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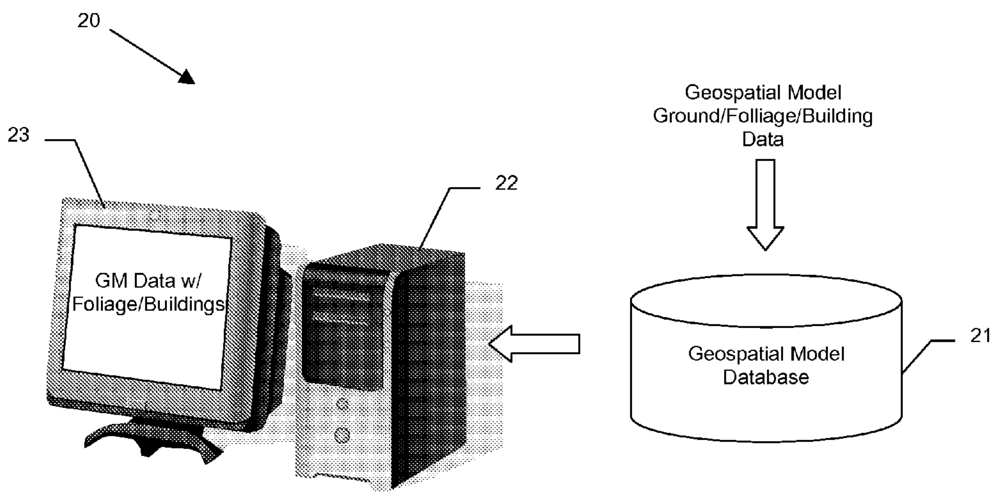
[Continued on next page]

(54) Title: GEOSPATIAL MODELING SYSTEM FOR SEPARATING FOLIAGE DATA FROM BUILDING DATA BASED UPON LOOSE AND STRICT TOLERANCE NOISE FILTERING OPERATIONS AND RELATED METHODS



(57) Abstract: A geospatial modeling system (20) may include a geospatial model database (21) and a processor (22). The processor (22) may cooperate with the geospatial model database (21) for extracting ground data from foliage and building data (51), and performing a plurality of noise filtering operations on the foliage and building data comprising a first loose tolerance filtering to determine an inclusive estimate of building locations and a second strict tolerance filtering to reduce false building locations. The processor (22) may also cooperate with the geospatial model database (21) for performing at least one edge recovery operation to compensate for noisy building perimeters, and separating foliage data from the building data based upon the noise filtering operations and the at least one edge recovery operation.

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GEOSPATIAL MODELING SYSTEM FOR SEPARATING FOLIAGE DATA FROM BUILDING DATA BASED UPON LOOSE AND STRICT TOLERANCE NOISE FILTERING OPERATIONS AND RELATED METHODS

The present invention relates to the field of topographical modeling, and, more particularly, to geospatial modeling systems and related methods.

Topographical models of geographical areas may be used for many applications. For example, topographical models may be used in flight simulators and for planning military missions. Furthermore, topographical models of man-made structures (e.g., cities) may be extremely helpful in applications such as cellular antenna placement, urban planning, disaster preparedness and analysis, and mapping, for example.

Various types and methods for making topographical models are presently being used. One common topographical model is the digital elevation map (DEM). A DEM is a sampled matrix representation of a geographical area which may be generated in an automated fashion by a computer. In a DEM, coordinate points are made to correspond with a height value. DEMs are typically used for modeling terrain where the transitions between different elevations (e.g., valleys, mountains, etc.) are generally smooth from one to a next. That is, DEMs typically model terrain as a plurality of curved surfaces and any discontinuities therebetween are thus "smoothed" over. Thus, in a typical DEM no distinct objects are present on the terrain.

One particularly advantageous 3D site modeling product is RealSite® from the present Assignee Harris Corp. RealSite® may be used to register overlapping images of a geographical area of interest, and extract high resolution DEMs using stereo and nadir view techniques. RealSite® provides a semi-automated process for making three-dimensional (3D) topographical models of geographical areas, including cities, that have accurate textures and structure boundaries. Moreover, RealSite® models are geospatially accurate. That is, the location of any given point within the model corresponds to an actual location in the geographical area with very high accuracy. The data used to generate RealSite® models may include aerial and satellite photography, electro-optical, infrared, and light detection and ranging (LIDAR).

Another advantageous approach for generating 3D site models is set forth in U.S. Patent No. 6,654,690 to Rahmes et al., which is also assigned to the present Assignee and is hereby incorporated herein in its entirety by reference. This patent discloses an automated method for making a topographical model of an area including terrain and buildings thereon based upon randomly spaced data of elevation versus position. The method includes processing the randomly spaced data to generate gridded data of elevation versus position conforming to a predetermined position grid, processing the gridded data to distinguish building data from terrain data, and performing polygon extraction for the building data to make the topographical model of the area including terrain and buildings thereon.

One potentially challenging aspect of generating geospatial models such as DEMS is distinguishing different types of geospatial data, e.g., foliage data and building data. This is because foliage such as trees results in noisy data (e.g., LIDAR data) because of the varying heights and contours of the leaves, etc. Even though buildings generally provide relatively smooth data towards the centers of the buildings, the edges of the buildings where a transition from roof to ground occurs often produces noisy data as well. Moreover, foliage is often placed directly adjacent to or overlies buildings, which makes distinguishing the two using automated computer processing techniques particularly challenging. As a result, if an operator wants to separate foliage and building data to provide a model of just one or the other types of data, the operator may have to manually designate foliage and buildings in a raw image data scene. However, this can be extremely time consuming and, thus, cost prohibitive in many applications.

In view of the foregoing background, it is therefore an object of the present invention to provide a geospatial modeling system having automated geospatial data type separation features and related methods.

This and other objects, features, and advantages are provided by a geospatial modeling system which may include a geospatial model database and a processor. More particularly, the processor may cooperate with the geospatial model database for extracting ground data from foliage and building data, and performing a plurality of noise filtering operations on the foliage and building data comprising a first loose tolerance filtering to determine an inclusive estimate of building locations, and a second strict tolerance filtering to reduce false building locations. The processor may also cooperate with the geospatial model database for performing at least one edge recovery operation to compensate for noisy building perimeters, and separating foliage data from the building data based upon the noise filtering operations and the at least one edge recovery operation.

In addition, the processor may further perform a masking operation based upon the inclusive estimate of the building locations to generate masked building data. Moreover, the processor may further perform a third filtering based upon the masked building data and the output of the second strict tolerance filtering.

The foliage data and building data may each include elevations associated with respective location points. As such, the plurality of noise filtering operations may include determining a respective center point elevation difference for each location point and based upon a sum of differences between elevations of a given location point and a plurality of neighboring location points. By way of example, the plurality of neighboring location points may be eight neighboring location points. Also, the plurality of noise filtering operations may further include determining a respective neighboring points elevation difference for each pair of adjacent location points based upon a sum of differences between elevations of respective center point elevation differences for the adjacent location points.

The plurality of noise filtering operations may also include selectively replacing foliage and building data points with nulls based upon at least one sum of differences operation and an elevation difference threshold. In addition, the geospatial modeling system may further include a display coupled to the processor for displaying at least one of the separated foliage and building data.

A geospatial modeling method aspect may include extracting ground data from foliage and building data using a processor, and performing a plurality of noise filtering operations on the foliage and building data using the processor comprising a first loose tolerance filtering to determine an inclusive estimate of building locations and a second strict tolerance filtering to reduce false building locations. The method may further include performing at least one edge recovery operation to compensate for noisy building perimeters using the processor, and separating foliage data from the building data using the processor based upon the noise filtering operations and the at least one edge recovery operation.

A computer-readable medium having computer-executable modules may include a geospatial model database module and a processing module. The processing module may cooperate with the geospatial model database for extracting ground data from foliage and building data, and performing a plurality of noise filtering operations on the foliage and building data comprising a first loose tolerance filtering to determine an inclusive estimate of building locations and a second strict tolerance filtering to reduce false building locations. The processing module may further cooperate with the geospatial model database for performing at least one edge recovery operation to compensate for noisy building perimeters, and separating foliage data from the building data based upon the noise filtering operations and the at least one edge recovery operation.

FIG. 1 is a schematic block diagram of a geospatial model system in accordance with the invention.

FIG. 2 is a flow diagram illustrating a geospatial modeling method in accordance with the invention for separating building and foliage geospatial data.

FIGS. 3-5 are 3D grid views illustrating sum of difference filtering operations in accordance with the method of FIG. 2.

FIGS. 6-15 are a series of screen prints illustrating various aspects of the method of FIG. 2.

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

Referring initially to FIG. 1, a geospatial modeling system **20** illustratively includes a geospatial model database **21** and a processor **22** that may advantageously be used for separating different types of geospatial data, such as building and foliage data, for example. By way of example, the processor **22** may be a central processing unit (CPU) of a PC, Mac, or other computing workstation, for example. A display **23** may also be coupled to the processor **22** for displaying geospatial modeling data, as will be discussed further below. The processor **22** may be implemented using a combination of hardware and software components/modules to perform the various operations that will be discussed further below, as will be appreciated by those skilled in the art.

