invention, to the full extent extended by the broad generally meaning of the terms in which the appended claims are expressed.

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WHAT IS CLAIMED:

1. A method of graphical representation of a two dimensional form of uniform width on a suitable media, comprising the steps of;

providing a set of data points generally located along a longitudinal center line of the two dimensional form;

converting said data points to second sets of data for second or higher order parametric equations which define a plurality of adjoining curves that closely approximate said center line;

converting said second set of data to a plurality of line segments closely approximating each of said adjoining curves;

defining for each line segment four vertices of a rectangle having a predetermined uniform width, each of said rectangles being divided by its associated line segment into two generally equal portions, said rectangles generally defining the two dimensional form;

smoothing the junction of said rectangles; and

recreating a graphic representation of said two dimensional form from the smooth rectangle data.

2. A graphic design apparatus for graphical representation of a two dimensional form on a media, said graphic design apparatus compising;

an input device for inputting a set of data points positioned generally along a line having a longitudinal configuration similar to the two dimensional form;

control means for converting the data points into second sets of data for second or higher parametric equations which define a plurality of adjoining curve segments that closely approximate said line;

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second control means for converting each of said curve segments into one or more straight line segments;

third control means defining for each of said line segments corner vertices associated with a rectangle, said rectangles closely approximating the configuration of the two dimensional form; and

means for presenting said rectangle vertices data on a media so as to closely approximate the two dimensional form.

3. An apparatus in accordance with claim 2, further including fifth control means for smoothing the ends of said rectangles.

4. A method of providing a graphical representation of a curve with a uniform width, comprising the steps of;

providing a set of data points generally along said curve;

converting said data points to second sets of data for second or higher order parameteric equations which define a plurality of adjoining curve segments closely approximating said curve;

converting each of said curve segments to one or more straight line segments closely approximating said associated curve segments;

defining in association with each of said straight line segments, the vertices of a rectangle having a width equal to the width of the curve; and

utilizing said rectangle vertices to recreate on a medium, a two dimensional image having a uniform width representative of the desired curve width.

