ISSN 2229-5518

Line Generation between Existing Contours In Order to Reduce Stair Case Effect

Mohan P Pradhan, M K Ghose

Abstract— Contours lines are used to represent same elevation points throughout the reference map. These lines plays a pivotal role while determining the shape of the terrain i.e. these lines in combination with its elevation details are used for creating Digital Elevation Model (DEM) for the terrain. Reference maps are released at different scales which imply that objects represented in the reference maps are represented at different scales. Smoothness of the terrain shape created taking into consideration contours and the inter-contour distance hugely depends on the number of contour lines running across the terrain. Greater the scale lesser will be the of lines with larger inter-contour where as lesser the scale greater will be the number of contour lines with smaller inter-contour distance used in-order to cover a terrain of same dimension.Shape extracted from image with a smaller inter-contour distance usually appears smooth as a consequence of increased variation in slope where as shape extracted from image with a greater inter-contour distance suffers from what can be referred to as a Stair Case Effect where the object appears sharper as a consequence of lesser variation in slope. In case of legacy reference data where the inter-contour distance is very large stair case effect will be prominently visible. To overcome the above stated problem this work proposes an efficient contour line generation algorithm based on angular movement technique combined with interpolation after acquiring knowledge of the existing contour lines.

Index Terms—Centroid, Contour, Digital Elevation Model (DEM), Interpolation, Scale, Spiral Traversal, Stair Case Effect.

1 INTRODUCTION

A reference map pertaining to an area of interest hosts various morphological features. These morphological features are used for various inferential studies related to geography and GIS. These morphological features can be broadly classified into either point or line or polygon. Point feature is used to represent landmark and reference point etc. Line feature is used in order to represent road, river and contours etc. Polygon feature is used in order to represent enclosed contours and lakes etc. Each of these features in the reference map for the ease of visual interpretation is represented using different color codes. While different color code not only eases visual interpretation, it is also used as a basis for segmenting features using a computational process.

One of the key feature represented in a reference map are contour lines. Fundamentally contours line can be thought of a continuous line joining point that are at same height from a reference datum. Actually these lines are not physically present on the terrain but are rather abstract line linking locations at same elevation. These lines can be used for various morphological studies to name a few such as determination of shape, slope, elevation of a particular point and type of ridge.

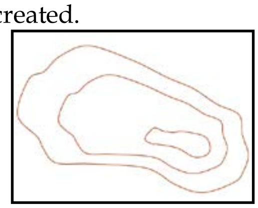
Contour line can be of various types. It can be best classified by correlating contours with ridges in the human finger print. The features in the human finger print are often referred to as minutiae's. These minutiae's can be either ridges or enclosures etc. Ridge can be either complete ridge or incomplete ridge or short ridge. Enclosure can be either a simple enclosure or an enclosure within another enclosure. Likewise contour line can also be complete or incomplete or short line as well as it can have enclosures.

The different types of contour lines are attributed by the fact that they have certain length and have different originating and terminating coordinate. Whereas enclosures are attributed by the fact that they have certain length and have originating and terminating coordinate.

These contour lines are used in-order to create Digital Elevation Model pertaining to a terrain. Digital Elevation Model is created by elevating the identified contour lines by associated elevation details in the third dimensional plane. Elevation details are associated with few of the contour lines at certain intervals. Once the contour lines are identified the elevation values may be either manually or automatically associated to create the DEM.

The smoothness of DEM created from the identified contours lines highly depends on the inter-contour distance. Greater the distance between the contour lines lesser will be the smoothness of DEM and lesser the distance between the identified contour lines greater will be the smoothness. Here smoothness refers to increased variation in slope.

The variation in slope can be used in-order to create a stair case representation. It was observed that when there is less variation in the slope the size of the stair in the stair case increase. This problem may be correlated to stair case effect. Consider Fig. 1(a). represents contour lines. Fig. 1(b). represents the elevation model created using contour lines along with the stair case created.



- *Mohan P Pradhan is currently pursuing Ph. D in Automatic Digitization from Sikkim Manipal University, India, PH+91-9434356799, e-mail:- mohanp_pradhan25@yahoo.com.sg*
- *Prof. (Dr.) M K Ghose is currently working as Dean (R&D) and Professor & Head of the Department of Computer Science & Engineering at Sikkim Manipal Institute of Technology, Sikkim Manipal University, email:- mkghose@smu.edu.in*

Fig. 1(a). Contour Lines

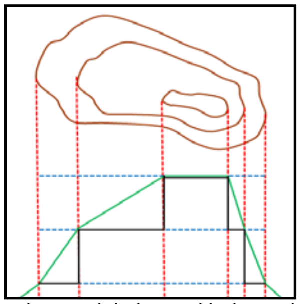


Fig. 1(b). elevation model along with the stair case created

In Fig. 1(b) it is observed that the due to less variation in the slope the size of the stair in the stair case is relatively big. Consider Fig. 2(a) represents contour lines. Fig. 2(b) represents the elevation model created using contour lines along with the stair case created

