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(54) APPARATUS AND METHOD FOR SIMULATION

(57) A simulation method and system is provided for simulating a terrain and the objects above the terrain to a viewer. The method includes the steps of providing a first data base which includes a digital representation of the terrain and a second data base which includes a digital representation of the objects located above the terrain. The method also includes the steps of generating individual images, each of which simulates a viewing volume of the terrain and the objects and finally repeating the step of generating, thereby producing a plurality of images simulating a plurality of viewing volumes. The step of generating includes independently producing first and second images from information stored in separate first and second data bases, respectively, merging the first image and the second image, thereby forming an image simulating a viewing volume and displaying the image simulating the viewing volume.

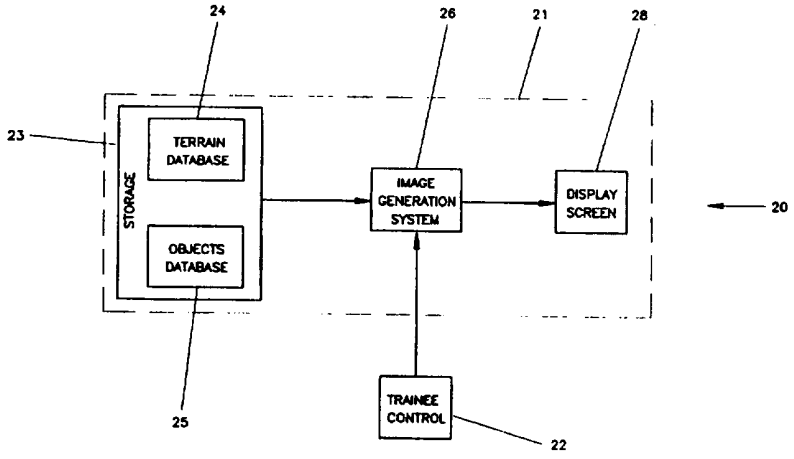

Fig. 2

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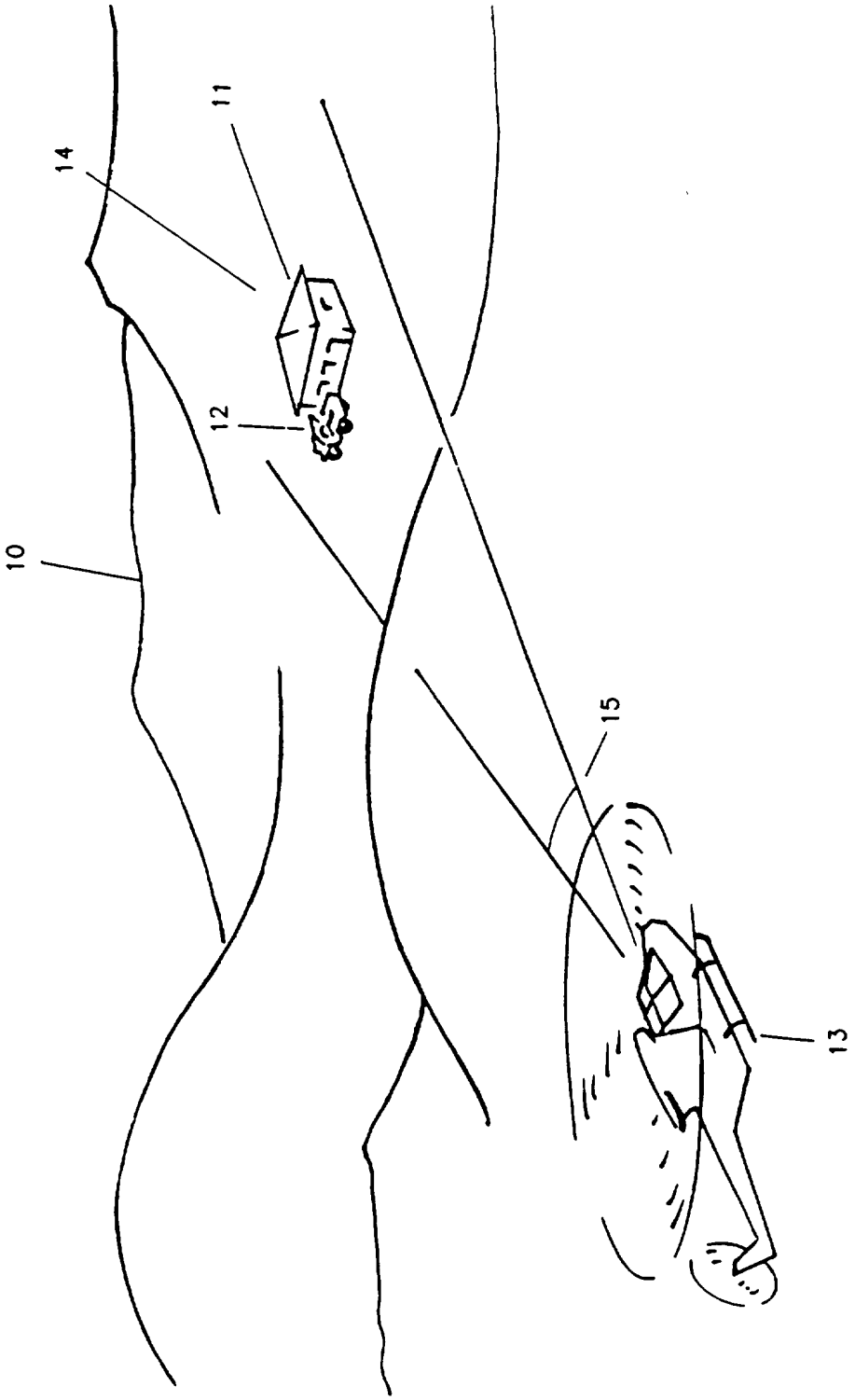