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FIG. 1

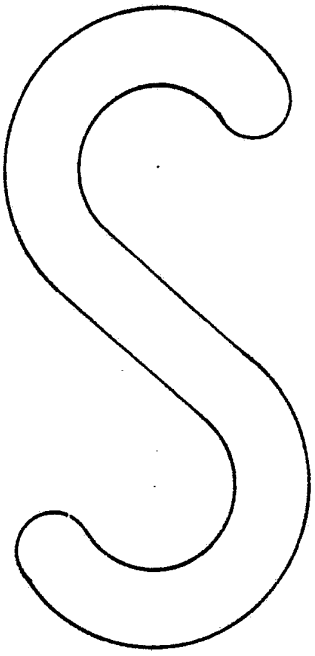

FIG. 2

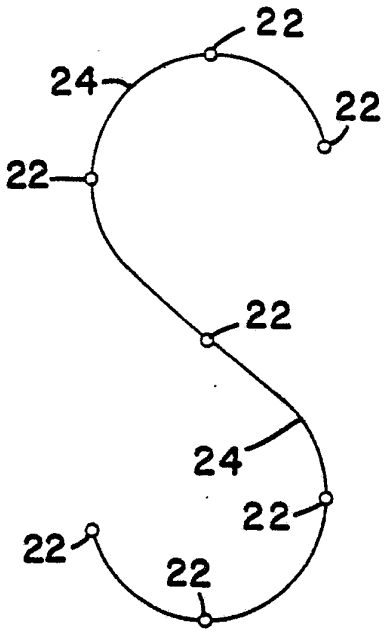

FIG. 3

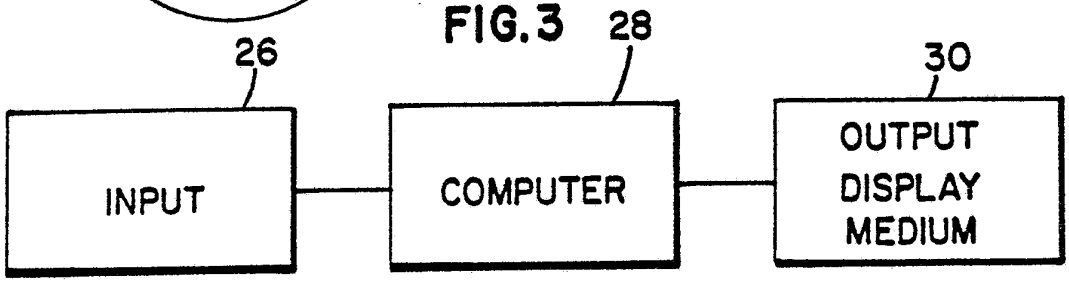

FIG. 4

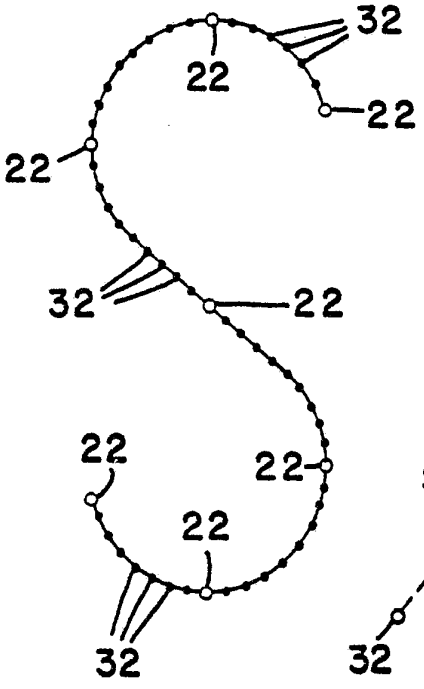