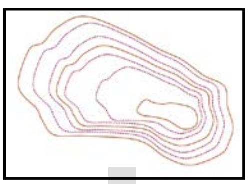


Fig. 2(a): Contour Lines

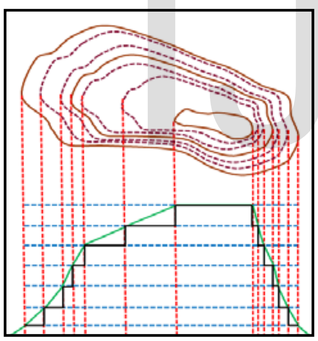
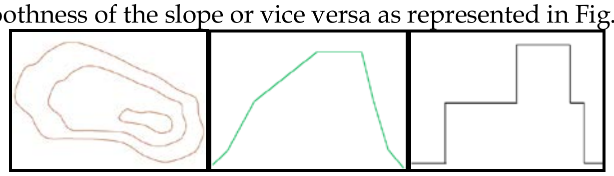
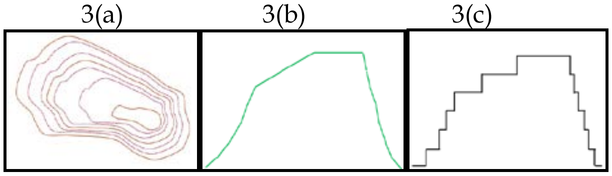


Fig. 2(b). elevation model along with the stair case created

On, comparing the slope and the stair case it can be concluded that the greater the factoring of stair case greater will be the smoothness of the slope or vice versa as represented in Fig. 3.



3(a) 3(b) 3(c)



3(d) 3(e) 3(f)

Fig. 3. Comparison of two cases

So, in-order to overcome this problem either reference map which has contour with smaller inter-contour distance can to be taken into consideration or intermediate contour lines are to be generated using the knowledge of the existing contours that are already present. In situation where the former approach is not applicable (in case of legacy maps) the later approach may be deployed where are intermediate contours are generated based on the knowledge of the existing contours.

In order to generate intermediate contour, first knowledge of the existing contours are to be acquired with its relevant information and are subsequently stored in a repository. Then the knowledge is used in-order to interpolate a set of points. Upon inflation the dataset with interpolated points an appropriate line construction algorithm is to be used for connecting the interpolated point's in-order to create a continuous line

This proposed work in abstraction involves the following steps,

- Color segmentation of extracting only the contours
- Application of morphological operation for skeletonizing the pattern representing feature using single pixel width
- Identification of minutiae's representing the contour lines
- Interpolate intermediate points
- Resolve hit and miss
- Connect the interpolated points with continuous line for creating contour.

for effective use of memory all the data structure used by the process is jazzed in nature.

2 Related Work

Interpolation is essential in order to create additional contour line in case where the scale of representing the object is very high for enhancing DEM representation. [1] As DEM is used in order to describe the relief form of the earth's surface including various parameters such as elevation, slope etc. A. P. Ozah et. al. [2] proposed a method for performing accuracy tests of contours interpolated from the two different sources. It was performed taking into consideration different terrain configuration and context fro determining their suitability for topographical mapping in different scenarios. Gill Barequet [3] proposed a method for performing surface interpolation in order to create an elevation model of an object based on contour information contained by multiple slices pertaining to the object. In order to create the elevation model first the contours in the slices were oriented towards same direction then the overlapping contours in each of the slices were analyzed in order to interpolate. Further triangulation was used in order to join the contour and to elevate it in third dimensions to create the elevation model. Chin-Shung Yang [4] performed comparative assessment of various interpolation methods for enhancing data representation based on Inverse Distance to a Power , Kriging , Minimum Curvature, Modified Shepard's, Natural Neighbor, Nearest Neighbor, Polynomial Regression, Moving Average, Radial Basis Function Interpolation, Data Metrics, Local Polynomial, Triangulation with Linear Interpolation.

ISSN 2229-5518

Each of the algorithms were analyzed from the perespective of applicability, algorithm, efficiency and advantage and concluded that the different interpolation algortihms performs best under certain desired circumstances.

Inorder to interpolate intermediate contour line it is of utmost importance to identify the existing contours and their information Chao-hsiung Wu et. al [5] proposed a technique for labeling the various contour lines by first creating a undirected contour tree and then applying a set of heuristic rules were applied to derive minimum set of height information required in order label the contours in the reference map.

Interpolation between lines based on profile, proportional distance, window or tin methods [6]. In case of profile method first a profile is generated through the interpolated point and then spline curve is used. Applicability of profile method depends on the type of curves in the contour lines. In case of proportional distance points are interpolated based on distance ratio. In case of window based method a circular window along with the adjacent contours are used to interpolate using polynomial. In case of TIN approach TINs are created using terrain points along contour lines. Jianyun Chai et. al. proposed a technique that takes the gradient conditions across contours into consideration in order to generate interpolated lines [7]. Michael B. Gousie et. al. [8] proposed a way for determining location where intermediate contours can and cannot be generated using Hermite splines and then gaps are filled by inverse distance weighting taking into consideration elevation points along cardinal directions. Türkay Gökgöz et. al. [10] stated that the skeleton line extracted related to the contour provides information regarding the contour to be generated.