Fig. 1

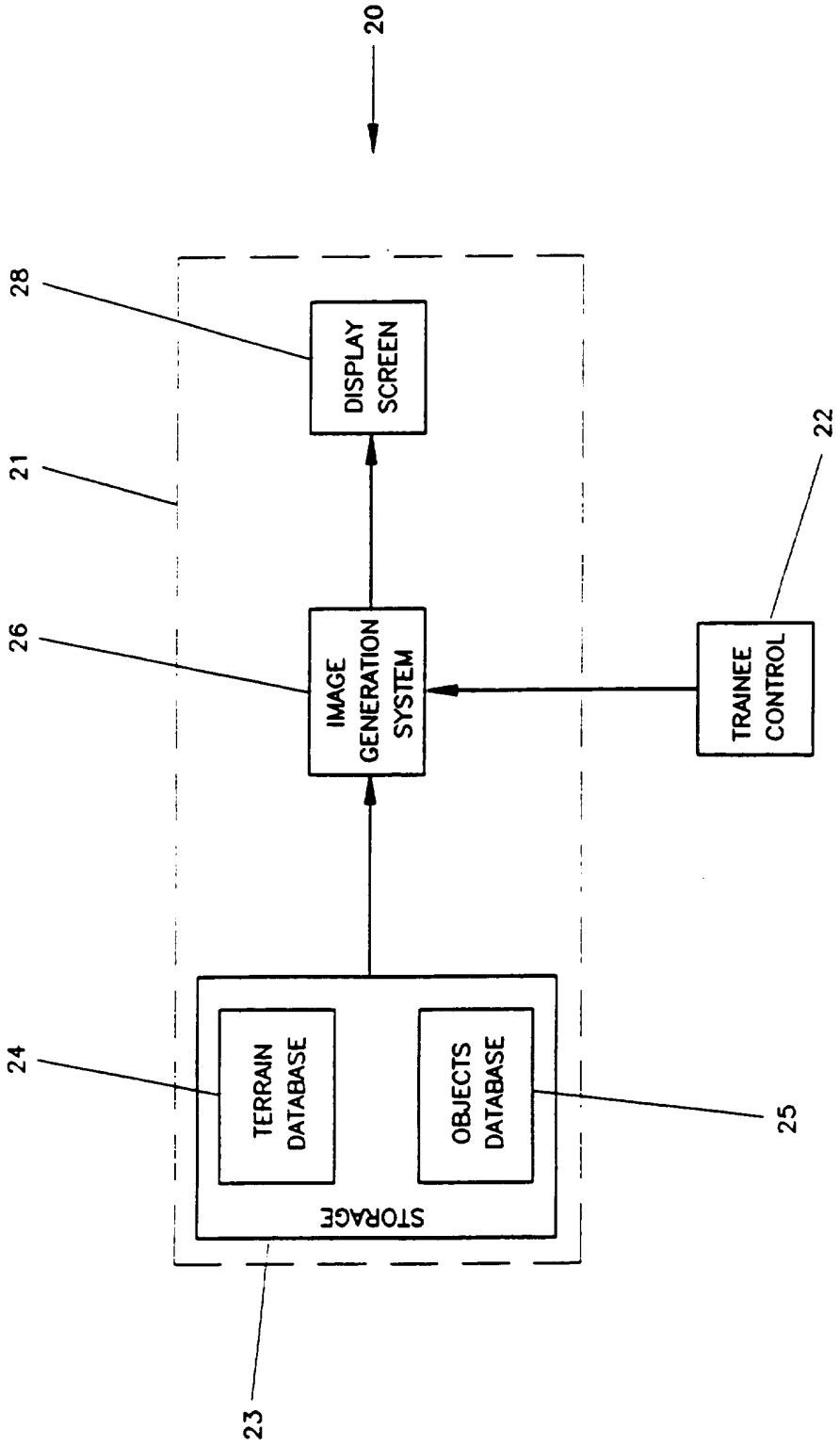
20
28
DISPLAY SCREEN
21
22
26
IMAGE GENERATION SYSTEM
TRAINEE CONTROL
24
TERRAIN DATABASE
OBJECTS DATABASE
25
STORAGE
23

Fig. 2

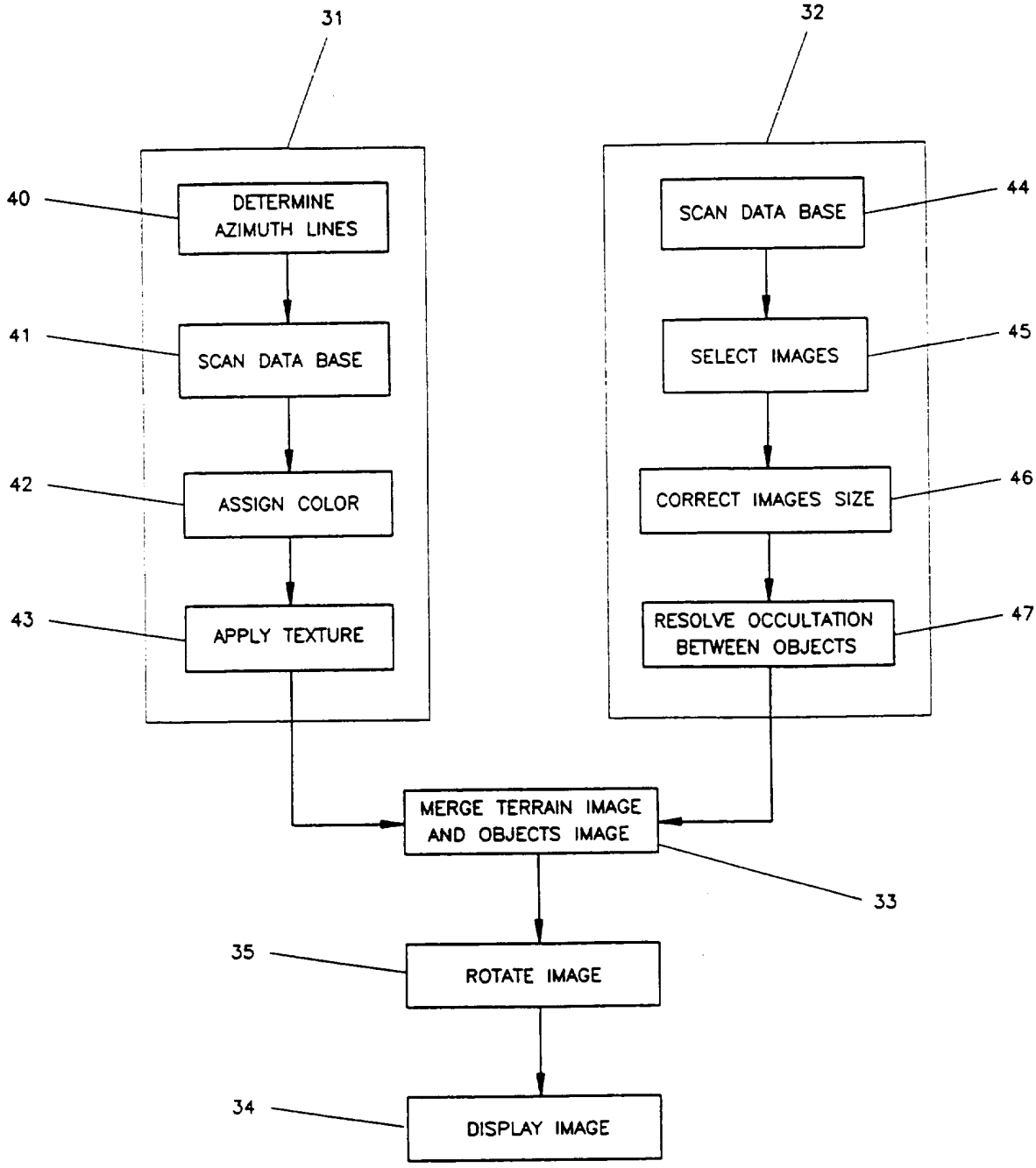
31
32
40
DETERMINE AZIMUTH LINES
41
SCAN DATA BASE
42
ASSIGN COLOR
43
APPLY TEXTURE
44
SCAN DATA BASE
45
SELECT IMAGES
46
CORRECT IMAGES SIZE
47
RESOLVE OCCULTATION BETWEEN OBJECTS
MERGE TERRAIN IMAGE AND OBJECTS IMAGE
33
35
ROTATE IMAGE
34
DISPLAY IMAGE