FIG. 5

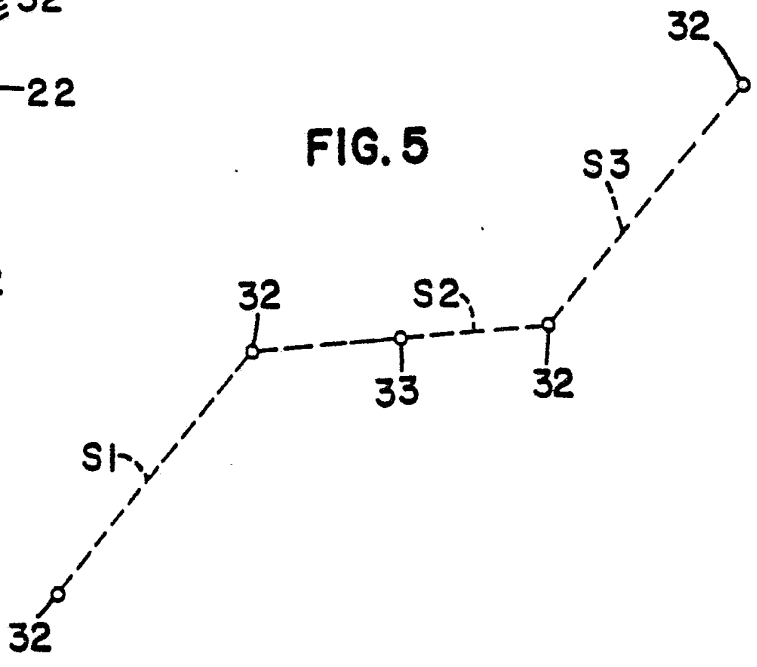

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FIG.6

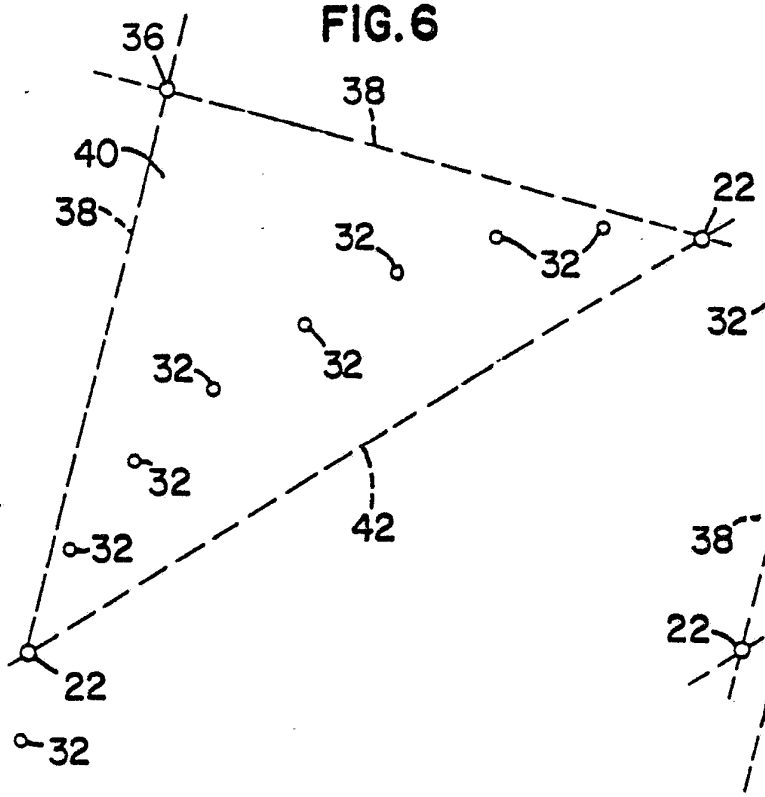

FIG.7

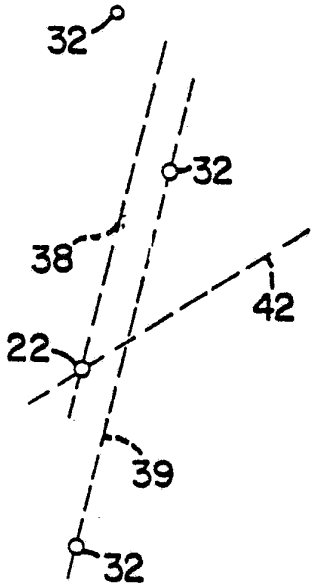

FIG.8