3 Methodology

The methodology can be represented using the following schematic diagram

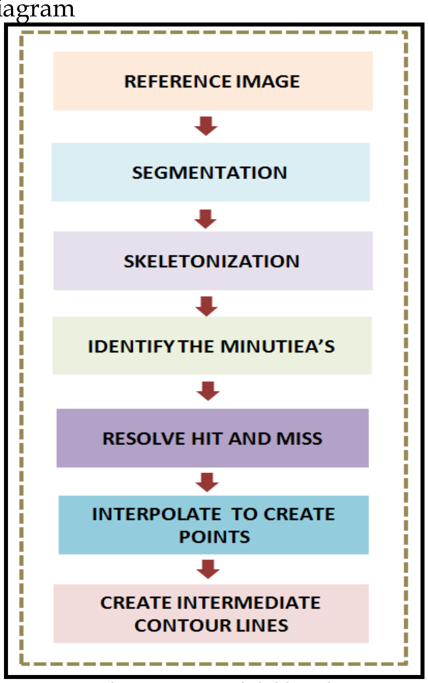


Fig. 4. Approach initiated

In order to initiate any of the data manipulation operation firstly the image is to be read and stored in a 3D dataset where the layers represents blue, green and red layers. In-order to ease the computational process the image is converted in single layer (representing shades of gray) image from a multi layer image. A coordinate in the single layer image (i.e. intensity) is a result of the proportion contribution of the red, green and blue at the same coordinate and is implemented as sum of products.

So, intensity at a given coordinate x,y in a gray image G is equal to

G(x,y)=proportion contribution of blue * Blue(x,y) + proportion contribution of green * Green(x,y) + proportion contribution of red * Red(x,y)

Where, proportion contribution of blue + proportion contribution of green + proportion contribution of red = 1

3.1 Segmentation

Segmentation process is used in-order to highlight on the required feature and suppress all other features i.e. it partitions the data set. The partitioning is done based on the value of the intensity (or range) representing a particular feature. This process is referred to as thresholding. This process takes as basis the range of intensity value representing the feature of interest as a parameter for segmentation.

3.2 Skeletonization

Skeletonization or thinning is a morphological operator in image processing is the process of representing the feature of interest using single pixel width. The advantage of Skeletonization process is that it eases computation procedure.

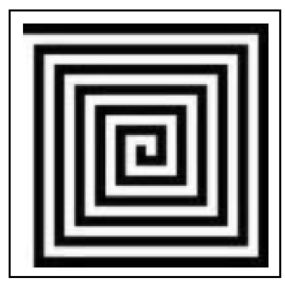


Fig. 5. Spiral Traversal

3.3 Spiral Traversal Technique

The traditional technique of row column data set traversal technique has O(f) and o(f) in order of m*n. On analyzing the input set pertaining to the pattern was observed that the leaf of the pattern would be efficiently identified by a spiral traversal technique rather than row column technique. In addition spiral traversal is also capable of identifying enclosure within another enclosure without any additional complexity. Lastly in this case the O(f) would remain the same that is m *n, o(f) can be much less than m * n.[9]

This process has four sub modules Traverse right, Traverse down, Traverse left, and Traverse up

- Traverse right: This process was used in order to traverse right by keeping the row intact and incrementing the column by one until and unless a significant value is not encountered or the column bound is not reached.

- Traverse down: This process was used in order to traverse down by keeping the column intact and incrementing the row by one until and unless a significant value is not encountered or the row bound is not reached.
- Traverse left: This process was used in order to traverse left by keeping the row intact and decrementing the column by one until and unless a significant value is not encountered or the column bound is not reached.
- Traverse up: This process was used in order to traverse up by keeping the column intact and decrementing the row by one until and unless a significant value is not encountered or the row bound is not reached.

After every spiral the row and column bound values are decremented.

3.4 Identification of minutiae's

Minutiae's are different types of elementary morphological element contributing to morphological features. There are various categories of minutiae:

- Lines- Line better known as Ridge is linear feature that runs in the morphological terrain. Ridges in morphological study of terrain can be used for identification of contours, rivers and water bodies etc. There are different types of ridges namely
  - Complete Ridge - Complete ridge is a ridge that runs through the terrain i.e. it starts from either of the edges and ends at the other, it can start and end in the same edge as well.
  - Ridge Ending - Ridge ending is a ridge that starts at either of the edges but ends at a coordinate position that fall into neither of the edges.
  - Ridge Enclosure - Ridge enclosure is a ridge that slits and again joins.
  - Short Ridge - Short ridge is a ridge that starts and ends at non edge coordinates.
  - Bifurcations- Bifurcation or slit is a division of a ridge into two or more ridges. Bifurcation in morphological study of terrain can be used for identification of river convergence and divergence etc.
- Enclosures - Enclosure or Island is a ridge that starts and ends at same point. Enclosure in morphological study of terrain can be used for identification of closed contour etc. An enclosure with a ridge extension is referred to as a lake.
- Point - Point or dot is a feature that starts and ends at same coordinate without intermediate coordinates. Points in morphological study of terrain can be used for identification of landmark etc.

