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A 3-D Terrain Visualization Database for Highway Information Management

A Final Report, MBTC 1092

Submitted to
Mack-Blackwell Transportation Center

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July 26, 1999

ABSTRACT

A Multimedia based Highway Information System (MMHIS) is described in the paper to improve the existing photologging system for various operation and management needs. The full digital, computer based MMHIS uses technologies of video, multimedia data synchronization, three-dimensional visualization, high-speed networking, and video server. This paper presents the development for the three-dimensional (3-D) terrain visualization user-interface of MMHIS, based on the Application Programming Interface (API) of OpenGL. Digital Elevation Models (DEM) from the US Geological Survey (USGS) were used to construct the 3-D terrain surface of the entire state. A unique picking algorithm was devised to conduct visual queries on the terrain surface of the state. The 3-D user-interface allows the user to zoom, rotate, and pan around the statewide terrain surface for multimedia data query. Based on this visualization technology, a number of transportation related tasks can be conducted visually and interactively at real-time for transportation planning, engineering design, public hearing, and highway management.

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REPORT SUMMARY

Two types of engineering information are used in highway departments for various studies: (1) video images collected through photo logging, and (2) site data. The video images provide visual information for pavement management, highway signing and marking improvement, and accident analysis. The site data may contain some or all of the information on construction and rehabilitation history, pavement layer information, pavement width and type, Average Daily Traffic (ADT), accident history, signing and marking inventory, and road geometric data. The limitations of many existing systems are apparent in the areas of accessibility, search capability of the video library, and synchronization of video data with engineering site data. Some of the existing systems also lack the capability of simultaneous multiple-user-access to high-resolution video and site data. Due to the analog nature of the video signals, it is difficult to integrate the visual information with computer databases. In summary, it is a time consuming process to look up and reassemble the video and site data in different formats and from various sources.

To improve the usage of the photo logging system and provide better tools for highway management systems, a Multimedia Based Highway Information System (MMHIS) was developed. This multimedia service employs new technologies in digital video, high-speed networking and relational databases, so that users can look at photo logging video and corresponding data sets simultaneously without leaving their offices. A data synchronization algorithm was developed to dynamically display motion digital video with traditional engineering data sets. The data sets can contain any data records, such as as-built data, pavement condition and performance, traffic safety, geometric features and other infrastructure data. MMHIS can be used by not only traditional users of photo logging systems, but also other engineering and planning professionals.

An important element in MMHIS is the user interface. As all inventory data from photo logging are location-specific and have spatial characteristics, it was determined that an efficient and visual interface is needed for users to conduct query runs and visualize terrain features for planning and management purposes. In addition, it will be beneficial to have statewide terrain surface at high resolution for examination in public hearings and

management meetings. Furthermore, recent technological advances in both visualization hardware and three-dimensional (3-D) software allow the development of these capabilities. For instance, it is possible to obtain 1-meter resolution satellite imagery for terrain models.

Terrain visualization is frequently used in military applications and high-end commercial areas. For decades, stereo photogrammetry has been widely used in highway departments for roadway design and improvement. However, all these applications require high capital investment. For stereo photogrammetry, only a limited number of stations are needed in a department and they are not used for any management purposes. However, the primary goal of using a terrain based user interface for MMHIS is to develop a low-cost solution, so that users can efficiently use the interface in a PC environment to query infrastructure data routinely from their offices.

This 3-D user interface should allow the user of MMHIS to do the following:

1. Users can interact with a 3-Dimensional, color digital map for the entire state on a personal computer.
2. Users can select data queries from this 3-D map based on visually available information on highway and road network.
3. The visualization interface allows the user to rotate, zoom in and out, and pan around the terrain surface of the state.

Currently, the data sources for MMHIS are from an existing highway data vehicle and USGS. It requires less than one full-time employee to maintain the operation of MMHIS. However, a computer network and workstations are needed to support a multi-user environment, as digital video files have to reside in a central location due to their large sizes. Video decompression of MPEG-2 support is also necessary of the workstations. This feature is becoming a standard for many new computers. 3-D visualization hardware is recommended for the workstations, but not required. 3-D rendering can be conducted by the CPU, but with slower speed than a computer can do with dedicated 3-D hardware.