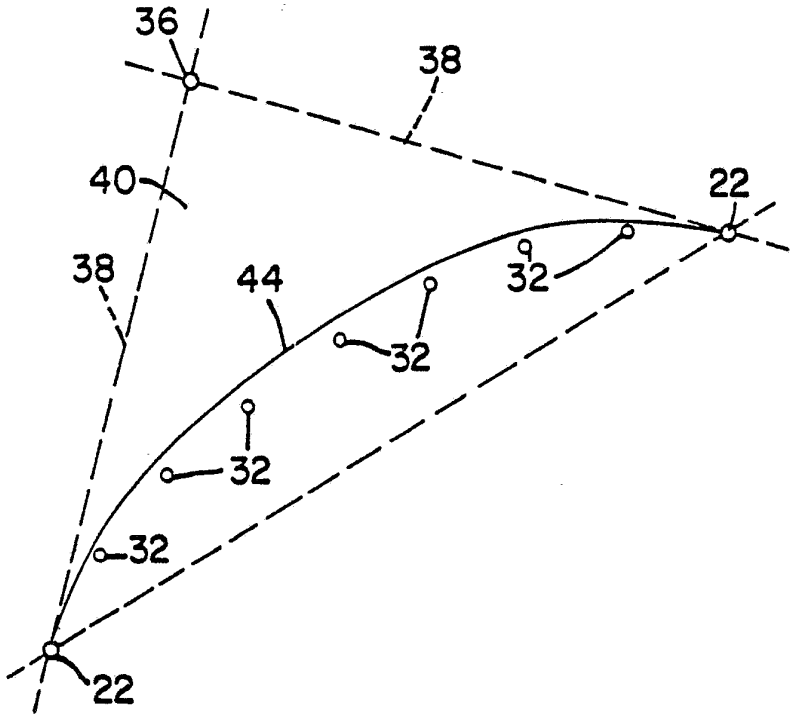

FIG.9

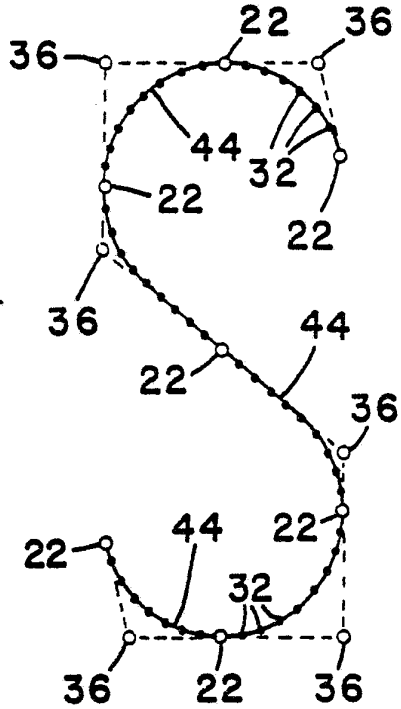

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FIG. 10

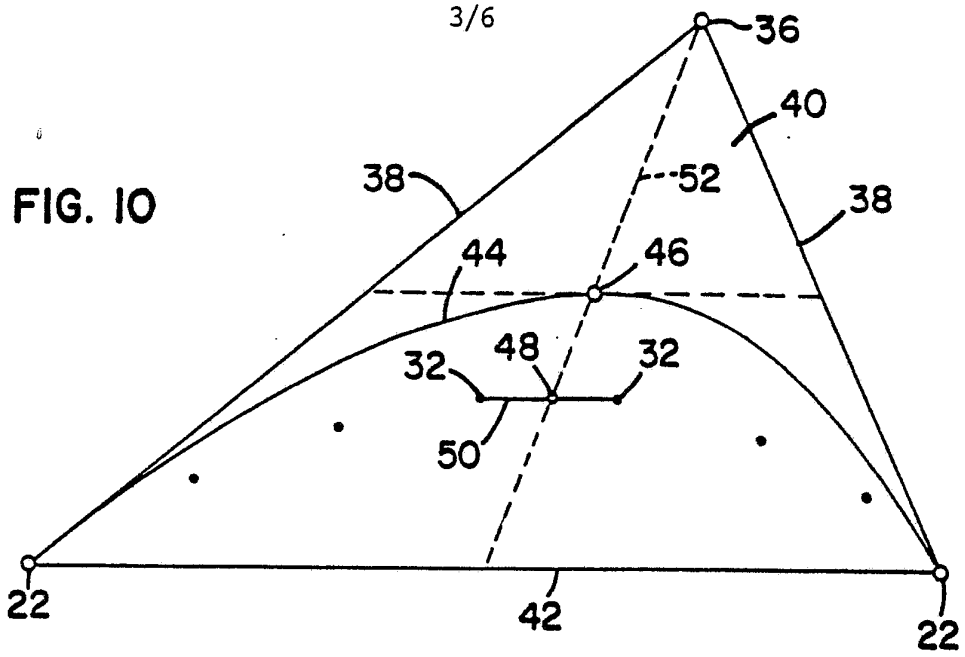

FIG. 11

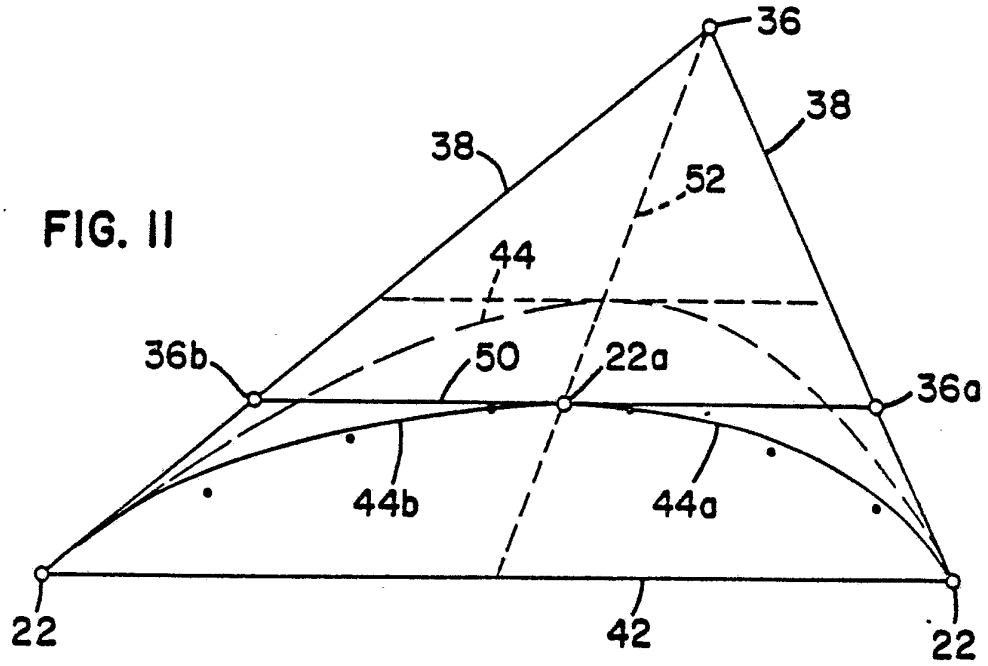