By way of example, the geospatial data may be captured using various techniques such as stereo optical imagery, Light Detecting and Ranging (LIDAR), Interferometric Synthetic Aperture Radar (IFSAR), etc. Generally speaking, the data will be captured from overhead (e.g., nadir) views of the geographical area of interest by airplanes, satellites, etc., as will be appreciated by those skilled in the art. However, oblique images of a geographical area of interest may also be used in addition to (or instead of) the nadir images to add additional 3D detail to a geospatial model. The raw image data captured using LIDAR, etc., may be processed upstream from the geospatial model database **21** into a desired format, such as a digital elevation model (DEM), or this may be done by the processor **22**.

Turning additionally to FIGS. 2 through 15, a method for separating foliage data from the building data using the system **20** is now described. Initially, a DEM **50** (FIG. 6) of a given geographical area of interest or scene is generated, at Block **30**. By way of example, the above-described RealSite® system or the system set forth in U.S. Patent No. 6,654,690 may be used for generating the initial DEM. Of course, other suitable approaches for generating DEMs may also be used. The DEM **50** may be generated by another computer and stored in the geospatial model database

21, or it may be created by the processor **22** based upon "raw" geospatial data (e.g., LIDAR data, etc.) stored in the database. The DEM **50** illustratively includes terrain (i.e., ground), buildings, and foliage data. Yet, in some applications it is desirable to separate one of these types of data, such as the building or foliage data, from the remainder of the DEM data so that it can be viewed and/or processed individually.

To this end, a first step of extracting ground data from foliage and building data is performed by the processor **22**, at Block **31**, to generate foliage and building data **51**. As will be appreciated by those skilled in the art, the foliage, building, and ground data include elevations or heights associated with respective location points or posts.

Following the ground extraction, a first filtering operation is performed on the foliage and building data **51** using a first loose tolerance to determine an inclusive estimate of building locations **52**, at Block **32**. Referring more particularly to FIG. 3, the filtering operation includes defining a center location point **45** and its neighboring location points **46**. Then, the processor **22** performs a sum of differences operation which includes determining a respective center point **45** elevation difference based upon a sum of differences between elevations of the center point and the neighboring location points **46**, where:

$$CenterDifference = \sum_{i=-1}^{1} \sum_{j=-1}^{1} | x_{i,j} - x_{o,o} |. \qquad (1)$$

In the illustrated embodiment, eight neighboring location points **46** are used, but in other embodiments more or less neighboring location points may be used. The above-described sum of differences operation is performed for each of the foliage and building data location points within the DEM. That is, each location point is defined as a center and the sum of differences with respect to its neighboring location points is determined in accordance with equation (1).

The filtering operation further includes determining a respective neighboring points **46** elevation difference for each pair of adjacent location points based upon a sum of differences between elevations of respective center point elevation differences for the adjacent location points. That is, given two adjacent location points, a sum of differences is determined between the two location point elevations relative to the original location point elevations (FIG. 4). In the present example, there will be eight non-trivial neighbor differences per each center location point, where:

$$NeighborDifference_{di,\,dj} = \sum_{i=-1}^{1} \sum_{j=-1,}^{1} | x_{i,\,j} - x_{i\,+\,di,\,j\,+\,dj} | \,. \qquad (2)$$

Once the neighboring points elevation differences are determined, then six adjacent points are identified that are not on a primary diagonal (indicated by shading in FIG. 5(a)) for a given center point **45**. The eight-neighbor difference is then determined for each of the six adjacent points (FIG. 5(b)), as is a center difference of each set of the eight neighbor differences (FIG. 5(c)). A self-similarity is determined to be the smallest center difference, where higher values correspond to larger differences.

The above-described filtering operation allows a "rough" estimation of the foliage in the building and foliage data DEM **51**, which can then be separated from the building data to provide the inclusive estimate of building locations **52**. Stated alternatively, using a loose tolerance filtering will identify a large portion of the foliage, but will intentionally allow some foliage data to remain (which appear as small spots or speckles in FIG. 7) so that little or no building data is excluded.

Next, a DEM subtract operation is performed, at Block **33**, in which the inclusive estimate of building locations **52** is "subtracted" from the building and foliage data **51** to provide a preliminary estimate of the foliage **53**. The processor **22** may then begin edge recovery operations, as indicated by the dashed box **34** in FIG. 2, to compensate for noisy building perimeters. More particularly, the first edge recovery operation includes a null expansion on the inclusive estimate of building locations **52**, at Block **35**, to remove the foliage remnants (i.e., specks) therein (FIG. 9), and produce an estimate of the buildings without specks **54**.

The processor **22** may then perform a null filling operation on the estimate of buildings without specks **54** to generate a mask of building data **55** (FIG. 10). That is, the null filling approximates geometric shapes of the buildings, which are shown in FIG. 11. The mask of building data **55** and the preliminary estimate of the foliage **53** are then used to perform a point in poly filtering operation to generate an improved estimate of the foliage **56**. A next edge recovery operation includes a DEM subtract operation, namely subtracting the improved estimate of the foliage **56** from the building and foliage data **51** to get an improved estimate of the building data, at Block **38**. The above-described edge recovery operations may then be repeated one or more times, depending upon the desired accuracy for a given implementation, to produce a final mask of building data **57** that will be used in a later step.

In addition, a second strict tolerance filtering is also performed on the building and foliage data **51** to reduce false building locations, and this filtering produces a second estimate of the building data **58**, at Block **39**. More particularly, the second filtering operation is similar to the first filtering operation described above with reference to FIGS. 3-5, but a more tight or strict tolerance is used. The relative values of the strict and loose tolerance thresholds used in the filtering operations may be determined based upon factors such as the type of data being processed, data resolution, and the desired accuracy of the resulting building and/or foliage data, for example, as will be appreciated by those skilled in the art.

A DEM subtract operation is then performed based upon the building and foliage data **51** and the second estimate of building data **58** to provide a second estimate of the foliage data **59**, at Block **40** (FIG. 13). Another point in poly filtering operation is then performed, at Block **41**, based upon the second estimate of the foliage data **59** and the final mask of building data **57** to produce a final estimate of the foliage data **60**. Then, another DEM subtract operation may be performed using the building and foliage data **51** and the final estimate of the foliage data **60** to generate a final building data estimate **61**, at Block **42**. The processor **22** may then selectively display the final separated foliage data **60** or the final building data **61** on the display **23**, or it may be stored for further processing or usage.

In summary, the above-described approach advantageously uses a center location point difference of neighbor differences as a noise metric, as well as an edge recovery routine to compensate for noisy building parameters. Furthermore, use of a loose tolerance to obtain a general idea of where the buildings are, and then a strict tolerance to help reduce the changes of false buildings, provides still further accuracy. However, it will be appreciated that in certain embodiments some of the above-described operations may be omitted or performed in an order different than shown or described.

The above-described approach may advantageously provide the ability to automatically detect and/or distinguish foliage from underlying terrain and man-made (i.e., building) structures within a DEM, and model them separately. It may further allow modeling of foliage as 3D point (i.e., voxels), as well as the modeling of man-made structures and terrain as polygons.

CLAIMS

1. A geospatial modeling system comprising:

a geospatial model database; and

a processor cooperating with said geospatial model database for extracting ground data from foliage and building data,

performing a plurality of noise filtering operations on the foliage and building data comprising a first loose tolerance filtering to determine an inclusive estimate of building locations and a second strict tolerance filtering to reduce false building locations,

performing at least one edge recovery operation to compensate for noisy building perimeters, and

separating foliage data from the building data based upon the noise filtering operations and the at least one edge recovery operation.

2. The geospatial modeling system of Claim 1 wherein said processor further performs a masking operation based upon the inclusive estimate of the building locations to generate masked building data.

3. The geospatial modeling system of Claim 2 wherein said processor further performs a third filtering based upon the masked building data and the output of the second strict tolerance filtering.

4. The geospatial modeling system of Claim 1 wherein the foliage data and building data each comprises elevations associated with respective location points; and wherein the plurality of noise filtering operations comprise determining a respective center point elevation difference for each location point and based upon a sum of differences between elevations of a given location point and a plurality of neighboring location points.

5. The geospatial modeling system of Claim 4 wherein the plurality of noise filtering operations further comprise determining a respective neighboring points elevation difference for each pair of adjacent location points based upon a sum of differences between elevations of respective center point elevation differences for the adjacent location points.

6. A geospatial modeling method comprising:

extracting ground data from foliage and building data using a processor;

performing a plurality of noise filtering operations on the foliage and building data using the processor comprising a first loose tolerance filtering to determine an inclusive estimate of building locations and a second strict tolerance filtering to reduce false building locations;

performing at least one edge recovery operation to compensate for noisy building perimeters using the processor; and

separating foliage data from the building data using the processor based upon the noise filtering operations and the at least one edge recovery operation.

7. The method of Claim 6 further comprising performing a masking operation using the processor based upon the inclusive estimate of the building locations to generate masked building data.