In case of contours the possible set of minutiae's that may be associated are Lines and Enclosures.

Line (or ridge) detection

- Complete Ridge: If both the starting coordinate and the terminating coordinate fall onto either of the boundary then the ridge is identified as complete ridge.
- Ridge Ending: If either of the starting coordinate or the terminating coordinate fall onto either of the boundary then the ridge is identified as ridge ending.
- Short Ridge: If neither of the starting coordinate nor the terminating coordinate fall onto either of the boundary then the ridge is identified as short ridge.

Enclosure detection

If a ridge start from a particular coordinate and after reaching certain length terminates at the same coordinate position from where it had started then the ridge is identified as an enclosure. Most of the enclosure tracking algorithm implemented are either not capable of identifying the holes within an enclosure or does identify with greater complexity (such as, triangulation, minimum distance, interval scaling to name a few). One of the most significant achievement of this process is that it is efficiently identifies the holes. This has been possible because of the spiral scheme designed for data traversal. Hence with no additional complexity involved the holes can be detected.

Determination of trail pattern

After identifying all the minutiae's the next task is to identify the trail pattern. Here trail basically refers to the continuous chain of values that represent the orientation at different coordinate. In this work we have identified 16 such coordinate orientations considering a mask of 3x3. On reaching a particular coordinate 3x3 values centered at the coordinate is extracted then it is compared with the sixteen masks a suitable match replaces the coordinate with the value associated with the mask. Table 1 represents the 16 masks.

TABLE 1
16 MASKS

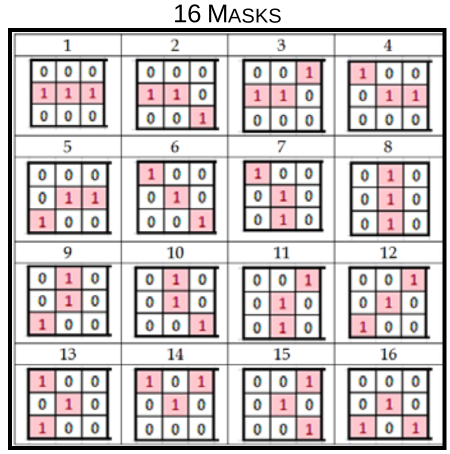


TABLE 2
(A) IMAGE (B) BINARY VALUE OF SELECTED AREA (C) REPLACING THE COORDINATE WITH VALUE MAPPED WITH MASK
(B)

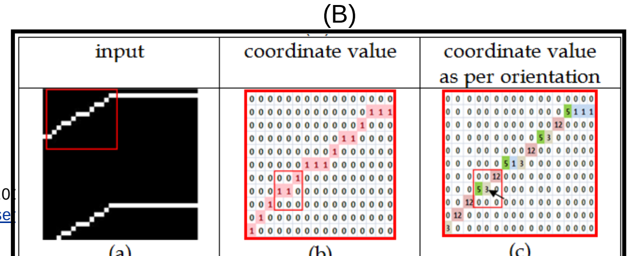


Table 2 (a) is a binary image where the features are represented using single pixel width. Table 2 (b) is coordinate values in the binary image from the selected are demarked in red. Table 3 represents the coordinate value after replacing the coordinate location the values mapped with the matching mask.
After associating the values with the sixteen masks we need to determine the direction of movement when such orientations are encountered.

3.5 Direction of movement for enclosures

While determining direction of traversal for enclosure (along the angle specified) it was observed that direction of traversal entirely depends on the position of the significant value in the pattern with respect to the Centroid. In order to resolve the conflict the Centroid of the enclosure is taken into consideration.

Centroid of a pattern can be determined by using the Centroid formulae. Let us consider a pattern represented by G, then the Centroid i.e. $G(x_c,y_c)$ where in X_c and X_c are the coordinate of the Centroid, is given by

$X_c= (\sum x_i)$/ no of instances where x_i represents x coordinate of significant value.
$X_c= (\sum y_i)$/ no of instances where y_i represents y coordinate of significant value.