The report is organized into three portions: (1) introduction to the capabilities of MMHIS and system design, (2) data sources and data preparation for the 3-D model in MMHIS, and (3) 3-D visualization methods and their implementations. Wang et al (1998) describes other algorithms and developments in MMHIS, including the synchronization of video and location data and database structure, which are not discussed in this report.

MMHIS provides multimedia data viewing capabilities to highway engineers. It allows a highway agency to examine road and roadside structures without taking certain field trips. In addition, MMHIS in a computer network environment can be used in communicating design and improvement ideas among engineers and managers, and to the general public. Future work includes the use of higher resolution data from satellite imagery vendors and USGS.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Two types of engineering information are used in highway departments for various studies: (1) video images collected through photo logging, and (2) site data. The video images provide visual information for pavement management, highway signing and marking improvement, and accident analysis. The site data may contain some or all of the information on construction and rehabilitation history, pavement layer information, pavement width and type, Average Daily Traffic (ADT), accident history, signing and marking inventory, and road geometric data. The limitations of many existing systems are exhibited in the areas of accessibility, search capability of the video library, and synchronization of video data with engineering site data. Some of the existing systems also lack the capability of simultaneous multiple-user-access to high-resolution video and site data. Due to the analog nature of the video signals, it is difficult to integrate the visual information with computer databases. In summary, it is a time consuming process to look up and reassemble the video and site data in different formats and from various sources.

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Connecticut Department of Transportation (ConnDOT) has been using an analog based laser disk based photo logging system for many years (Hanley and Larson, 1992). The original system is still actively used at ConnDOT, which recently started incorporating digital images into the photo logging system. Several other state highway departments are also studying the application of digital images and video for either just photo logging or an integrated information system. Based on the experiences from several existing applications, MMHIS was developed from ground-up into an integrated system that incorporates digital motion video, a customized database engine, tight data synchronization, and geo-referencing capabilities. MMHIS can be used by not only traditional users of photo logging systems, but also other engineering and planning professionals.

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CAPABILITIES OF MMHIS AND SYSTEM DESIGN OF THE 3-D VISUALIZATION

Figure 1 shows the main user screen of MMHIS. The highway video is presented along with the corresponding site data table left to the video. The site data table includes location data on the road being viewed. The two windows of graphs show roughness and rutting data. The capability of dynamic graphing is built into the two graphing windows. This capability allows the user to view the values of various attributes, such as roughness and rutting at the viewed location against values for the entire road section. Two vertical bars on the graphs indicate the location of the road being viewed relative to the whole road section.

The map shown at the left-hand side of Figure 1 is geo-referenced 3-D terrain map that can be used as a query tool. The actual terrain of the State of Arkansas is displayed so that users can see the current location on the 3-D map. When the map is clicked by the user, the system shows the location of the mouse cursor in a list. The items in this list can be selected and the MMHIS will query to the selected location to display the selected video and data records. Users can zoom in, pan, and zoom out freely using the small zooming window in the lower right corner of the terrain map, as shown in Figure 1. On the terrain surface, the dot shows the current query location. The viewing angles can also be adjusted in Figure 1 by using the two small slider bars by the side of the small map in the zooming window.

The following are additional MMHIS operations.

- The video runs at 30 frames per second with the resolution of 640 by 480. Data in the site data window will change dynamically with the motion video. The video window can be resized.
- Data query can be conducted by (1) keying in the route number, direction, and milepost, or (2) dragging the slider on the slider bar on the bottom of the video window to a new location.
- The data update rate can be selected through the slider bar at the bottom of the site data table.
- The user can open multiple video windows simultaneously.
- Making turns. Users can make turning movements at intersections or exit ramps, through user selectable turning arrows, shown in Figure 2.

Figure 3 shows the diagram of system level design of 3-D visualization in MMHIS. The 3-D visualization in MMHIS involves three tasks: the database design, the database preparation, and the user interface design. Databases offer the necessary data to render the map, and the user interface presents the map to the user. In MMHIS several database files are used in the 3-D rendering. The files provide elevation data, the two-dimensional (2-D) map data, the location information, and the intermediate rendering results. MMHIS uses custom designed database file formats to achieve high speed data accessing. The user interface design involves the design of three OpenGL C++ wrapper classes that facilitate the rendering of the 3-D map. It also involves the design of a picking algorithm that allows users to click on the 3-D map and get site data information for the corresponding point. Zooming and panning operation on the 3-D map is also implemented.