8. The method of Claim 6 wherein the foliage data and building data each comprises elevations associated with respective location points; and wherein the plurality of noise filtering operations comprise determining a respective center point elevation difference for each location point and based upon a sum of differences between elevations of a given location point and a plurality of neighboring location points.

9. The method of Claim 8 wherein the plurality of noise filtering operations further comprise determining a respective neighboring points elevation difference for each pair of adjacent location points based upon a sum of differences between elevations of respective center point elevation differences for the adjacent location points.

10. The method of Claim 6 wherein the plurality of noise filtering operations further comprise selectively replacing foliage and building data points with nulls based upon at least one sum of differences operation and an elevation difference threshold.

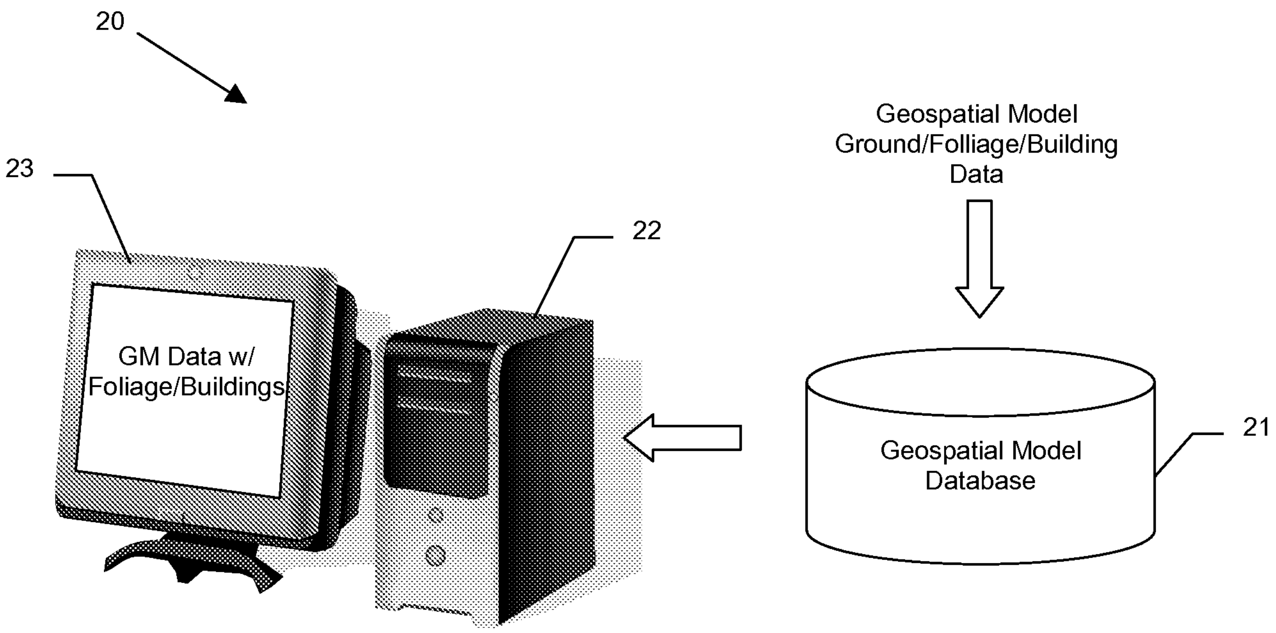
20
23
22
Geospatial Model
Ground/Folliage/Building
Data
GM Data w/
Foliage/Buildings
Geospatial Model
Database
21

FIG. 1

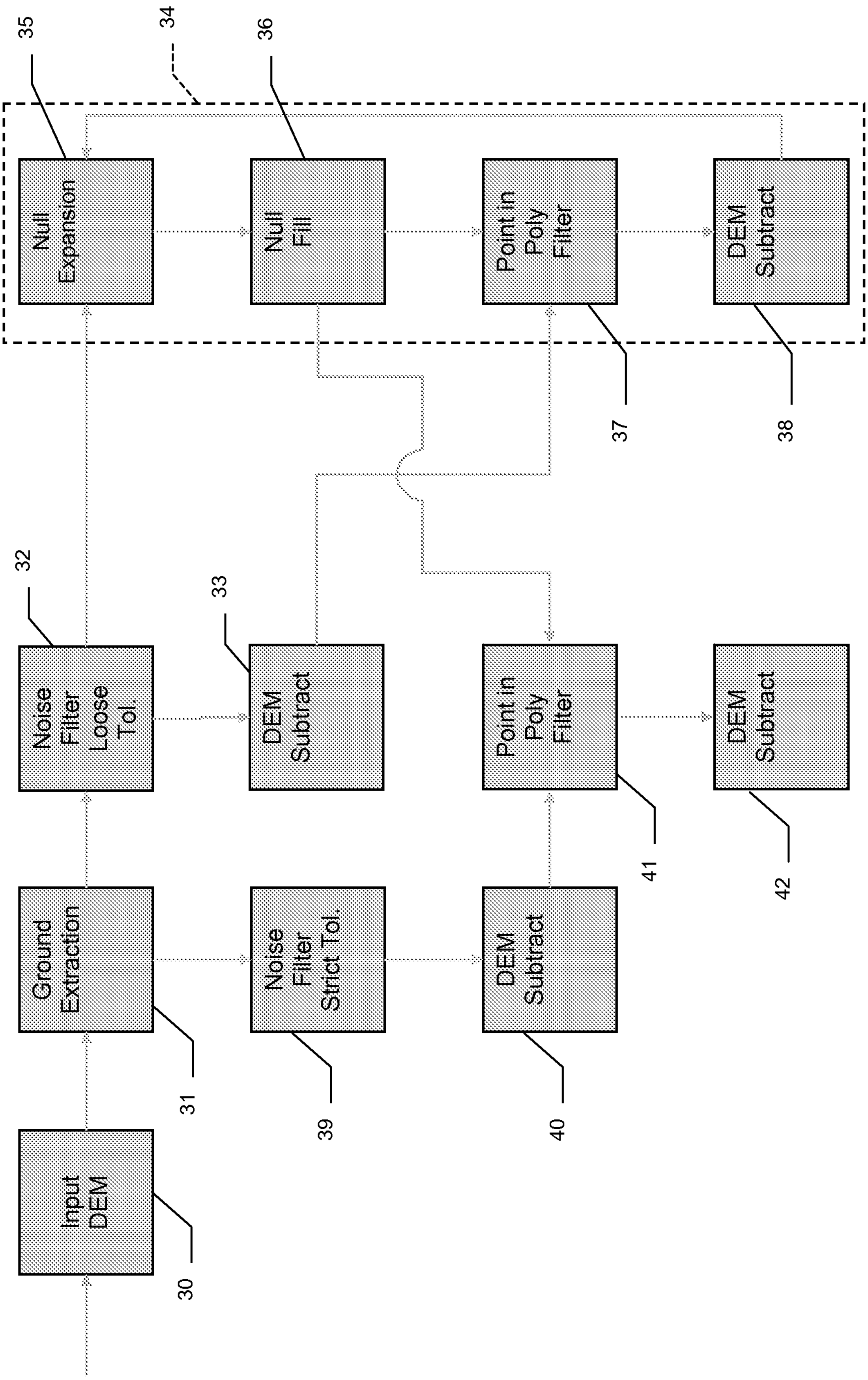
Input DEM
30
Ground Extraction
31
Noise Filter Loose Tol.
32
DEM Subtract
33
34
Null Expansion
35
Null Fill
36
Point in Poly Filter
37
DEM Subtract
38
Noise Filter Strict Tol.
39
DEM Subtract
40
Point in Poly Filter
41
DEM Subtract
42