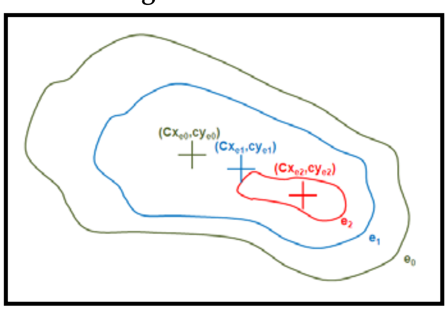


Fig. 6. Determination of the Centroid

On analyzing the problem it was observed that the movement has to always start from the innermost enclosure and should always converge outwards. So in-order to ensure proper traversal, the data structure used to store the coordinate values of the significant pixels was sorted as per the count of significant pixel i.e. enclosure having lowest significant pixel count is selected first and in the successive steps enclosures are selected in increasing value of count. As in case of Fig. 6, e_1 is selected, then e_2 followed by e_3.
The following 3x3 16 masks were designed taking into consideration different possible orientation in order to determine movement,

First Consideration:

If the coordinate value X_c (Centroid of object) is greater than or equal to X (coordinate) of the coordinate then movement will be along,

TABLE 3
DIRECTION OF TRAVERSAL WHEN X_C IS GREATER THAN OR EQUAL TO X

1	2	3	4
0 0 0 1 1 1 0 0 0	0 0 0 1 1 0 0 0 1	0 0 1 1 1 0 0 0 0	1 0 0 0 1 1 0 0 0
90^0	45^0	135^0	45^0
5	6	7	8
0 0 0 0 1 1 1 0 0	1 0 0 0 1 0 0 0 1	1 0 0 0 1 0 0 1 0	0 1 0 0 1 0 0 1 0
135^0	45^0	45^0	0^0 if $y>y_c$ 180^0 if $y<=y_c$
9	10	11	12
0 1 0 0 1 0 1 0 0	0 1 0 0 1 0 0 0 1	0 0 1 0 1 0 0 1 0	0 0 1 0 1 0 1 0 0
135^0	45^0	135^0	135^0
13	14	15	16
1 0 0 0 1 0 1 0 0	1 0 1 0 1 0 0 0 0	0 0 1 0 1 0 0 0 1	0 0 0 0 1 0 1 0 1
180^0	90^0	180^0	90^0

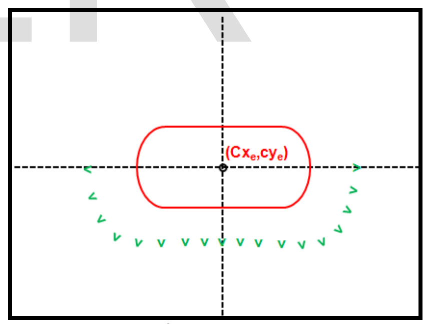


Fig. 7. $x_c >= x$

Second Consideration:
If the coordinate value X_c (Centroid of object) is lesser than X (coordinate) of the coordinate then movement will be along,

TABLE 4
DIRECTION OF TRAVERSAL WHEN X_C IS LESSER THAN X

1	2	3	4
0 0 0 1 1 1 0 0 0	0 0 0 1 1 0 0 0 1	0 0 1 1 1 0 0 0 0	1 0 0 0 1 1 0 0 0
270⁰	225⁰	315⁰	225⁰
5	**6**	**7**	**8**
0 0 0 0 1 1 1 0 0	1 0 0 0 1 0 0 0 1	1 0 0 0 1 0 0 1 0	0 1 0 0 1 0 0 1 0
315⁰	225⁰	225⁰	0⁰ if $y>y_c$ 180⁰ if $y<=y_c$
9	**10**	**11**	**12**
0 1 0 0 1 0 1 0 0	0 1 0 0 1 0 0 0 1	0 0 1 0 1 0 0 1 0	0 0 1 0 1 0 1 0 0
315⁰	225⁰	315⁰	315⁰
13	**14**	**15**	**16**
1 0 0 0 1 0 1 0 0	1 0 1 0 1 0 0 0 0	0 0 1 0 1 0 0 0 1	0 0 0 0 1 0 1 0 1
0⁰	270⁰	0⁰	270⁰

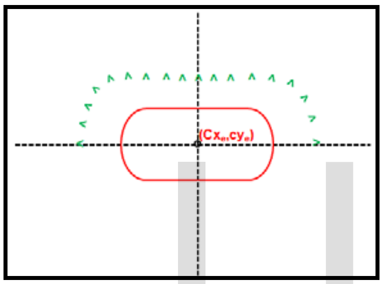


Fig. 8. $x_c < x$

Direction of movement for lines

While determining direction of traversal for line (along the angle specified) it was observed that direction of traversal entirely depends on the position of the line in the image. In order to resolve the conflict the Centroid of the entire reference data is taken into consideration along with the Centroid of the line.

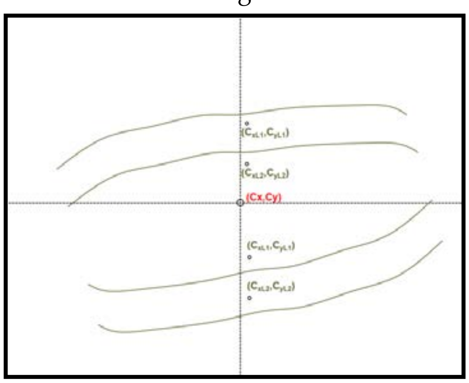


Fig. 9. Determination of the Centroid

On analyzing the problem it was observed that the movement has to always directed outwards from the lines depending on the Centroid of the image and the Centroid of the line