DATA SOURCES AND DATA PREPARATION FOR THE 3-D VISUALIZATION

MMHIS 3-D Map Internal Data Formats for DEM

General Information on USGS DEM and the Raster 2-D Map

3-D terrain data is needed for MMHIS to have a user interface of 3-D surface. The Earth Science Information Center (ESIC) distributes digital cartographic/geographic data files produced by the U.S. Geological Survey (USGS) as part of the National Mapping Program. The data type used in MMHIS is called a Digital Elevation Model (DEM), which consists of a sampled array of elevations for a number of ground positions at regularly spaced intervals.

In particular, the 1-degree DEM (3- x 3-arc-second data spacing) provides coverage in 1- x 1-degree blocks. The basic elevation model is produced by the Defense Mapping Agency (DMA), but is distributed by USGS in the DEM data record format. In addition, MMHIS uses a 2-D map that was scanned from a paper map as the basis for the features of the 3-D map. Information from the 2-D map is used in the final rendering of the 3-D map. It is also used in the road digitizing process. The resolution of this map is 1,800 pixels by 1,800 pixels. The resolution of the terrain map is 7200 pixels by 4800 pixels.

DEM Data File Format for MMHIS

There are 24 1-degree DEM files covering the state of Arkansas. The files are in fixed-length ASCII format. In MMHIS, the 24 DEM files were converted into one binary file, based on the following reasons: (1) it is more efficient to read one file than reading 24 separate files to render the surface, (2) the one binary file takes much less space than the 24 separate files, due to the elimination of header information in each of the 24 files. The DEM data presents position information in a grid-rectangular format with approximate resolution of 70 meters for longitudinal and latitudinal measurements. The conversion retains the original positioning data and resolution of the 24 DEM files.

There are three different records in the converted DEM file. The first record stores the origin of the area that is covered by the DEM. It contains two floating-point numbers representing the longitude and the latitude of the origin in degrees. The second record contains integers representing the number of grid points along both the longitude and latitude directions. The third record contains the elevations in meters of the grid points along the profiles organized from south to north and from west to east. The numbers are in internal integer formats.

Other Data Files for Rendering

In addition to the DEM data file and the 2-D raster map file, the rendering in MMHIS also uses several other data files, as follows:

- 2-D surface map file. It is a raster image file in Windows bitmap format based on the scanned 2-D raster map file. When the 3-D map is viewed from top directly down, the 3-D map changes to a 2-D map showing the raster image of the state. When viewed from an angle, this raster image drapes on top of the surface model in real-time.
- 2-D coordinate map files in Windows bitmap format. MMHIS uses these files to identify the longitude and latitude of any point on the 2-D map for picking operations. Altitude value is obtained by querying the converted DEM file.
- 2-D zoom surface map file in the Windows bitmap format. This file is similar to the 2-D surface map file, but has smaller size. It is used to speed up the zooming control in the MMHIS's map interface.
- 2-D zoom coordinate map files in the Windows bitmap format. These files are similar to the 2-D coordinate map files, but have smaller sizes. They are used in the zooming control in MMHIS's map interface.
- Raster map information file. This file is used in a texture mapping process to project the 2-D map to the 3-D terrain surface.

  As the 2-D size of the raster map is smaller than the size of longitude and latitude in the DEM, the raster map was linearly stretched to match the size of the DEM at the resolution of 7,200 longitudinal pixels and 4,800 latitudinal pixels. The colors of the raster map were then directly projected onto the surface of the DEM. The colors are saved into this raster map information file, which contains longitude, latitude, elevation and color of each pixel in the DEM. The projection principle is shown in Figure 4.

The information in this raster map information is used for final screen sub-sampling and rendering. The file contains three records. The first record stores the origin of the area, which uses two floating-point numbers to represent the longitude and the latitude of the origin, or the lower-left corner of the DEM. The second record stores the total number of grid points along the longitude and latitude lines. The third record stores the texture mapping information, or the color of each pixel. The majority of the data in the file is used for the third record, which is an array of RGB values ordered along the grid lines from south to north, west to east. Each RGB value contains three bytes that represent the mapped red, green, and blue color element on that grid point.