Fig. 3

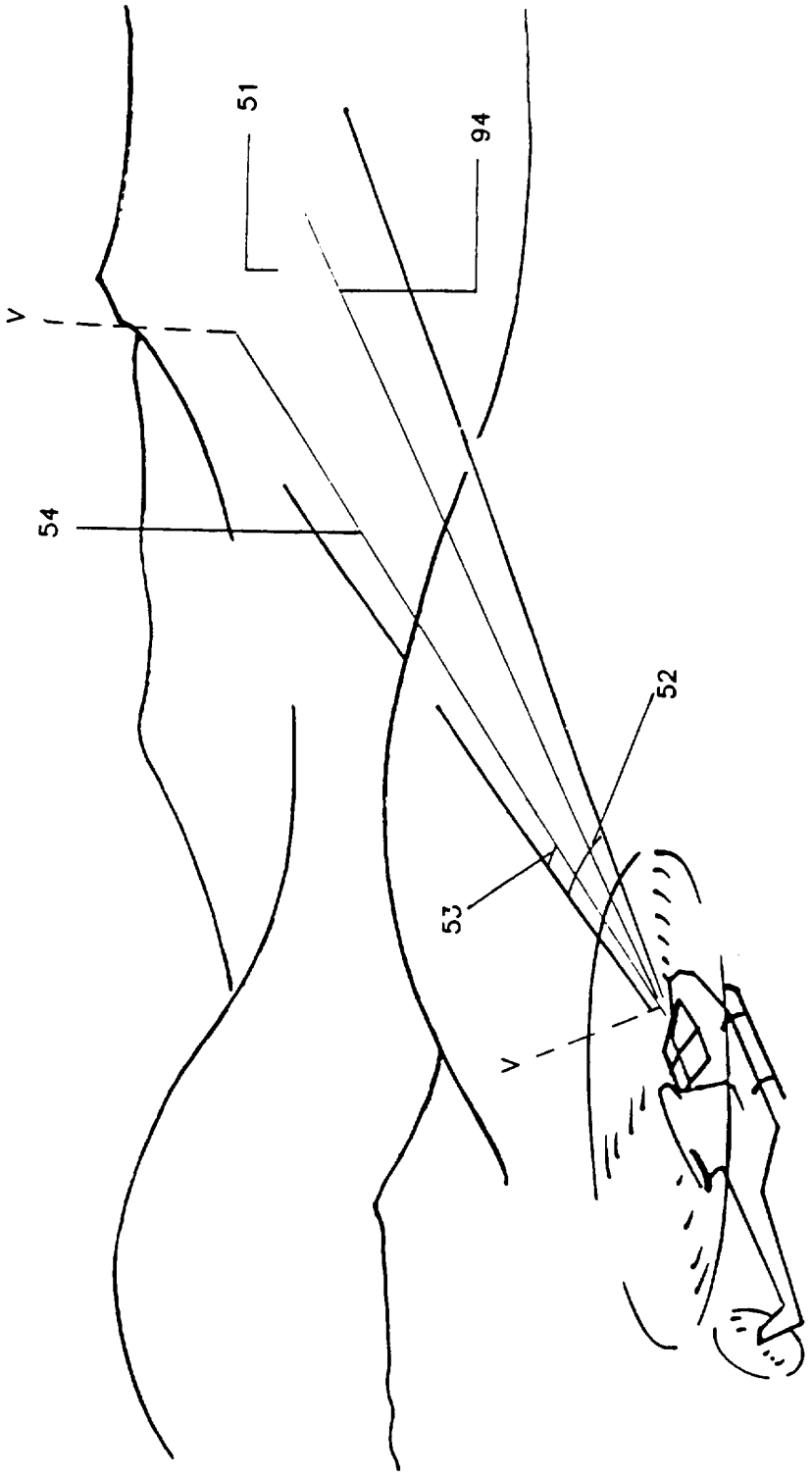

Fig. 4

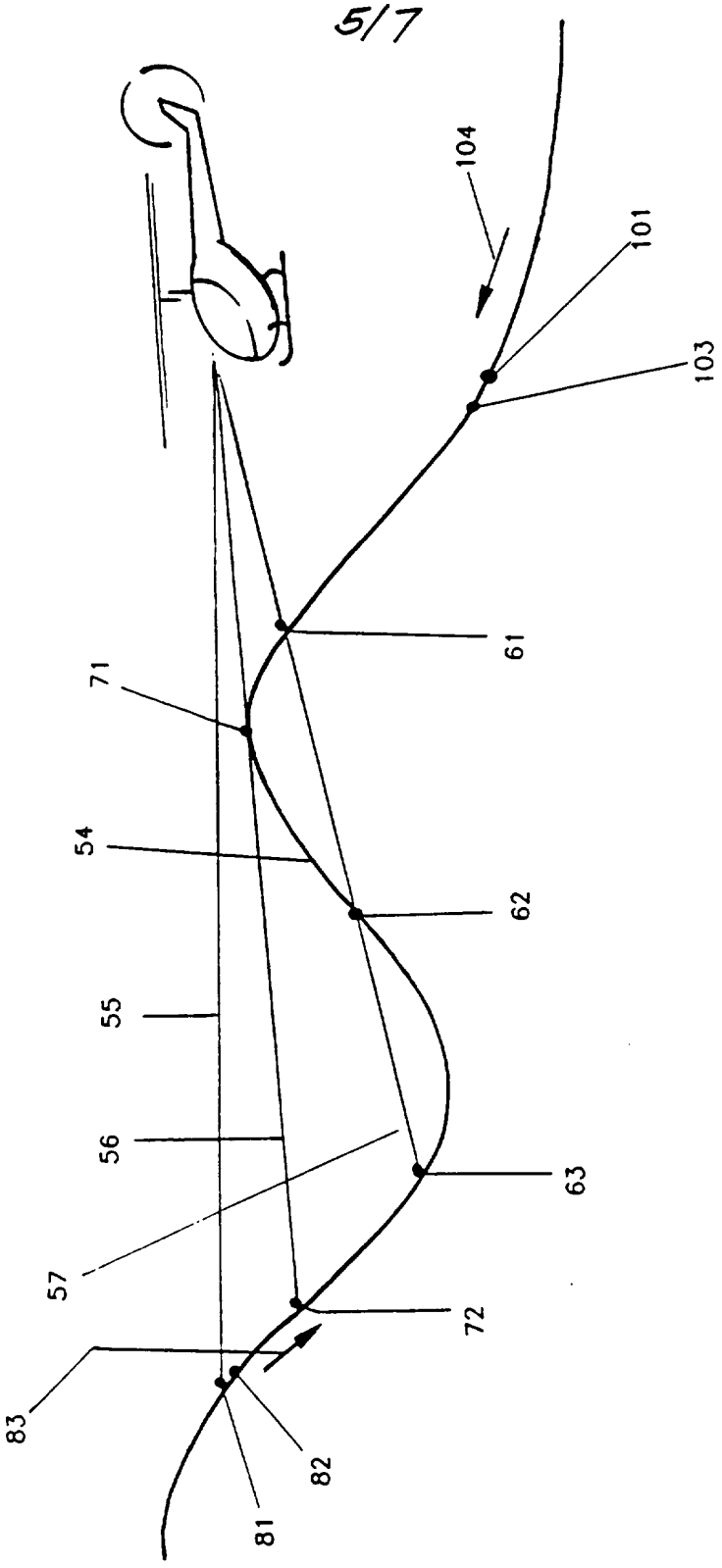

Fig. 5

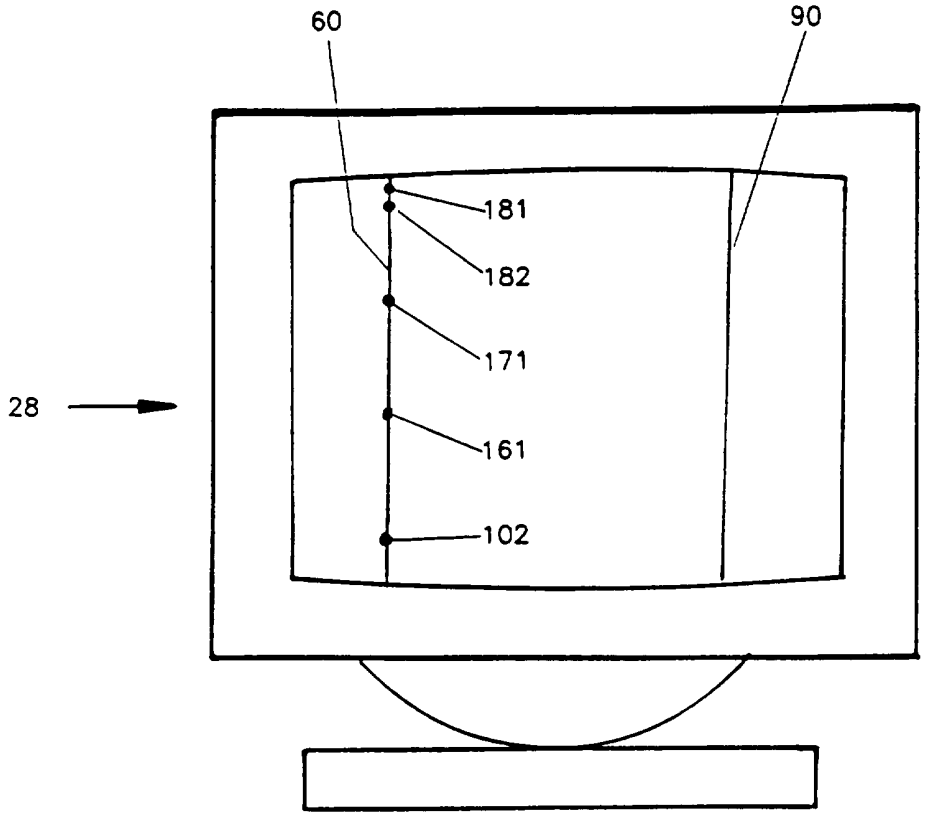

Fig. 6

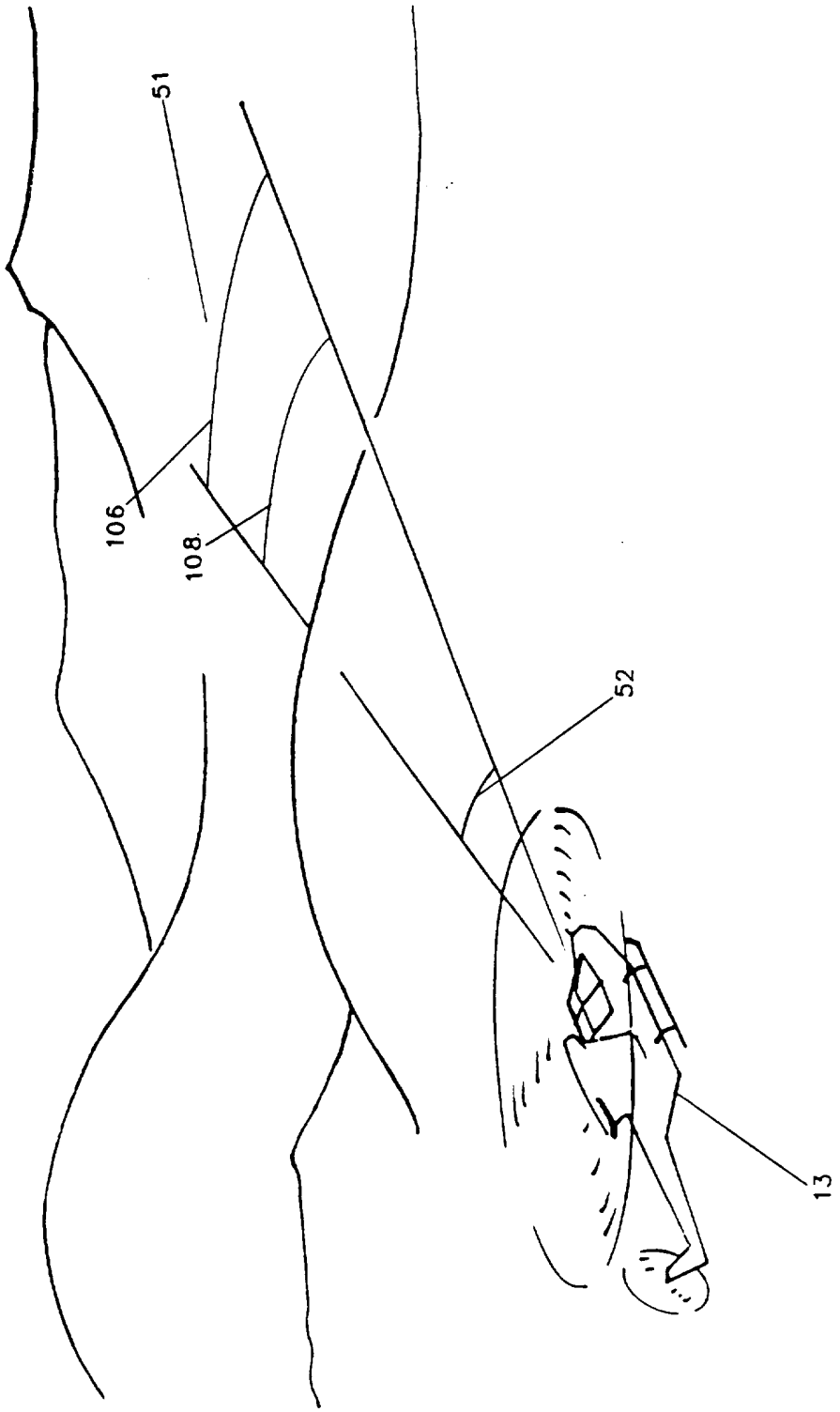

Fig. 7

APPARATUS AND METHOD FOR SIMULATION

FIELD OF THE INVENTION

The present invention relates to systems and methods for visual simulation generally and more particularly to a method and system for simulating a terrain with objects thereabove.

BACKGROUND OF THE INVENTION

Systems and methods for simulating a terrain with fixed and moving objects thereabove are well known in the art and are used in a wide range of applications, such as for training pilots or army personnel. A simulator typically includes two main systems, a simulation system for visually simulating a terrain and the objects thereabove, such as a terrain **10**, a house **11** and a jeep **12** as illustrated in Fig. 1 to which reference is now made, and a control system for simulating the control functions of an airborne or landborne vehicle, such as a helicopter **13**.

The terms above the terrain and thereabove are used herein to indicate both static and moving objects which are either on the terrain itself, such as the house **11** and the jeep **12**, or above the terrain, such as a bird or an aircraft.

Simulation systems typically include a data base which stores a digital representation of the terrain and the objects thereabove. During the simulation, a series of images are presented to the trainee, each of which represents a different viewing volume in accordance with input commands that he generates which simulate the movement of the helicopter 13. For example, an image representing a viewing volume 14 defined by the angle 15, i.e. an image representing a scene which the trainee views at one time, may be shown.