The following 3x3 16 masks were designed taking into consideration different possible orientation in order to determine movement,

First Consideration:

If the coordinate value C_x (image) is greater than or equal to X_c (line) of the coordinate then movement will be along,

TABLE 5

DIRECTION OF TRAVERSAL WHEN C_x IS GREATER THAN OR EQUAL TO X_C

1	2	3	4
0 0 0 1 1 1 0 0 0	0 0 0 1 1 0 0 0 1	0 0 1 1 1 0 0 0 0	1 0 0 0 1 1 0 0 0
90⁰	45⁰	135⁰	45⁰
5	**6**	**7**	**8**
0 0 0 0 1 1 1 0 0	1 0 0 0 1 0 0 0 1	1 0 0 0 1 0 0 1 0	0 1 0 0 1 0 0 1 0
135⁰	45⁰	45⁰	0⁰ if $y> C_y$ 180⁰ if $y<= C_y$
9	**10**	**11**	**12**
0 1 0 0 1 0 1 0 0	0 1 0 0 1 0 0 0 1	0 0 1 0 1 0 0 1 0	0 0 1 0 1 0 1 0 0
135⁰	45⁰	135⁰	135⁰
13	**14**	**15**	**16**
1 0 0 0 1 0 1 0 0	1 0 1 0 1 0 0 0 0	0 0 1 0 1 0 0 0 1	0 0 0 0 1 0 1 0 1
0⁰	90⁰	180⁰	90⁰

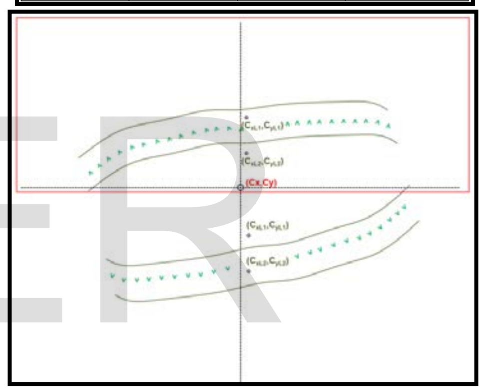


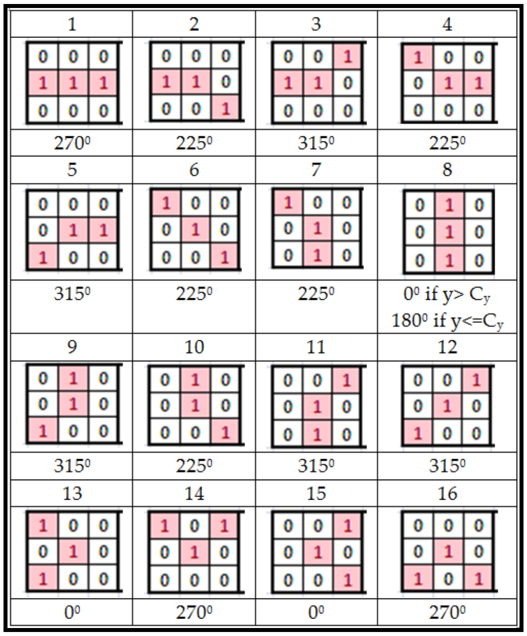
Fig. 10. $C_x >= x_c$

Second Consideration:

If the coordinate value C_x (image) is lesser than X_C (line) of the coordinate then movement will be along,

TABLE 6

DIRECTION OF TRAVERSAL WHEN C_x IS LESSER THAN X_C



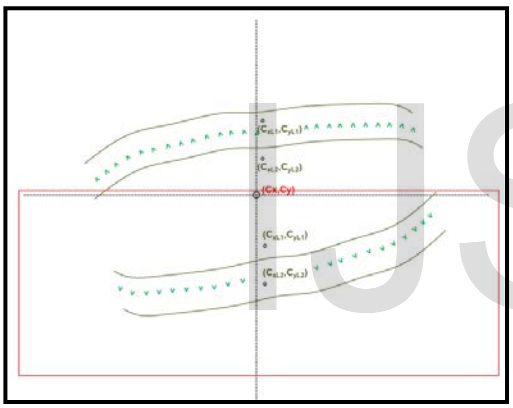


Fig. 11. $C_x < x_c$

Direction of movement

In case of either type of objects the movement considered is along 0^0, 45^0, 90^0, 135^0, 180^0, 225^0, 270^0 and 315^0.

- in order to move towards 0^0 only the column is incremented
- in order to move towards 45^0 the row is decremented and the column is incremented
- in order to move towards 90^0 only the row is decremented
- in order to move towards 135^0 the row is decremented and the column is also decremented
- in order to move towards 180^0 only the column is decremented
- in order to move towards 225^0 the row is incremented and the column is decremented
- in order to move towards 270^0 only the row is incremented
- in order to move towards 315^0 the row is incremented and the column is also incremented

until a significant value is encountered or the bound is not reached.