FIG. 2

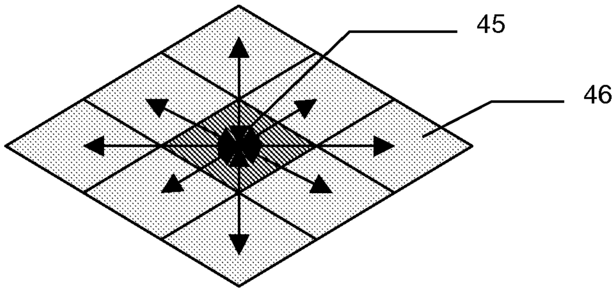

FIG. 3

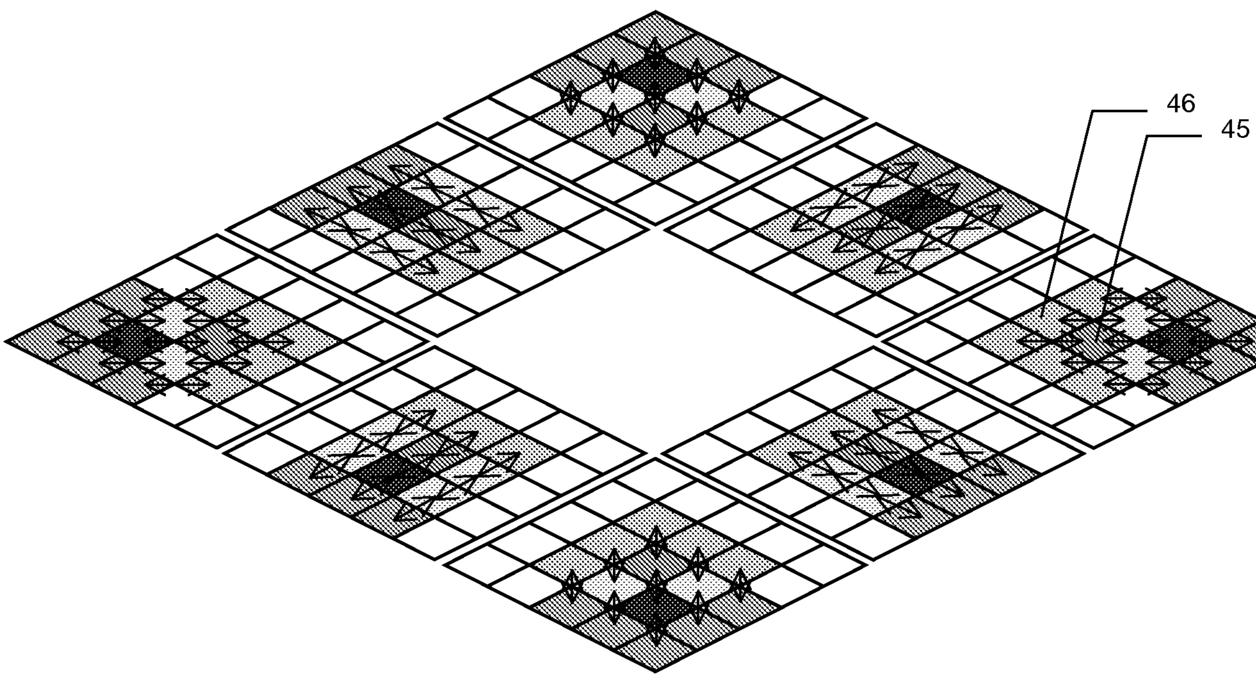

FIG. 4

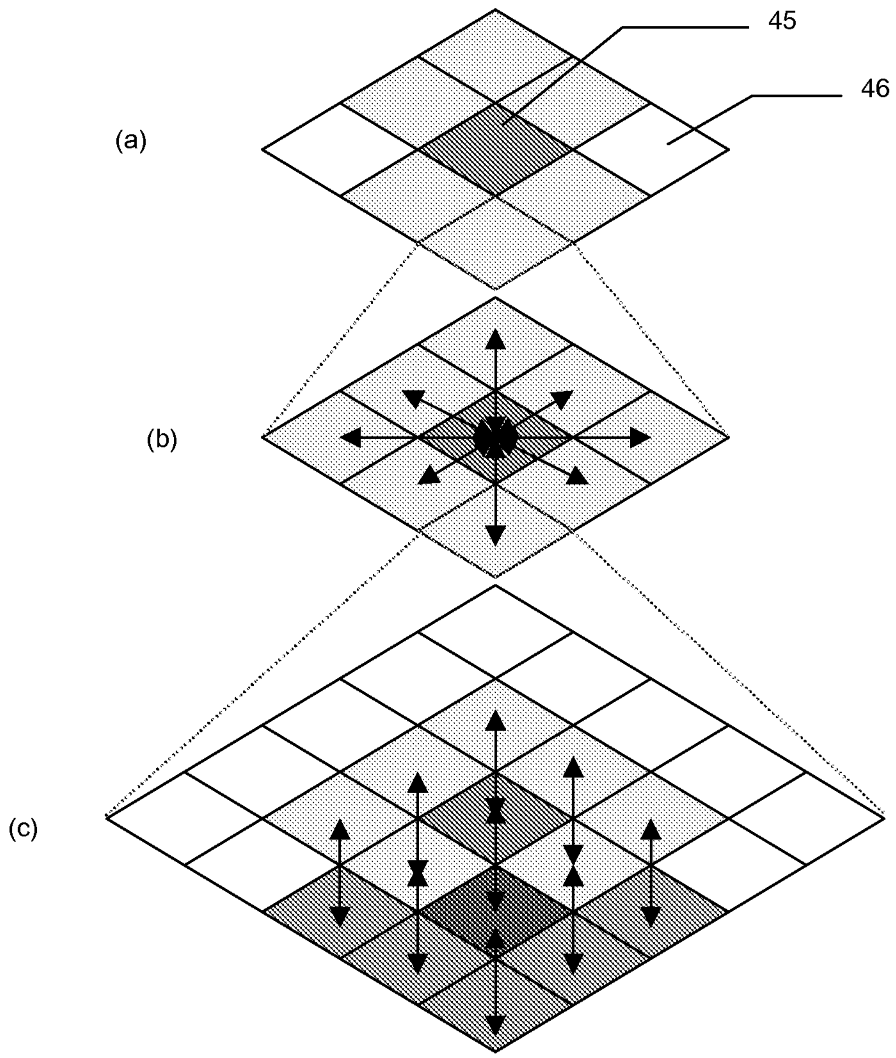

FIG. 5

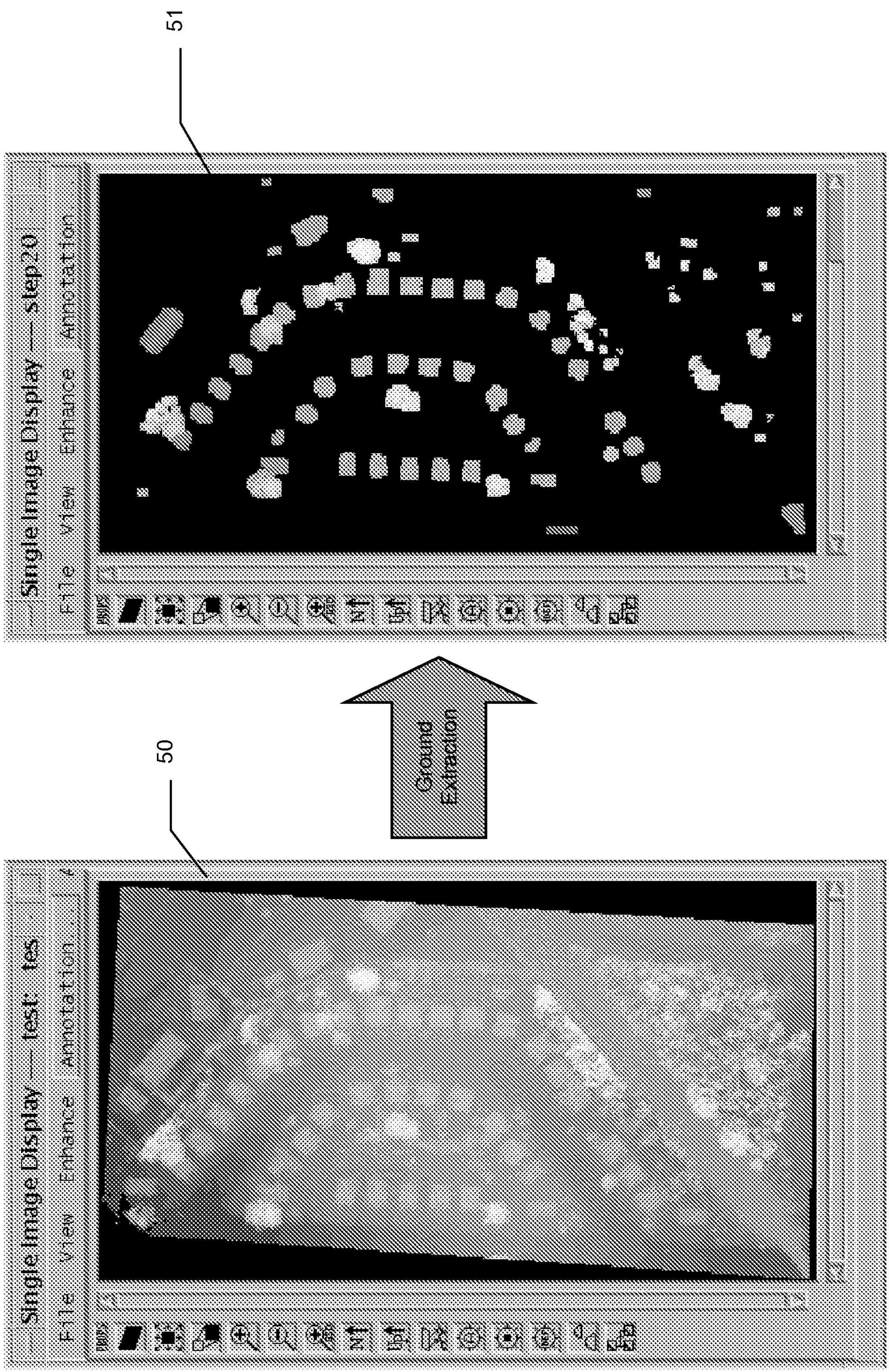
51
Single Image Display — step20
File View Enhance Annotation
Ground Extraction
50
Single Image Display — test: tes
File View Enhance Annotation