Since during the simulation a series of images of different viewing volumes are displayed, a series of computations for retrieving the digital representation of a particular viewing volume and for generating a two dimensional image therefrom are performed. In order to achieve smooth continuous display of simulated viewing volumes the rate in which the steps of retrieving and generating are performed, also termed the update rate, must be relatively high, such as 30 updates per second.

Generally speaking, there exist in the prior art two types of representation of the terrain and the objects thereabove in the simulator data base. In the first type, the terrain and the objects are represented as a series of geometrical objects, usually as polygons. Each polygon has a color associated therewith, and for each pixel to be displayed the imaging system calculates its color by finding the polygon closest to the viewing point.

A drawback of simulation systems which include a polygon representation of the terrain and the objects thereabove is that relatively large

numbers of polygons are required in order to achieve an image with a sufficient quality of the simulated viewing volume. Therefore, when it is desired to increase the update rate, image quality deteriorates and vice versa.

In the second type, the terrain and the objects thereabove are represented as volume elements ("voxels") which are usually cubes. Typically, a color is associated with each voxel.

During the simulation, a ray tracing algorithm is applied. The ray tracing algorithm incrementaly searches, starting from the trainee's vehicle as a starting point, the first voxel along each line of sight which is not blank, i.e. which includes a color value, and displays it to the trainee.

A drawback of simulation systems which include voxel representation of the terrain and objects thereabove is that the incremental calculation has to be repeated for each pixel in the image. Therefore, in order to achieve an image with a sufficient resolution, a large number of incremental calculations are performed. These calculations are time consuming, and therefore, the simulation update rate is not as high as desired.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved simulation method and system.