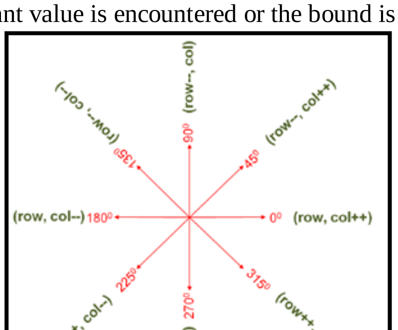


Fig. 13. Directions of movement

The problem of Hit and Miss

Movement from a particular location may be either angular or along the axis's. While traversing along the axis's the movement would definitely hit a significant value or the boundary coordinate but would not miss a coordinate with significant value. Hence the interpolated value would represent the actual intermediate value as represented in Fig. 14 where the pixel in green represent the starting point, the pixels in pink represents the intermediate stopping point and the pixels in blue represent the interpolated value.

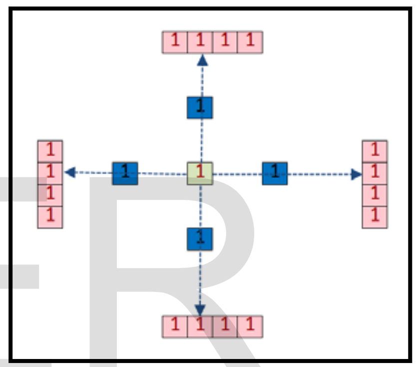


Fig. 14. Movement along axis's

Whereas, while traversing along the angles, the chances of hitting and missing a significant value is equally likely. Hence the interpolated value may represent the actual intermediate value in case of hit or it may represent false intermediate value as a consequence of miss. As represented in Fig. 15 the pixel in green represent the starting point, the pixels in pink represents the intermediate stopping point and the pixels in blue represent the interpolated value. As a consequence of miss the interpolated values are wrongly placed.

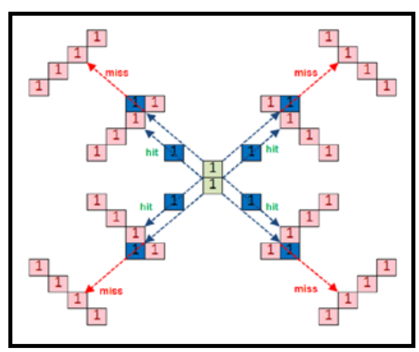


Fig. 15. Movement along axis's with hit and miss.

In order to resolve this problem for angular movement an enhanced mask is to be designed that takes into consideration additional coordinates for determining the intermediate stop-

ISSN 2229-5518

ping point for interpolation along the direction of the traversal. Fig. 16 represents the approach designed to overcome miss in case of angular movement.

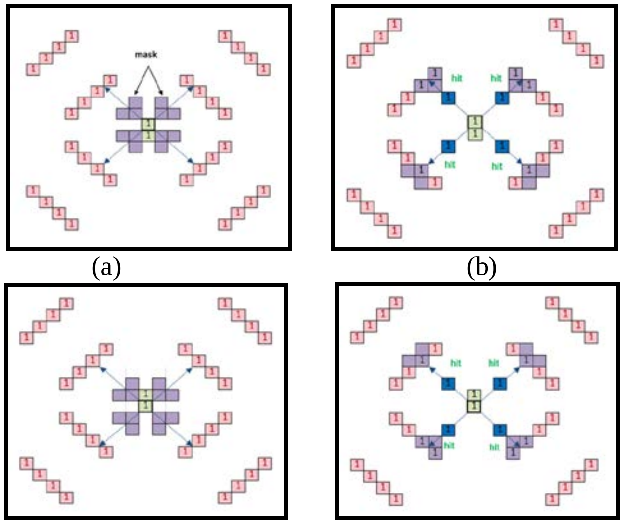


Fig. 16. Design of mask to eliminate miss.

This mask prevents miss and thus results in generation of actual interpolated value.

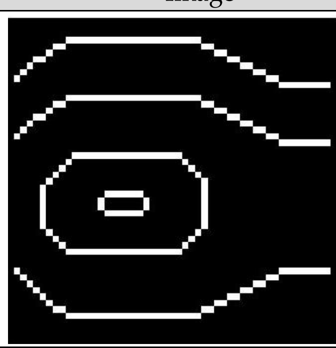
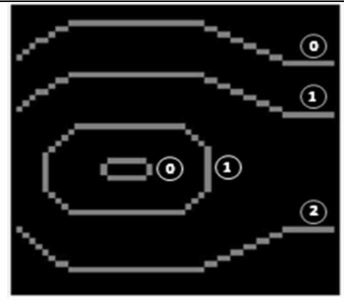
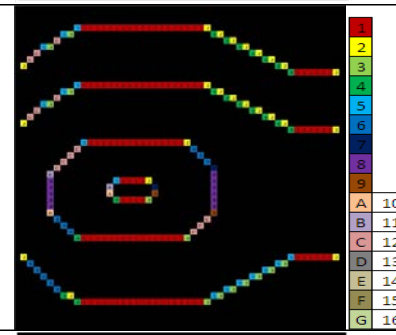
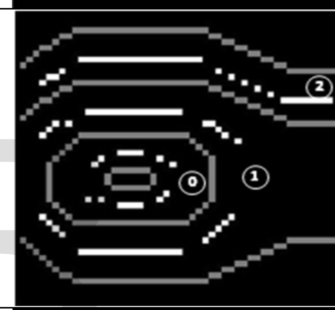
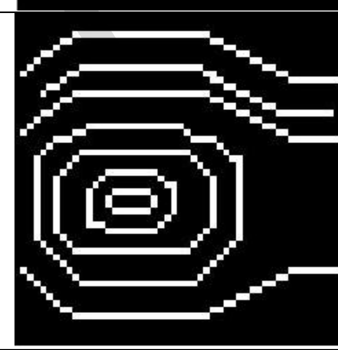
3.6 Reconstruction of broken lines