FIG. 6

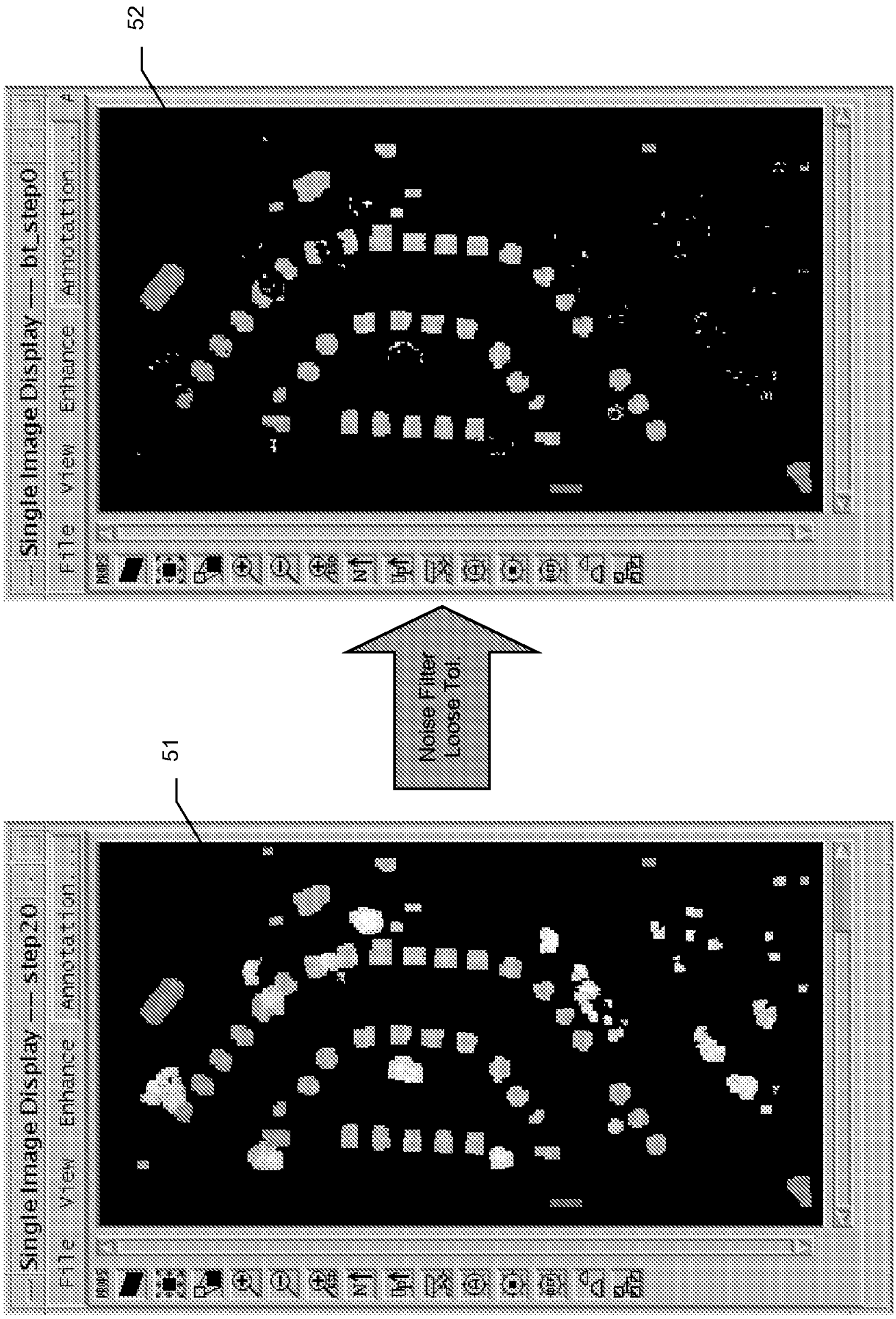
52
Single Image Display — bt_step0
File View Enhance Annotation
Noise Filter
Loose Tol.
51
Single Image Display — step20
File View Enhance Annotation

FIG. 7

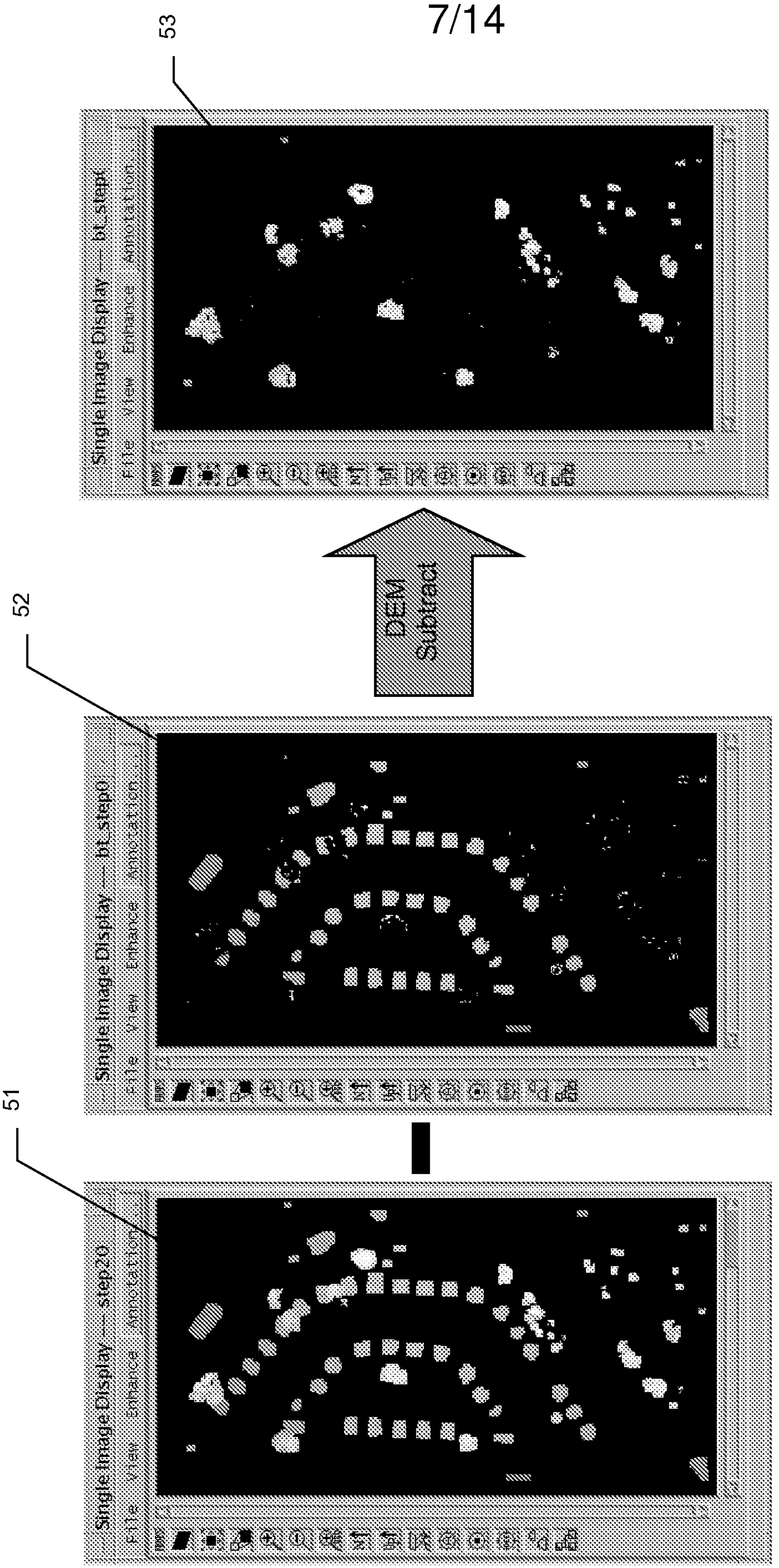
53
52
51
DEM Subtract
Single Image Display — step20
Single Image Display — bt_step0
File View Enhance Annotation