The present inventor has realized that a simulation method and a simulator which employ the fact that a scene, i.e a viewing volume observed by the trainee includes a terrain, i.e. the earth "skin" and natural or man made objects thereon, are advantageous both in terms of image quality and update rate.

There is thus provided, in accordance with a preferred embodiment of the present invention a simulation method for simulating a terrain and the objects thereabove to a viewer which includes the steps of:

A. providing a first data base includes a digital representation of the terrain;

B. providing a second data base includes a digital representation of the objects located above the terrain;

C. generating individual images, each of which simulating a viewing volume of the terrain and the objects where the step of generating includes:

C1. producing a first image from information stored in the first data base and, independently, producing a second image from information stored in the second data base;

C2. merging the first image and the second image, thereby forming an image simulating a viewing volume;

C3. displaying the image simulating the viewing volume; and

D. repeating the step of generating, thereby producing a plurality of images simulating a plurality of viewing volumes.

Further, according to a preferred embodiment of the present invention, the digital representation of each grid point includes at least its height and its color.

In accordance with a preferred embodiment of the present invention the step of producing includes the steps of:

A. scanning a portion of the data base representing the viewing volume; and

B. assigning the color of selected grid points to corresponding pixel points of the display.

Further, according to a preferred embodiment of the present invention, the step of scanning includes the step of scanning the portion of the data base such that each scanned point along the same azimuth line is closer to the viewer than a preceding scanned point.

Still further, according to a preferred embodiment of the present invention, the steps of scanning and assigning includes the steps of:

A. scanning the data corresponding to each of the azimuth lines independently, wherein each azimuth line corresponds to a pixel column in the display;

B. assigning the color of individual grid points along the azimuth line to corresponding pixel points in the display; and

C. replacing the color of a first grid point assigned to a pixel point by the color of a second grid point along the azimuth if the second grid point is along a same line of sight with the first grid point.

According to another preferred embodiment of the present invention the steps of scanning and assigning includes the steps of:

A. scanning the portion of the first data base along arcs of equal distance from the viewer;

B. assigning the color of individual grid points along each of the arcs to corresponding pixel points in the display; and

C. for each pixel, replacing the color of a first grid point assigned to a pixel point by the color of a second grid point if the second grid point is along a same line of sight with the first grid point.

In accordance with an alternative preferred embodiment of the present invention the step of scanning includes the step of scanning the portion of the data base such that each scanned point along the same azimuth line is more distant from the viewer than a preceding scanned point.

Further, according to an alternative preferred embodiment of the present invention, the steps of scanning and assigning includes the steps of:

A. scanning the data corresponding to each of the azimuth lines independently, wherein each azimuth line corresponds to a pixel column in the display; and

B. assigning the color of individual grid points along the azimuth line to corresponding pixel points in the display wherein for each pixel, the step of assigning is performed if a corresponding grid point is not along the same line of sight with a previously scanned grid point.

According to an alternative preferred embodiment of the present invention, the steps of scanning and assigning include the steps of:

A. scanning the portion of the first data base along arcs of equal distance from the viewer; and

B. assigning the color of individual grid points along each of the arcs to corresponding pixel points in the display wherein for each pixel, the step of assigning is performed if a corresponding grid point is not along the same line of sight with a previously scanned grid point.

Additionally, according to a preferred embodiment of the present invention the digital representation of the objects comprises a plurality of two dimensional representations of each one of the objects.

Further, in accordance with a preferred embodiment of the present invention the step of producing the second image includes the steps of:

A. selecting the two dimensional images of each object generally perpendicular to the direction of the lines of sight;

B. correcting the size of the selected two dimensional image in accordance to its distance from the viewer; and

C. resolving occultations between individual ones of the selected two dimensional images, thereby determining which pixels the second image includes.

Further, according to a preferred embodiment of the present application the step of merging includes the steps of:

A. comparing individual pixels of the first image and of the second image; and

B. determining for each pixel whether the color of the terrain or the color of the object will be displayed on the display

Still further, according to a preferred embodiment of the present invention, the method may include the step of replacing the color of a portion of the image simulating the viewing volume with the color of a texture selected from a texture library stored in the first data base.

Additionally, according to a preferred embodiment of the present invention, the method may include the step of rotating the image simulating the viewing volume in order to compensate for any cross-roll indicated by the viewer.

There is also provided, in accordance with a preferred embodiment of the present invention a simulator includes:

A. a first data base includes a digital representation of the terrain;

B. a second data base includes a digital representation of the objects located above the terrain;

C. an image generating system for generating individual images, each of which simulating a viewing volume of the terrain and the objects, the image generating system includes:

C1. means for producing a first image from information stored in the first data base and, independently, producing a second image from information stored in the second data base;

C2. means for merging the first image and the second image, thereby forming an image simulating a viewing volume;

C3. a display for displaying the image simulating the viewing volume; and

D. means for repeating the step of generating, thereby producing a plurality of images simulating a plurality of viewing volumes.

Further, according to a preferred embodiment of the present invention the digital representation of each grid point includes at least its height and its color.

According to a preferred method of the present invention the means for producing the first image include:

A. means for scanning a portion of the data base representing the viewing volume; and

B. means for assigning the color of selected grid points to corresponding pixel points of the display.

Further, according to a preferred embodiment of the present invention the means for scanning includes means for scanning the portion of the data base such that each scanned point along the same azimuth line is closer to the viewer than a preceding scanned point.

Still further, according to a preferred embodiment of the present invention the means for scanning and assigning includes:

A. means for scanning the data corresponding to each of the azimuth lines independently, wherein each azimuth line corresponds to a pixel column in the display;

B. means for assigning the color of individual grid points along the azimuth line to corresponding pixel points in the display; and

C. means for replacing the color of a first grid point assigned to a pixel point by the color of a second grid point along the azimuth if the second grid point is along a same line of sight with the first grid point.

According to another preferred embodiment of the present invention, the means for scanning and assigning includes:

A. means for scanning the portion of the first data base along arcs of equal distance from the viewer;

means for assigning the color of individual grid points along each of the arcs to corresponding pixel points in the display; and

means for replacing, for each pixel, the color of a first grid point assigned to a pixel point by the color of a second grid point if the second grid point is along a same line of sight with the first grid point.

In accordance with an alternative preferred embodiment of the present invention the means for scanning include means for scanning the portion of the data base such that each scanned point along the same azimuth line is more distant from the viewer than a preceding scanned point.

Further, according to an alternative preferred embodiment of the present invention, the means for scanning and assigning include:

A. means for scanning the data corresponding to each of the azimuth lines independently, wherein each azimuth line corresponds to a pixel column in the display; and

B. means for assigning the color of individual grid points along the azimuth line to corresponding pixel points in the display wherein for each pixel, the means for assigning operate if a corresponding grid point is not along the same line of sight with a previously scanned grid point.

According to an alternative preferred embodiment of the present invention, the means for scanning and assigning include:

A. means for scanning the portion of the first data base along arcs of equal distance from the viewer; and

B. means for assigning the color of individual grid points along each of the arcs to corresponding pixel points in the display wherein for each pixel,

the step of assigning operate if a corresponding grid point is not along the same line of sight with a previously scanned grid point.

Further, according to a preferred embodiment of the present invention the digital representation of the objects comprises a plurality of two dimensional representations of each one of the objects.

Additionally, according to a preferred embodiment of the present invention the means for producing the second image includes:

A. means for selecting the two dimensional images of each object generally perpendicular to the direction of the lines of sight;

B. means for correcting the size of the selected two dimensional image in accordance to its distance from the viewer; and

C. means for resolving occultations between individual ones of the selected two dimensional images, thereby determining which pixels the second image includes.