After the process has successfully interpolated the value using the advanced masks the broken generated lines are to be reconnected to create continuous contour lines.

For creating continuous contour from the set of interpolated values it is mandatory to store the interpolated values in sequence in-order to preserve correctness. A data structure was used to store successively interpolated value and the reconnection point was determined by analyzing the successive values in the data structure i.e. if the difference of x's and difference of y's of successive stored values sum yields value greater than 2 then there reconnection is required.

4 Results

TABLE 7
INTERPOLATION STEPS

	Image
Step1: Read image	
Step 2: Identify object	
Step 3: Direction of movement, **number 1 to 16 is in correlation with table 3,4,5 and 6 depending upon th type of mask and the centroid**	
Step 4: Generation of interpolated points	
Step 5: Determination of reconnection point	

5 Conclusion

Automatic reconstruction of feature plays a significant role in GIS based application for improvised data representation. Recreation of features plays a significant role especially in situation where the scale at which the reference data is represented is very high. This work aims at generating intermediate contour lines by creating various orientation masks followed by assignment of movement directions in accordance with the position of the coordinate at the center of the mask with reference to the Centroid. An enhanced mask was also designed for angular movement to overcome the problem of miss. The spiral data traversal scheme adds to the ability of the process to efficiently identify features. The process thus implements successfully interpolates lines in between existing lines to overcome stair case effect by reducing the stair size.

REFERENCES

[1] FEI Lifan, HUANG Lina, HE Jin, "An Indirect Generalization of Contour Lines Based on DEM Generalization using the 3D Douglas-Peucker Algorithm", The International archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. pp-751-755 Part B1. Beijing 2008 . (Conference proceedings)

[2] A. P. Ozah, O. Kufoniyi, "Accuracy Assessment of Contour Interpolation from 1:50,000 Topographical Maps and SRTM Data For 1:25,000 Topographical Mapping", The International archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. pp- 1347-1354, Part B7. Beijing 2008. (Conference proceedings)

[3] Gill Barequet, Michael T. Goodrich,Aya Levi-Steiner, Dvir Steinerd, "Contour Interpolation By Straight Skeletons", Graphical Models Vol. 66 (2004) pp- 245–260 (Journal)

[4] Chin-Shung Yang, Szu-Pyng Kao, Fen-Bin Lee, Pen-Shan Hung, "Twelve Different Interpolation Methods: A Case Study of SURFER 8.0" XXth ISPRS Congress Technical Commission II July 12-23, 2004 Istanbul, Turkey, pp- 778-785 . (Conference proceedings)

[5] Chao-Hsiung Wu, William Mackaness, " Automatic Contour Labeling for Scanned Topographic Maps" XVIIth ISPRS Congress Technical Commission IV: Cartographic and Data Base Applications of Photogrammetry and Machine Vision August 2-14, 1992, Washington, D.C., USA PP-665-269 (Conference proceedings)

[6] http://stlab.iis.u-tokyo.ac.jp/~wataru/lecture/rsgis/giswb/vol2/cp3/cp3-4. htm(Link).

[7] Jianyun Chai,Takaharu Miyoshi, Eihachiro Nakamae, "Contour Interpolation and Surface Reconstruction of Smooth Terrain Models" Visualization '98. Proceedings 1998 , Page(s): 27 – 33 (Conference proceedings)

[8] Michael B. Gousie Wm. Randolph Franklin, "Constructing a DEM from Gridbased Data by Computing Intermediate Contours" Proceedings of the Eleventh ACM International Symposium on Advances in Geographic Information Systems, November 7–8, 2003, New Orleans, Louisiana, USA (Conference proceedings)

[9] Mohan P. Pradhan, M.K. Ghose, "Automatic Association of Stream Order for Vector Hydrograph Using Spiral Traversal Technique", IOSR Journal of Computer Enginering, Volume 1, Issue 5, pp 09-12, 2012. (Journal)

[10] Türkay Gökgöz1, Mehmet Selçuk, A New Approach for the Simplification of Contours, Cartographica: The International Journal for Geographic Information and Geovisualization, University of Toronto Press, Volume 39, Number 4 / Winter 2004, pp-37-44. (Journal)