FIG. 8

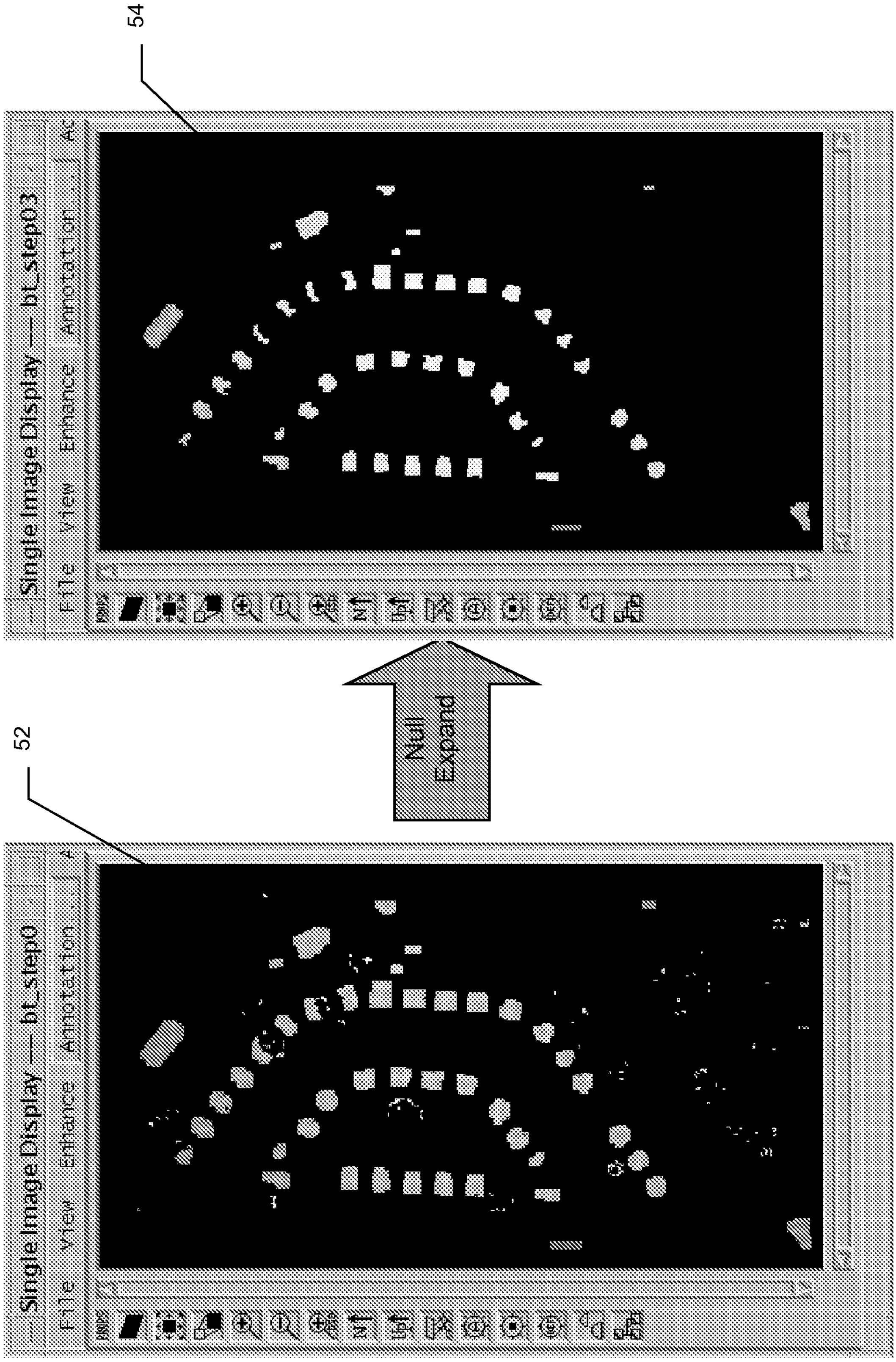
54
Single Image Display — bt_step03
File View Enhance Annotation
Null
Expand
52
Single Image Display — bt_step0
File View Enhance Annotation

FIG. 9

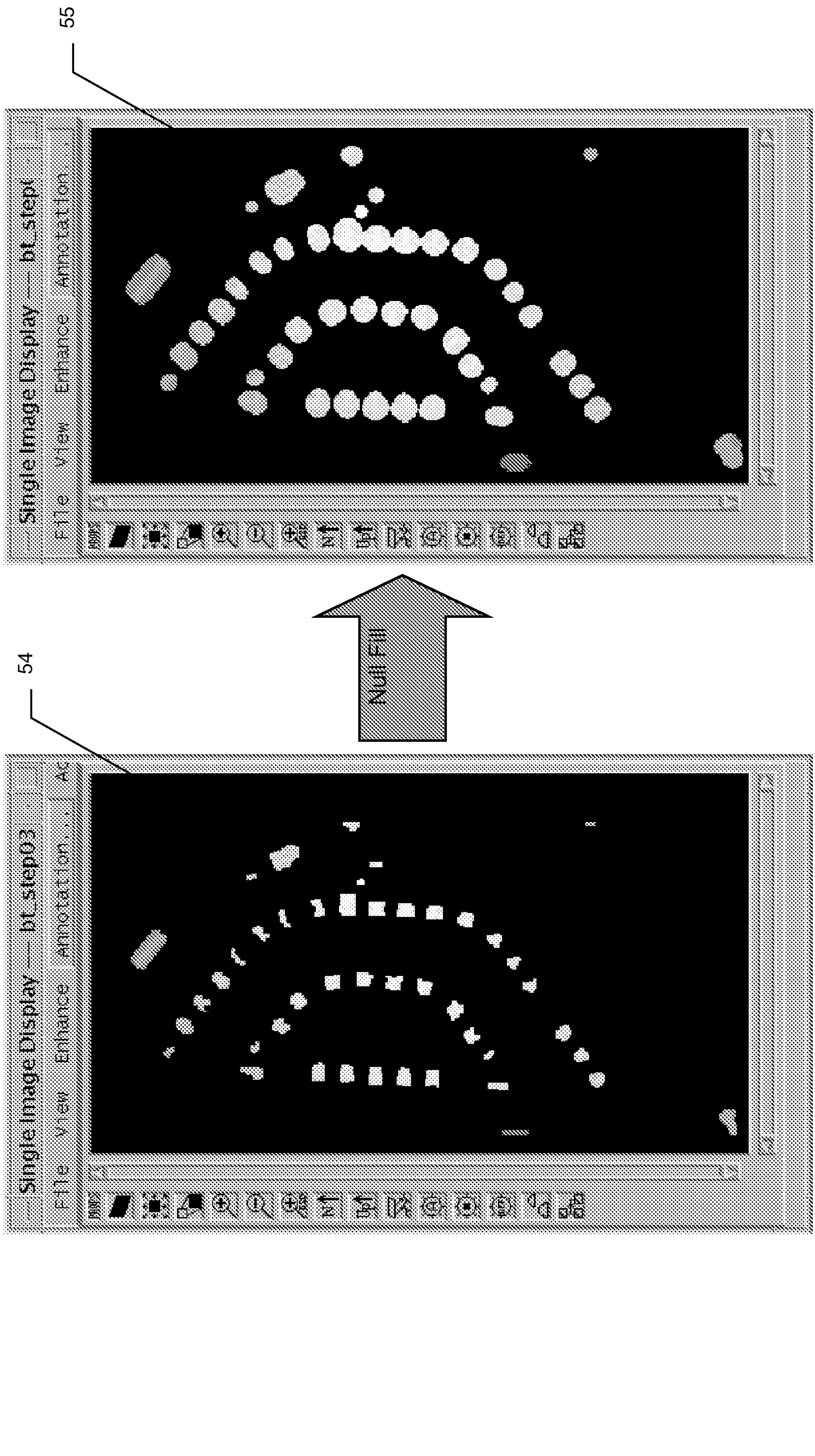
55
Single Image Display — bt_stept
File View Enhance Annotation
Null Fill
54
Single Image Display — bt_step03
File View Enhance Annotation...

FIG. 10

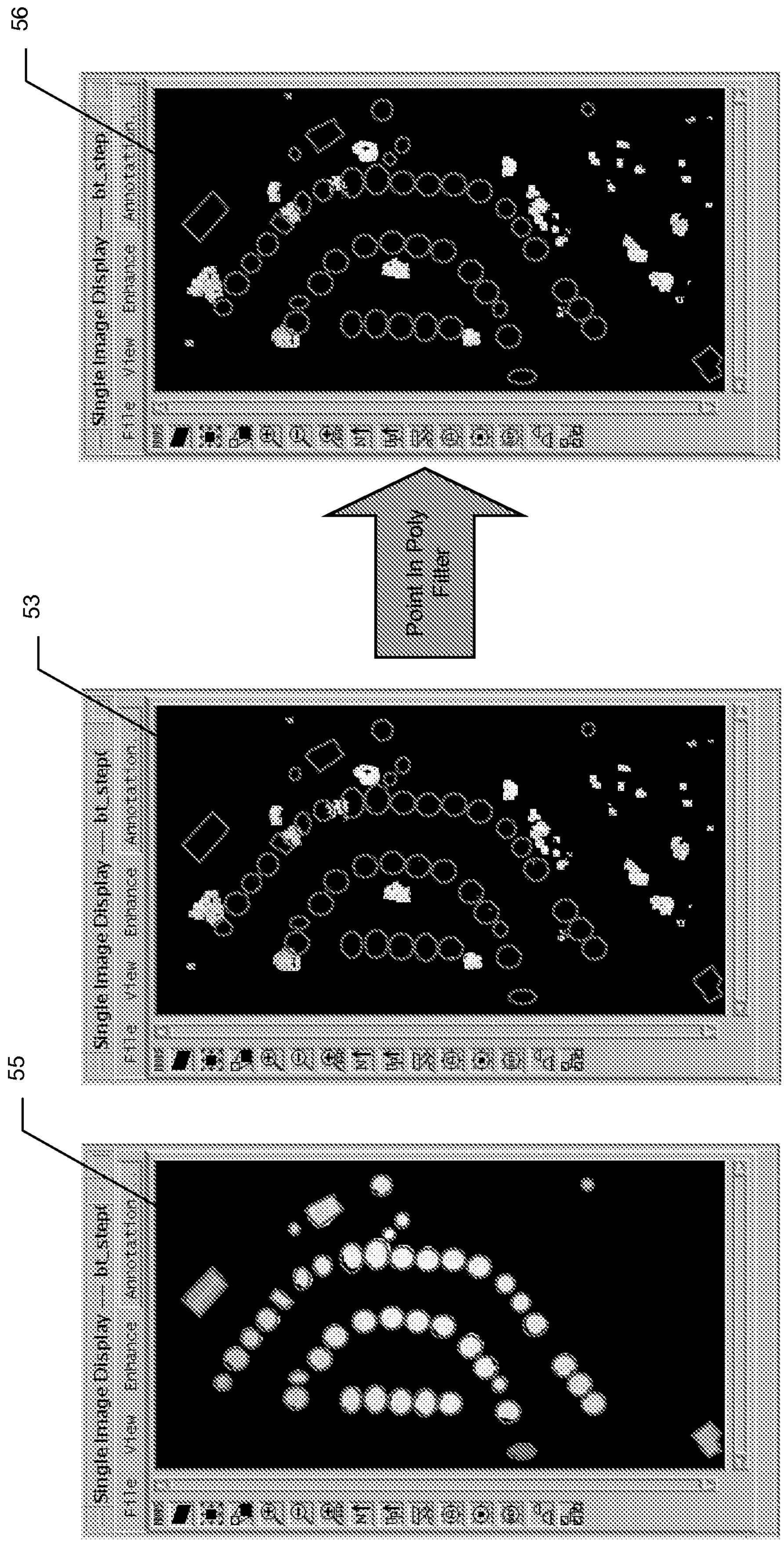
56
53
55
Point In Poly Filter
Single Image Display — bt_step
File View Enhance Annotation