FIG. 12

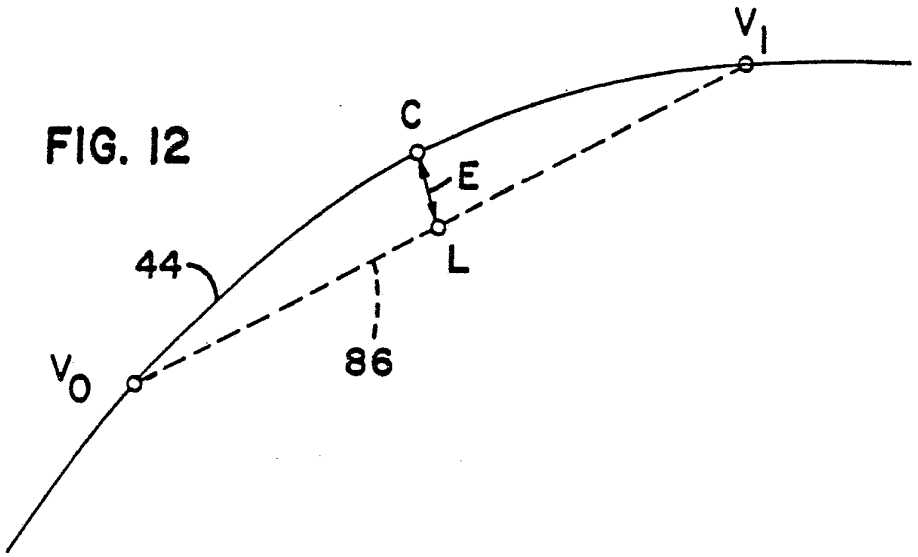

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FIG. 13

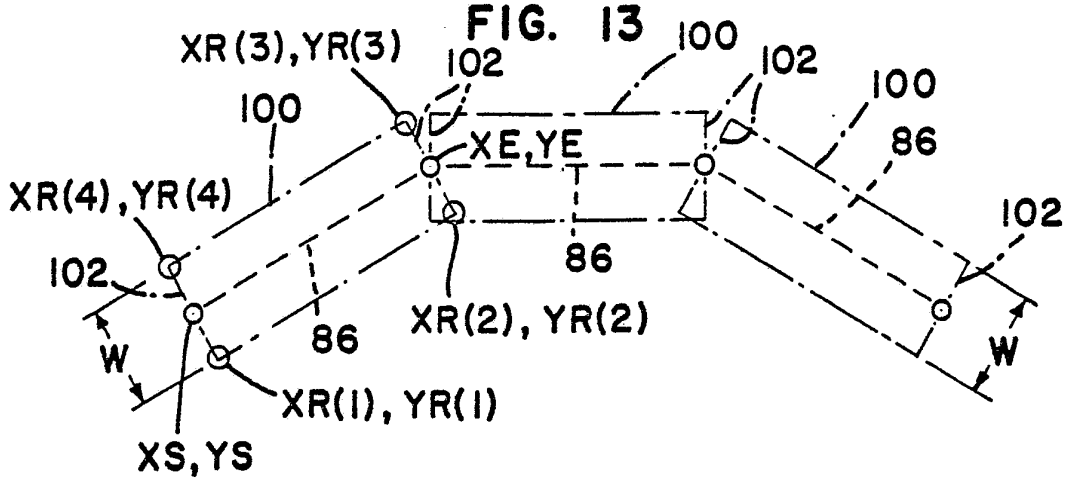


FIG. 14

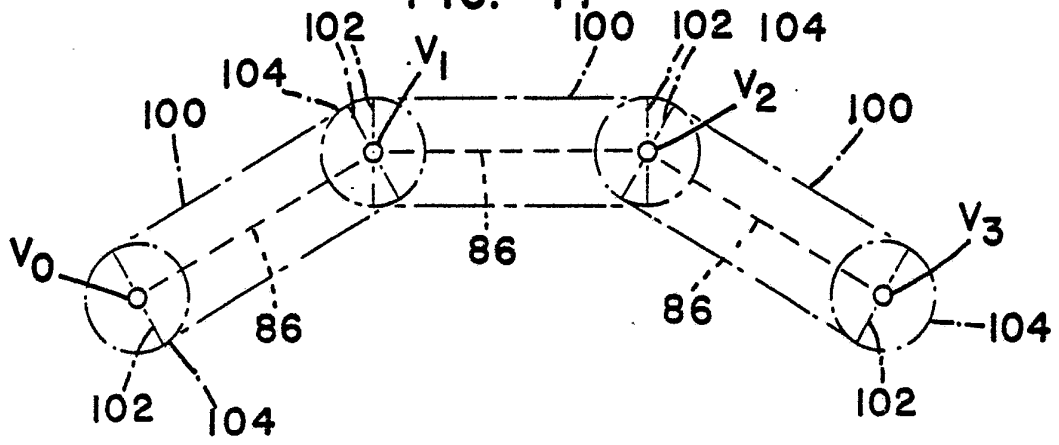


FIG. 15