Additionally, according to a preferred embodiment of the present invention the means for merging includes:

A. means for comparing individual pixels of the first image and of the second image; and

B. means for determining for each pixel whether the color of the terrain or the color of the object will be displayed on the display

Further, in accordance with a preferred embodiment of the present invention the simulator also includes means for replacing the color of a portion

of the image simulating the viewing volume with the color of a texture selected from a texture library stored in the first data base.

Finally, according to a preferred embodiment of the present invention the simulator includes means for rotating the image simulating the viewing volume in order to compensate for any cross-roll indicated by the viewer.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the appended drawings in which:

Fig. 1 is a pictorial illustration of a terrain, the objects thereon and a helicopter to be simulated;

Fig. 2 is a block diagram illustration of a simulator, constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 3 is a block diagram illustration of a preferred simulation method employing the simulator of Fig. 2;

Fig. 4 is a pictorial illustration of a terrain which is simulated in accordance with the method of Fig. 3;

Fig. 5 is a pictorial cross section through the line V - V of Fig. 4;

Fig. 6 is a schematic illustration of the display screen of Fig. 2, illustrating two exemplary pixel columns corresponding to two azimuth lines of the viewing volume of Fig. 4; and

Fig. 7 is a pictorial illustration of a terrain which is simulated in accordance with another preferred method of the present invention.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

Reference is now made to Fig. 2 which is a block diagram illustrating a simulator, constructed and operative in accordance with a preferred embodiment of the present invention. The simulator, generally referenced 20, preferably comprises a simulation system 21 and a trainee's control system 22. The control system 22 may be any control system known in the art, such as the TP series tank gunnery simulators, manufactured and sold by Simtech Advanced Training & Simulation Systems Ltd. (SIMTECH) of Israel, assignees of the present invention.

The simulation system 21 preferably comprises a data base storage system 23 for storing therein a terrain data base 24 and an objects data base 25, an image generation system 26, and a display screen 28.

The terrain data base 24 stores a digital representation of the terrain which is simulated and may also include a texture library. The objects data base 25 preferably stores a digital representation of the objects located above the terrain.

For each grid point in the terrain database 24 a height and an associated color are preferably stored. The objects data base 25 preferably includes two dimensional images of each object in every aspect thereof, i.e. as viewed from any possible angle which may be simulated. Preferably, but not necessarily, the objects are stored in their largest size as if viewed from a close distance.

The terrain data base 24 and the objects data base 25 are preferably pre-prepared data bases loaded into the storage unit 24 and into the storage unit 25, respectively. The data base may be prepared employing any prior art system and method for preparing data bases for simulators, such as by digitizing the data available from satellite photographs, aerial photographs, maps, and image generation applications, such as 3D Studio, manufactured and sold by AutoDesk of the USA.

The objects data base 25 may include objects which are not present on the terrain which is simulated in order to increase and to diversify the number of objects presented to the trainee.

It is a particular feature of the present invention that the storage unit 23 includes two separate data bases, the terrain data base 24 for storing a digital representation of the terrain which is simulated and the objects data base 25 for storing a digital representation of the objects thereon.

It will be appreciated that the terrain data base 24 and the objects data base 25 may occupy different physical portions of a storage space or two virtual spaces of the same physical storage space.

It is another particular feature of the present invention that the image generation system resolves any occultation within the terrain image and within the objects image and thereafter therebetween as described in more detail hereinbelow.

The image generation system 26 scans data from the terrain data base 24 and the objects data base 25 in accordance with an indication from the

trainee's control system 22 and produces an image simulating a viewing volume having a terrain and objects thereon.

The image generation system 26 produces an image of the terrain from the scanned information from the terrain data base 24 and, independently, an image of the objects thereon from information retrieved from the objects data base 25. Then the image generation system merges the two images to produce the simulated viewing volume as described in detail hereinbelow.

The image generation system 26 preferably also updates the displayed image in accordance with the desired simulation. For example, the image generation system 26 updates the displayed image in response to the trainee control system 22 indication that the viewing volume has been changed. Alternatively, or in addition thereto, the image generation system updates the displayed image to simulate the movement of a moving objects, such as the jeep 12 or to simulate changes in weather conditions, such as adding the effects of fog.

Reference is now made to Fig. 3 which is a block diagram illustration of a preferred simulation method employing the simulation system of Fig. 2. Fig. 3 illustrates the general steps of the present invention for producing an image which represents a viewing volume being simulated.

The method of Fig. 3 preferably includes the step, generally referenced 31, of producing the image representing the terrain without the objects thereabove and the step, generally referenced 32, of producing the image of the objects without the terrain.

It is a particular feature of the present invention that, unlike prior art methods, the image of the terrain is produced independently of the image of the objects thereabove and vice versa.

The method also includes a merging step, referenced **33**, for producing an image of the simulated viewing volume having the terrain and the objects thereabove and the step **34** of displaying the image simulating the viewing volume. Preferably, but not necessarily, the steps **31** and **32** are generally simultaneous, thereby reducing the time required to produce the image of the simulated viewing volume, thereby improving the simulation update rate. Alternatively, steps **31** and **32** may be sequential.

According to the present invention, the step of producing **31** includes the step referenced **40**, of determining azimuth lines within the viewing volume and a step **41** of scanning data from the terrain data base **24** along each azimuth line. The producing step **31** preferably also includes the step, referenced **42**, of assigning, for each azimuth line separately, the color of data base grid points into points of display in the screen space and replacing the color of data points with the color of closer data points along a similar line of sight as described in more detail hereinbelow.

According to a preferred embodiment of the present invention, the step of scanning **41** is performed by scanning the appropriate portion of the terrain data base from the most distant point from the viewer to closer point to the viewer as described in more detail hereinbelow.

The step of producing **31** may also include the step of applying a selected texture to the terrain image, referenced **43**, as explained in more detail hereinbelow.

Reference is now also made to Figs. 4 - 6 which are, respectively, a pictorial illustration of a terrain which is simulated in accordance with the method of Fig. 3, a pictorial cross section through the line V - V of Fig. 4, and a schematic illustration of the screen display of Fig. 2, illustrating two columns of pixels of the image of the terrain within a viewing volume **51** schematically indicated by angle **52**.

It will be appreciated that the viewing volume is defined by two angles since the viewing volume has a conical shape if the viewer sight is circular and a pyramidal shape if the viewer sight is rectangular.

According to the present invention, each column of pixels in the screen image, such as the column **60** (Fig. 6) corresponds to a plurality of lines of sight which differ in their elevation but have similar azimuth with respect to the trainee.

According to a preferred embodiment of the present invention, the effects of cross-roll are not accounted for in the simulation during the producing step **31**. Without cross-roll, each column of pixels, such as the column **60** (Fig. 6) corresponds to the plurality of lines of sight along a real-world azimuth, such as the azimuth line **54** (Fig. 4) defined schematically by the angle **53**, and therefore, the number of azimuths to be traced preferably corresponds to the number of pixel columns of the display screen **28**.

It will be appreciated, as best seen from Fig. 5, that azimuth lines, such as the azimuth line **54**, are not necessarily straight lines but lines which follow the topography of the terrain. For each azimuth line, such as for the azimuth line **54**, a multiplicity of straight lines of sight which differ only in their elevation of which three, referenced **55**, **56** and **57** are shown here for simplicity, exist.

Unlike prior art methods, according to the present invention for each azimuth line an independent computation is performed in order to determine the points which will be displayed in the corresponding column of the display screen **28**.

According to a preferred method of the present invention, the color of each pixel along pixel column **60** (Fig. 6) corresponds to the data base grid point along a line of sight which is not occulted by any other point in the terrain along the selected line of sight.