FIG. 11

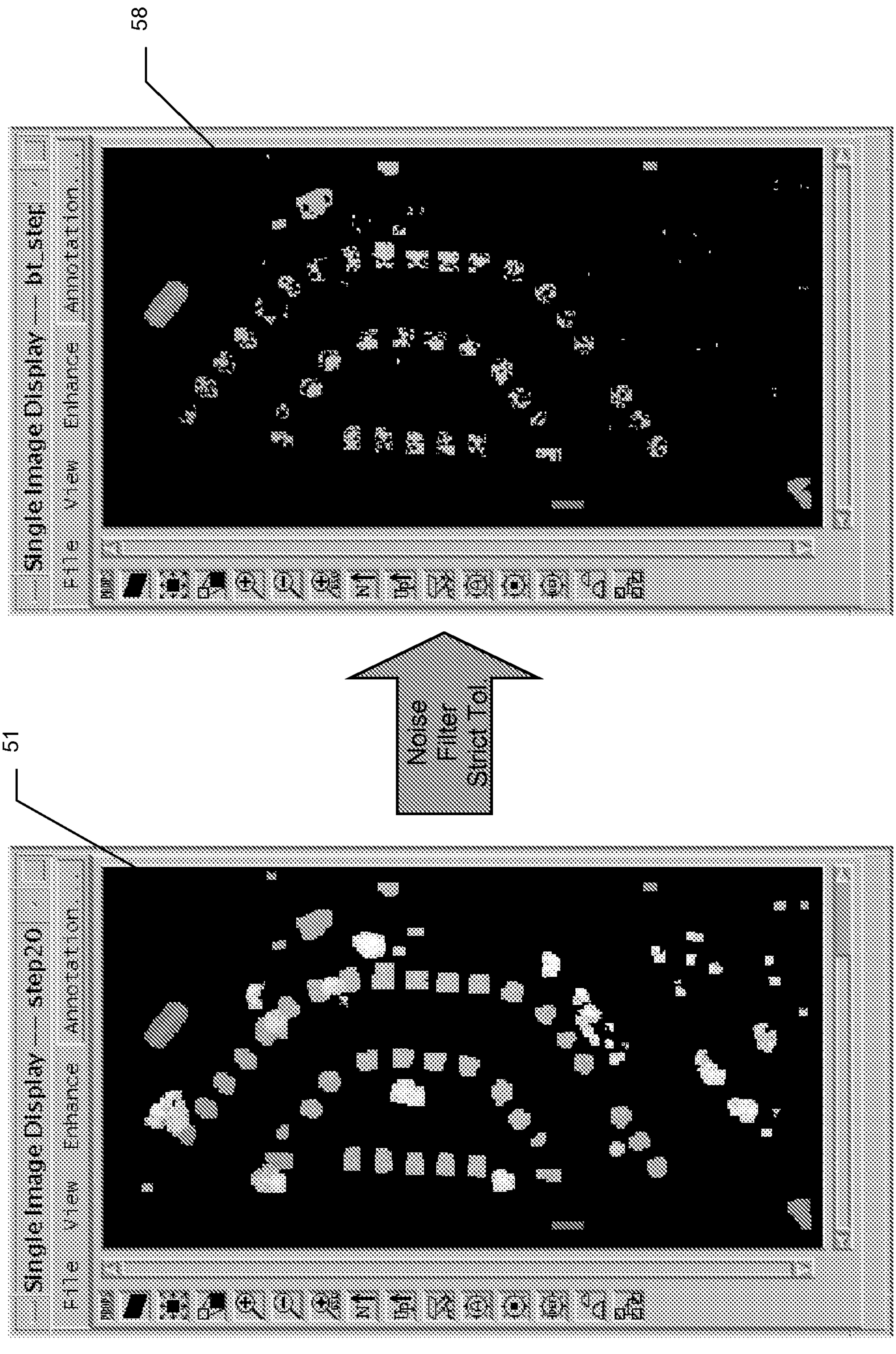
58
Single Image Display — bt_step
File View Enhance Annotation
Noise Filter Strict Tol.
51
Single Image Display — step20
File View Enhance Annotation

FIG. 12

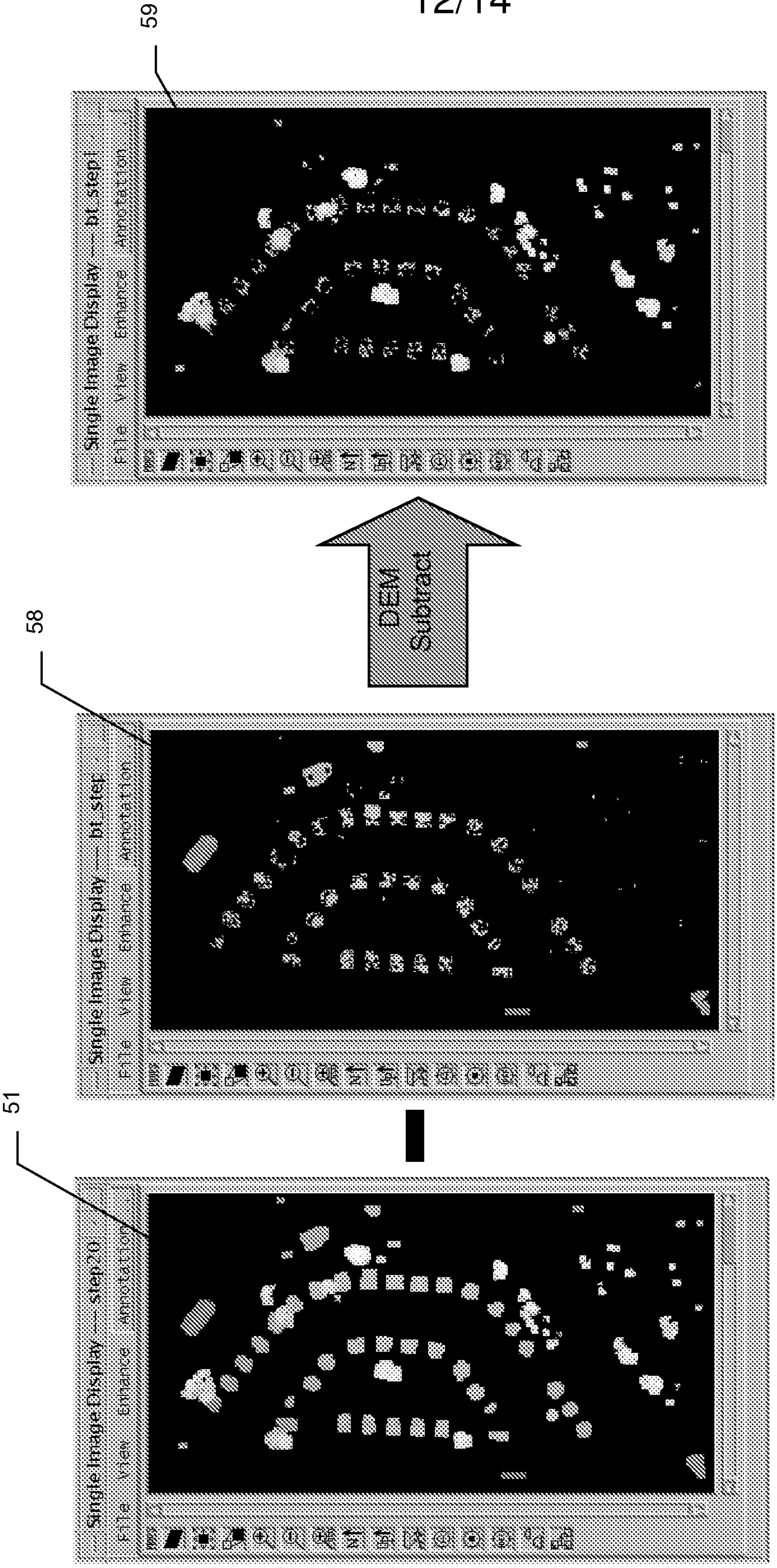
59
58
51
DEM Subtract
Single Image Display — bt_step1
Single Image Display — bt_step
Single Image Display — step20
File View Enhance Annotation