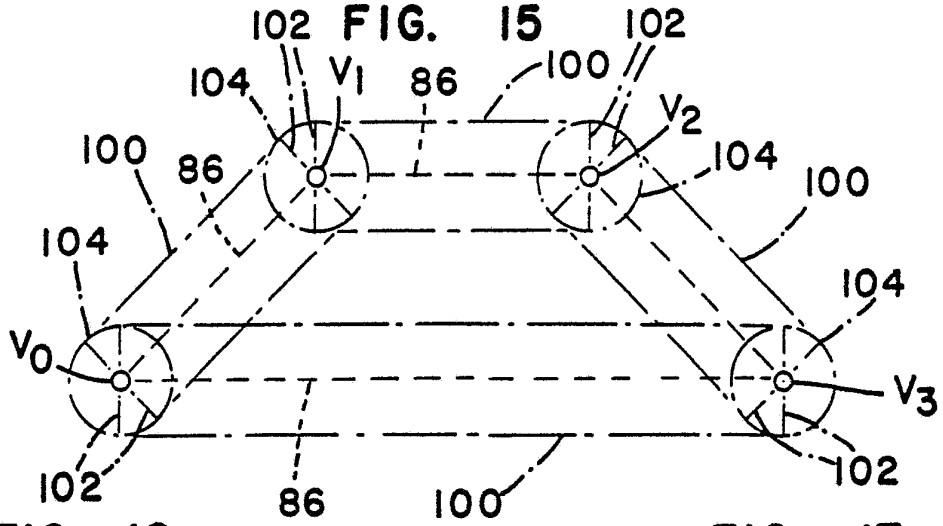


FIG. 16

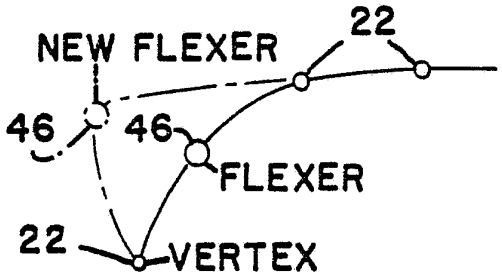
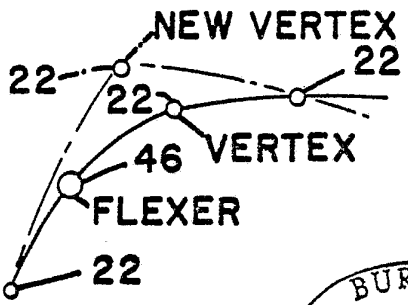


FIG. 17



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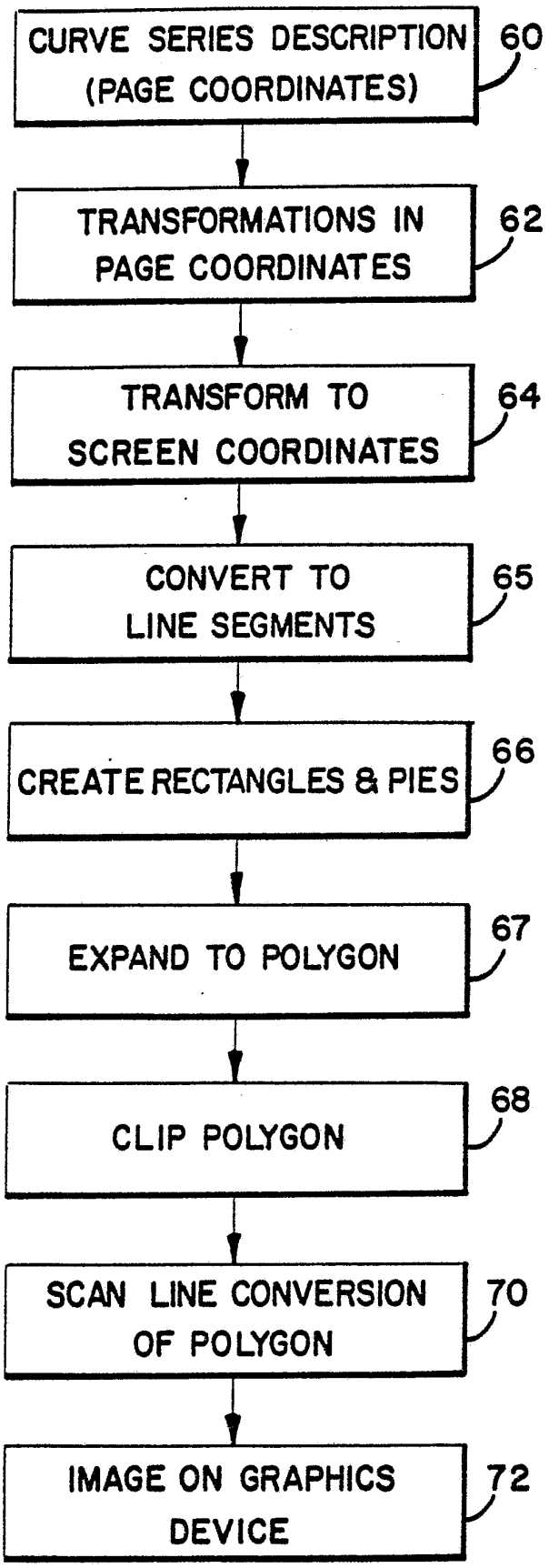