As best seen in Fig. 5, the color of the point along line **57** which will be displayed in the pixel point **161** in the column **60** of the display screen is point **61** which occults points **62** and **63**. Similarly, the color of point **71**, which occults point **72** of line of sight **56** will be displayed in the pixel **171**.

According to a preferred embodiment of the present invention, the displayed data grid points are determined by scanning a corresponding portion of the data base along straight lines which correspond to the azimuth lines. Preferably, the scanning starts from the most distant viewable point in the terrain which is predetermined in accordance with the properties of the

simulated vehicle, such as the helicopter 13 of Figs. 1 and 5, and progresses to less distant points. For example, the representation of point 72 is first stored for the line of sight 56 and than replaced by the representation of the point 71.

According to a preferred method of the present invention the displayed image is produced as follows:

A. Select an azimuth line, start from the most distant point therealong and define it as the current grid point.

B. Calculate the projected pixel position in the pixel column on the screen associated with the current grid point. For example, for the azimuth line 54 the color of the point 81 is displayed by the pixel point 181 along the pixel column 60 which corresponds to the azimuth line 54. Preferably, the location of the pixel along the pixel column which corresponds to the point along the azimuth line is determined based on the viewers altitude, the height associated with the data point in the terrain data base and the viewing volume parameters, i.e. the viewing angles defining it.

C. Assign the color of the current grid point to its corresponding pixel point. The first assigned color is that of the most distant point.

D. Move to the next data point along the azimuth line, such as from the data point 81 to the data point 82. The scanning direction as indicated by the arrow 83 is from the most distant points closer to the viewer along the azimuth line.

E. Repeat steps B, C and D until reaching the viewer's position. It is a particular feature of the present invention that, if a more distant point is occulted by a closer terrain point along a similar line of sight, the color of the occulted point is automatically overwritten by the color of the closer terrain point which will be displayed for the pixel corresponding to that line of sight.

According to an alternative preferred method of the present invention the displayed image is produced as follows:

A. Select an azimuth line, start from the most closest point therealong and define it as the current grid point.

B. Calculate the projected pixel position in the pixel column on the screen associated with the current grid point. For example, for the azimuth line **54** the color of the point **101** is displayed by the pixel point **102** along the pixel column **60** which corresponds to the azimuth line **54**.

C. Assign the color of the current grid point to its corresponding pixel point. The first assigned color is that of the most closest point.

D. Move to the next data point along the azimuth line, such as from the data point **101** to the data point **103**. The scanning direction as indicated by the arrow **104** is from the most closest point to the viewer along the azimuth line.

E. Repeat steps B, C and D until reaching the most distant point **81**. Step C is repeated only if a color has not been assigned before to that pixel, i.e. if a former grid point is on the same line of sight.

The process described hereinabove with respect to the multiplicity of lines of sight along azimuth line **54** is then repeated for each azimuth to compose the entire image representing the viewing volume **51** to be simulated. For example, the pixels column **90** (Fig. 6) is produced from performing the above process for the azimuth line **94** (Fig. 4).

It will be appreciated that the method for producing the terrain image hereinabove does not necessarily require the use of the color value of each of the terrain data points. According to a preferred embodiment of the present invention, a selected texture, from a library of textures stored in the terrain data base **24** and associated with the terrain points in the database, may be retrieved and attached to each selected terrain point.

Moreover, for terrain which is close to the trainee's vehicle, the quality of the image typically deteriorates because of the finite resolution of the database grid, and therefore, it is advantageous to apply a texture selected from the texture library in the data base **24** to such desired portion of the terrain displayed image.

According to one preferred embodiment of the present invention, texture is used instead of the color values whenever the displayed point is close to the trainee's vehicle such that it covers more than a single pixel on the screen.

It will be appreciated that each grid point in the terrain data base does not necessarily correspond to a pixel point in the screen since the resolution of the data base along azimuth lines changes. For further distances,

few data base points may correspond with one pixel point while, when a terrain point is close to the trainee's vehicle one grid point may correspond to many pixel points. According to one preferred embodiment of the present invention, the scanning resolution of each azimuth line is not fixed. Preferably, for terrain far from the vehicle, the azimuth line is under sampled, i.e., data base points are overlooked during scanning, whereas for close terrain each grid point is scanned. This method reduces scanning time.

Alternatively, or in addition thereto, the scanning time of each azimuth line may be reduced by employing the fact that in close distances to the trainee, adjacent azimuth lines almost overlap. Therefore the scanning results of the portion closest to the trainee for one azimuth line may be copied for its adjacent azimuth line.

As described hereinabove, the objects image can be produced simultaneously with the terrain image or thereafter. The preferred method for producing the objects **32** (Fig. 3) preferably includes the following steps:

A. Step **44** - Scan the data base for the objects within the viewing volume of interest, i.e., the same viewing volume of the terrain image.

B. Step **45** - The two angles defining the object's aspect relative to the viewer are determined and the images with the correct aspect in respect to the simulated viewing points from the objects data base **25** (Fig. 2) are selected therefrom.

C. Step **46** - The image is zoomed to its correct size according to its range from the trainee's vehicle. Preferably, the image size is reduced since the

objects may be stored in the data base at their largest size as if viewed from the minimal range to the trainee's simulated vehicle. Therefore, step **46** preferably reduces the size of the object without losing details thereof.

D. Step **47** - The occultations between the objects are determined based on the distances calculated for each one of them. For each pixel, the system keeps only the color of the closest object, and its distance from the observer.

As described above, after the terrain image and the object's image are produced, they are merged as indicate by step **33** to produce the final image of the viewing volume as presented to the trainee. The merging process preferably includes a comparison of each terrain pixel with its corresponding object pixel, the one with the smaller distance being used for the final display.

It will be noted that the final image, after the merging step does not account for any cross-roll effect. If such effect is required in the simulation, then the final image is rotated in order to compensate for the cross-roll as indicated by step **35**. Preferably, the image is rotated such that the final image **34** is displayed on the display screen **28** (Fig. 2) with a rotation which corresponds to the cross-roll introduced by the trainee.

Reference is now made to Fig. 7 which is a pictorial illustration of a terrain and objects thereabove which are simulated in accordance with another preferred embodiment of the present invention. Fig. 7 illustrates a different scanning mode of the portion of the terrain data base associated with the viewing volume **51** than the scanning mode of Fig. 4.

As described above, it is a particular feature of the present invention that more distant points along azimuth lines are scanned before less distant points. According to the embodiment of Fig. 7, scanning is not performed along each azimuth line separately but along arcs which intersect azimuth lines in a similar distance from the trainee's vehicle. For example, the points along arc **106** are scanned before the points along arc **108** or vice versa.

It will be appreciated that the embodiment of Fig. 7 differs from the embodiment of Figs. 3 - 6 only with respect to the scanning order, i.e. with respect to the step **41** (Fig. 3). It will be appreciated all other steps are similar to those described hereinabove with respect to all the embodiments described hereinabove, mutatis mutandis.

It will be appreciated that the preferred embodiments described hereinabove are described by way of example only and that numerous modifications thereto, all of which fall within the scope of the present invention, exist. For example, each of the embodiments described hereinabove may also include one of the prior art features of anti aliasing, blending, range cuing and the data base of each one thereof may be a hierarchical data base.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention is defined only by the claims that follow:

CLAIMS

1. A simulation method for simulating a terrain and the objects thereabove to a viewer, the method comprising:

   a. providing a first data base comprising a digital representation of said terrain;

   b. providing a second data base comprising a digital representation of said objects located above said terrain;

   c. generating individual images, each of which simulating a viewing volume of said terrain and said objects, said step of generating comprising:

      i. producing a first image from information stored in said first data base and, independently, producing a second image from information stored in said second data base;

      ii. merging said first image and said second image, thereby forming an image simulating a viewing volume; and

      iii. displaying the image simulating said viewing volume; and

   d. repeating said step of generating, thereby producing a plurality of images simulating a plurality of viewing volumes.