FIG. 13

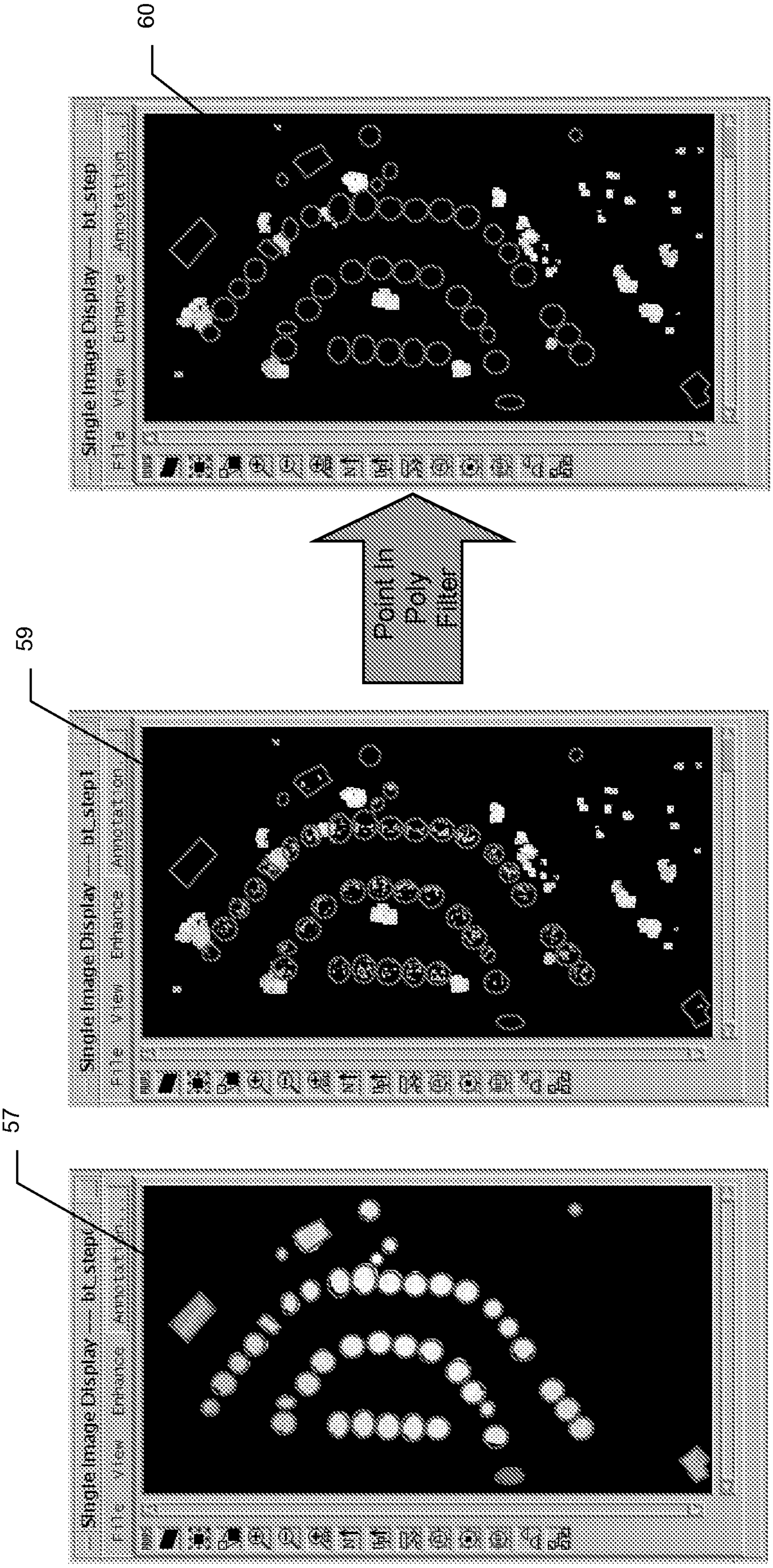
60
Single Image Display — bt_step
File View Enhance Annotation
Point In Poly Filter
59
Single Image Display — bt_step1
File View Enhance Annotation
57
Single Image Display — bt_step
File View Enhance Annotation

FIG. 14

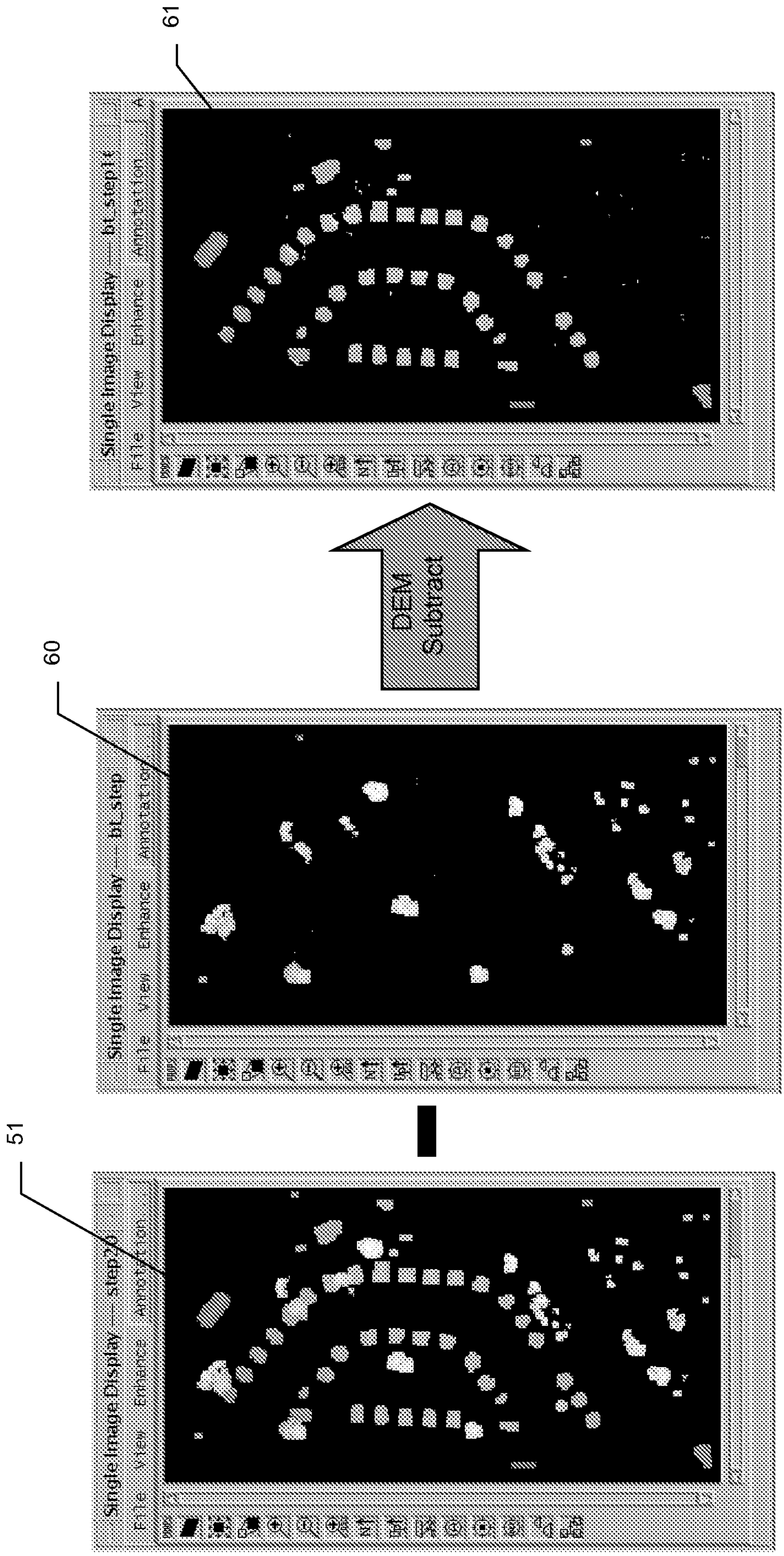
61
60
51
DEM Subtract
Single Image Display — bt_step1t
Single Image Display — bt_step
File View Enhance Annotation

FIG. 15