FIG. 18

FIG. 14A

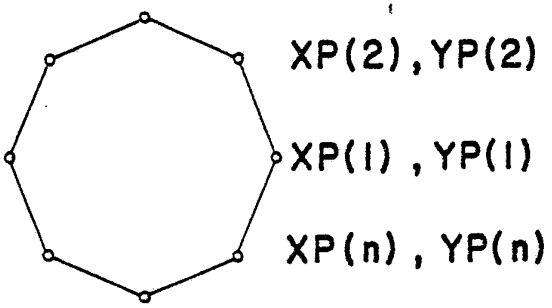

FIG. 14B

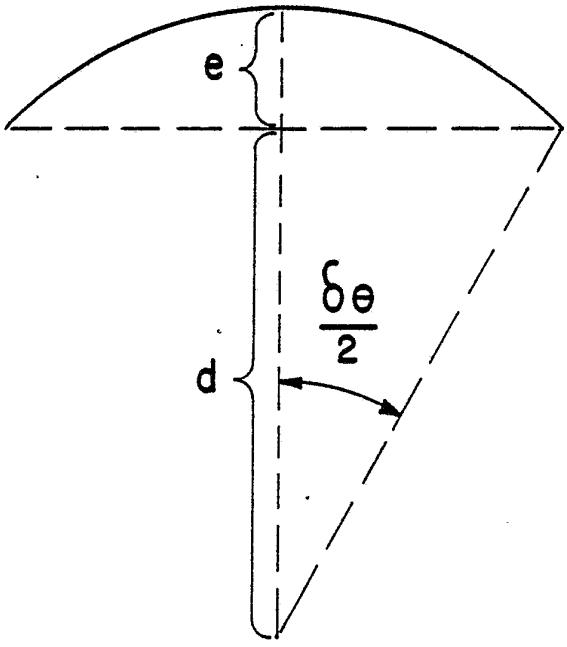

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FIG. 19

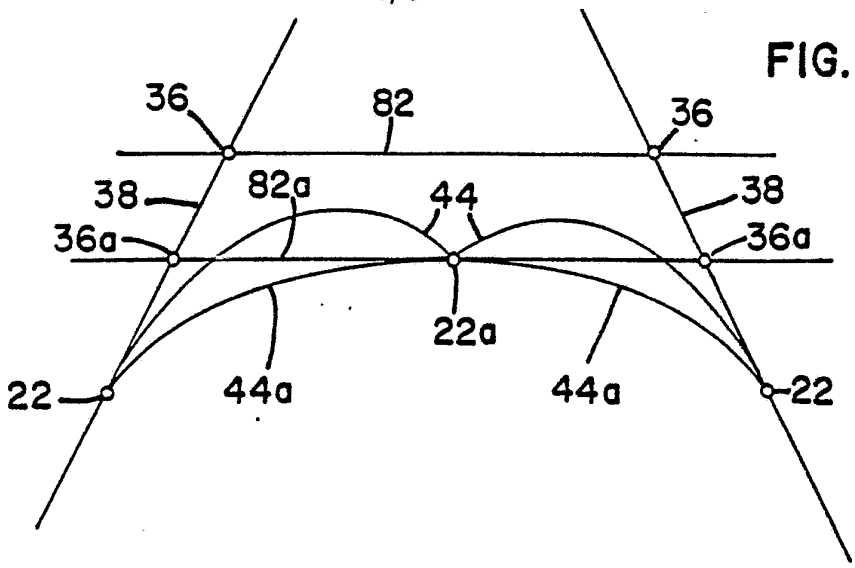


FIG. 20

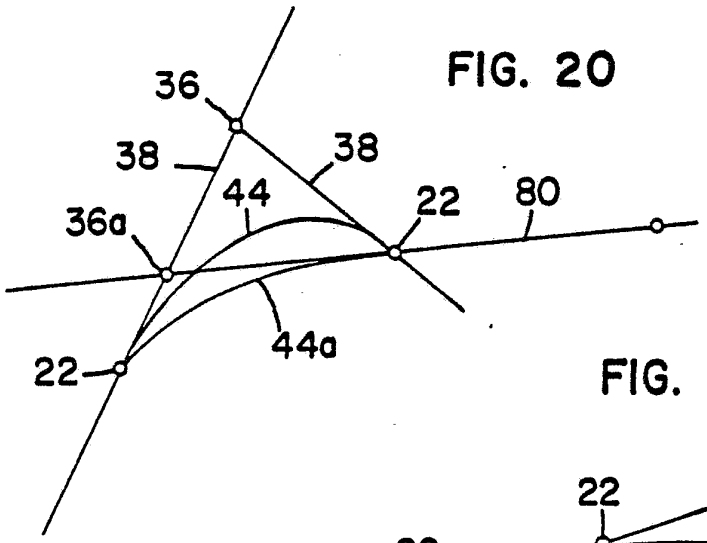


FIG. 21

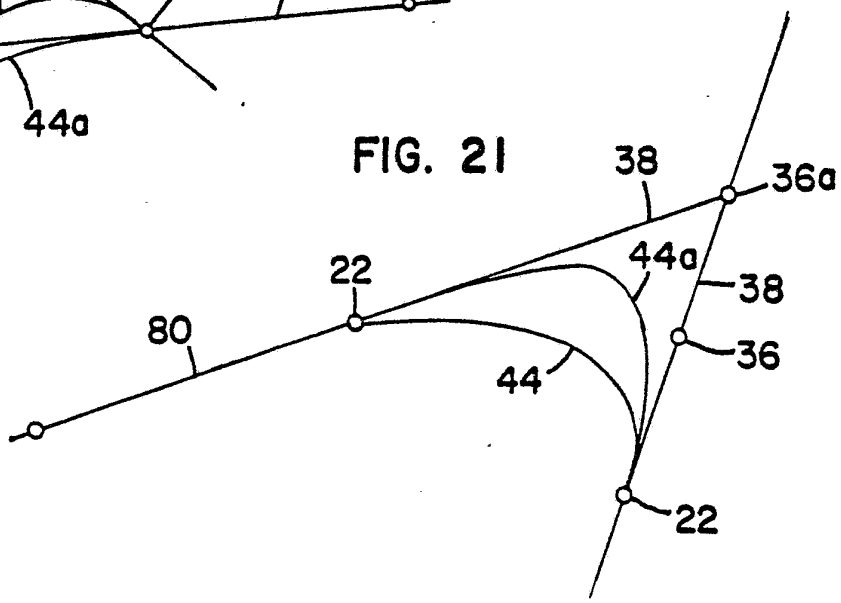
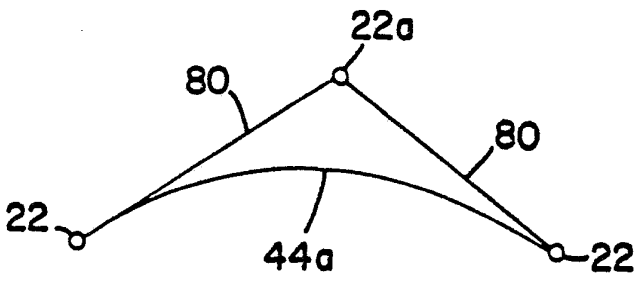


FIG. 22



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INTERNATIONAL SEARCH REPORT

International Application No PCT/US84/00062

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.[3] G06F 15/353, 3/14
U.S. CL. 364/518; 340/728; 364/718, 723

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	364/ 518, 521, 607, 608, 718, 723, 851, 852, 853 340/ 728, 741, 742, 743 Inquired re classes 358, 382

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
A	US, A, 4,115,863, (BROWN) 19 Sept. 1978	1-4
A	US, A, 4,095,216, (SPICER) 13 June 1978	1-4
A	US, A, 3,809,868, (VILLALOBOS ET. AL.) 07 May 1974	1-4
A	US, A, 3,789,200 (CHILDRESS ET. AL.) 29 January 1974	1-4
A	US, A, 3,450,865, (PERAS) 17 June 1969	1-4

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
07 March 1984	23 MAR 1984
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	ERROL A. KRASS PRIMARY EXAMINER