2. A simulation method according to claim 1 wherein the digital representation of each grid point comprises at least its height and its color.

3. A simulation method according to claim 2 wherein said step of producing said first image comprises:

a. scanning a portion of said data base representing said viewing volume; and

b. assigning the color of selected grid points to corresponding pixel points of said display.

4. A simulation method according to claim 3 wherein said step of scanning comprises the step of scanning said portion of said data base such that each scanned point along the same azimuth line is closer to the viewer than a preceding scanned point.

5. A simulation method according to claim 4 wherein said steps of scanning and assigning comprises:

a. scanning the data corresponding to each of said azimuth lines independently, wherein each azimuth line corresponds to a pixel column in said display;

b. assigning the color of individual grid points along said azimuth line to corresponding pixel points in said display; and

c. replacing the color of a first grid point assigned to a pixel point by the color of a second grid point along said azimuth if said second grid point is along a same line of sight with said first grid point.

6. A simulation method according to claim 4 wherein said steps of scanning and assigning comprises:

a. scanning said portion of said first data base along arcs of equal distance from said viewer;

b. assigning the color of individual grid points along each of said arcs to corresponding pixel points in said display; and

c. for each pixel, replacing the color of a first grid point assigned to a pixel point by the color of a second grid point if said second grid point is along a same line of sight with said first grid point.

7. A simulation method according to claim 6 wherein said step of scanning comprises the step of scanning said portion of said data base such that each scanned point along the same azimuth line is more distant from the viewer than a preceding scanned point.

8. A simulation method according to claim 7 wherein said steps of scanning and assigning comprises:

a. scanning the data corresponding to each of said azimuth lines independently, wherein each azimuth line corresponds to a pixel column in said display; and

b. assigning the color of individual grid points along said azimuth line to corresponding pixel points in said display wherein for each pixel, said step of assigning is performed if a corresponding grid

point is not along the same line of sight with a previously scanned grid point.

9. A simulation method according to claim 7 wherein said steps of scanning and assigning comprises:

a. scanning said portion of said first data base along arcs of equal distance from said viewer; and

b. assigning the color of individual grid points along each of said arcs to corresponding pixel points in said display wherein for each pixel, said step of assigning is performed if a corresponding grid point is not along the same line of sight with a previously scanned grid point.

10. A simulation method according to any of the previous claims wherein the digital representation of said objects comprises a plurality of two dimensional representations of each one of said objects.

11. A simulation method according to claim 10 wherein said step of producing said second image comprises:

a. selecting the two dimensional images of each object generally perpendicular to the direction of said lines of sight;

b. correcting the size of said selected two dimensional image in accordance to its distance from said viewer; and

c. resolving occultations between individual ones of said selected two dimensional images, thereby determining which pixels said second image comprising.

12. A simulation method according to claim 11 wherein said step of merging comprises:

a. comparing individual pixels of said first image and of said second image; and

b. determining for each pixel whether the color of said terrain or the color of said object will be displayed on said display.

13. A method according to any of the previous claims and also comprising the step of replacing the color of a portion of said image simulating said viewing volume with the color of a texture selected from a texture library stored in said first data base.

14. A simulation method according to any of the previous claims and also comprising the step of rotating said image simulating said viewing volume in order to compensate for any cross-roll indicated by said viewer.

15. A simulator comprising:

a. a first data base comprising a digital representation of said terrain;

b. a second data base comprising a digital representation of said objects located above said terrain;

c. an image generating system for generating individual images, each of which simulating a viewing volume of said terrain and said objects, said image generating system comprising:

i. means for producing a first image from information stored in said first data base and, independently, producing a second image from information stored in said second data base;

ii. means for merging said first image and said second image, thereby forming an image simulating a viewing volume; and

iii. a display for displaying the image simulating said viewing volume; and

d. means for repeating said step of generating, thereby producing a plurality of images simulating a plurality of viewing volumes.

16. A simulator according to claim 15 wherein the digital representation of each grid point comprises at least its height and its color.

17. A simulator according to claim 16 wherein said means for producing said first image comprises:

a. means for scanning a portion of said data base representing said viewing volume; and

b. means for assigning the color of selected grid points to corresponding pixel points of said display.

18. A simulator according to claim 17 wherein said means for scanning comprising means for scanning said portion of said data base such that each scanned point along the same azimuth line is closer to the viewer than a preceding scanned point.

19. A simulator according to claim 18 wherein said means for scanning and assigning comprises:

a. means for scanning the data corresponding to each of said azimuth lines independently, wherein each azimuth line corresponds to a pixel column in said display;

b. means for assigning the color of individual grid points along said azimuth line to corresponding pixel points in said display; and

c. means for replacing the color of a first grid point assigned to a pixel point by the color of a second grid point along said azimuth if said second grid point is along a same line of sight with said first grid point.

20. A simulator according to claim 19 wherein said means for scanning and assigning comprises:

a. means for scanning said portion of said first data base along arcs of equal distance from said viewer;

b. means for assigning the color of individual grid points along each of said arcs to corresponding pixel points in said display; and

c. means for replacing for each pixel, the color of a first grid point assigned to a pixel point by the color of a second grid point if said second grid point is along a same line of sight with said first grid point.

21. A simulator according to claim 17 wherein said means for scanning comprising means for scanning said portion of said data base such that each scanned point along the same azimuth line is more distant from the viewer than a preceding scanned point.

22. A simulation method according to claim 21 wherein said means for scanning and assigning comprises:

a. means for scanning the data corresponding to each of said azimuth lines independently, wherein each azimuth line corresponds to a pixel column in said display; and

b. means for assigning the color of individual grid points along said azimuth line to corresponding pixel points in said display wherein for each pixel said means for assigning operate if a corresponding grid point is not along the same line of sight with a previously scanned grid point.

23. A simulator according to claim 22 wherein said means for scanning and assigning comprises:

a. means for scanning said portion of said first data base along arcs of equal distance from said viewer; and

b. means for assigning the color of individual grid points along each of said arcs to corresponding pixel points in said display wherein for each pixel, said means for assigning operate if a corresponding grid point is not along the same line of sight with a previously scanned grid point.

24. A simulator according to any of claims 15 - 23 wherein the digital representation of said objects comprises a plurality of two dimensional representations of each one of said objects.

25. A simulator according to claim 24 wherein said means for producing said second image comprises:

a. means for selecting the two dimensional images of each object generally perpendicular to the direction of said lines of sight;

b. means for correcting the size of said selected two dimensional image in accordance to its distance from said viewer; and

c. means for resolving occultations between individual ones of said selected two dimensional images, thereby determining which pixels said second image comprising.

26. A simulator according to claim 25 wherein said means for merging comprises:

a. means for comparing individual pixels of said first image and of said second image; and

b. means for determining for each pixel whether the color of said terrain or the color of said object will be displayed on said display.

27. A simulator according to any of claims 15 - 26 and also comprising means for replacing the color of a portion of said image simulating said viewing volume with the color of a texture selected from a texture library stored in said first data base.

28. A simulator according to any of claims 15 - 27 and also comprising means for rotating said image simulating said viewing volume in order to compensate for any cross-roll indicated by said viewer.

29. A simulation method substantially as hereinbefore described with reference to Figures 1 to 7.

30. A simulator substantially as hereinbefore described with reference to Figures 1 to 7.

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Other: ONLINE DATABASE: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2253549 A	[GEC-MARCONI] See page 3	1, 15
A	WO 88/06775 A1	[Logicblend] See abstract	1, 15
A	WO 88/02156 A	[Hughes A/C] See abstract	1, 15

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