- Shape information file. Results of rendering of the terrain surface are stored in this file. As rendering data is saved in this file, picking and other operations can be repeatedly applied to the surface without re-rendering. This file does not record hidden surface information. OpenGL is still used to render the scene to show the 3-D objects' positions. The real rendering process uses only one light source to reduce the computation overhead, resulting in efficient rendering of the scene.
- Location information file. The location information file contains the route number and milepost information for each grid points. MMHIS uses this information to decide the location of a point on the map. There are three records in this file. The first two records are the same as in the shape information file. The third record contains an array of integer pairs representing the route number and milepost of each grid points. An interactive digitizing utility was developed in the research to map highway routes on the 2-D raster map.

3-D VISUALIZATION METHODS AND THEIR IMPLEMENTATIONS

OpenGL is the industry standard software interface for high-quality 3-D graphics applications. OpenGL is hardware-independent and available on a variety of platforms and operating systems, including Windows NT. The interface consists of more than 150 distinct commands that can be used to specify the objects and operations needed to produce interactive 3-D applications (Fosner 1996). With OpenGL, 3-D object is constructed with a small set of geometric primitives—points, lines, and polygons. The terrain model in MMHIS's 3-D user interface was constructed directly with OpenGL Application Programming Interface (API). Woo, Neider, and Davis (1997) provide a guide to OpenGL programming, which was frequently used for this research.

Terms in 3-D Transformation

When a 3-D object is to be viewed, the positions of both the object and the viewer may need to be changed for proper viewing results. This process is called coordinate transformation. Here are some important concepts in OpenGL for coordinate transformation that were used in the terrain visualization of MMHIS.

(1) Viewpoint is the location of the user's eyes. Its initial position is at the origin of the world coordinate system.

(2) The process of moving the terrain model is called model transformation. When viewpoint is moved, it is called view transformation. If both model transformation and view transformation occur, it is referred to as modelview transformation. However, OpenGL internally treats view transformation as model transformation. Therefore, mathematically within OpenGL, the only transformation is model based. Even though logically the term of view transformation is used, the transformation is actually achieved through model transformation in OpenGL. As a result, the position of the viewpoint is internally always at the origin of the world coordinate system, disregard of any type of transformations being conducted.

(3) Projector is a vector pointing from the center of the object being viewed to the viewpoint.

(4) Up vector is used to determine the orientation of the object being viewed. During transformation, in order to ensure that this orientation is preserved, a vector is used in the transformation calculations. This vector is called up vector, which is defined by a 3-D position in the world coordinate system. The direction and length of the vector are from the origin of the world coordinate system to the 3-D position. However, the length of the vector is not used in transformation. In MMHIS, for the convenience of calculation, the direction of the vector is tangent

to the center of the terrain map. Also in MMHIS, the north of the terrain map must always point from bottom to the top.

(5) Projection is an approach to map 3-D objects to a 2-D surface. There are two projection methods: perspective and parallel. In MMHIS, the 3-D terrain map is projected to the 2-D viewing surface using parallel projection. Perspective projection was not chosen because accurate measurement of the map is needed to calculate the zoom factors and to conduct zooming and panning operations.

(6) A viewing volume is a portion of 3-D space that is projected to the 2-D viewing surface. Anything outside this volume is clipped, or not shown in the terrain map. In parallel projection only the viewing volume's width and height are important to the rendered view. The near and far planes only need to be set to proper locations so that the area of the earth's surface to be shown is between these two planes.

(7) As parallel projection is used, as long as the user is in front of the terrain map, the distance between the user and the terrain map does not affect the visualization of the map. For the sake of convenience, MMHIS always uses the radius of the earth as the distance between the user and the map.

View and Map Transformations in MMHIS

Initialization of the Terrain Map: Model Transformation

In OpenGL, the initial viewpoint is always at the center of the world coordinate system disregard of any type of transformations being conducted. For the MMHIS 3-D terrain model, it is assumed that this initial viewpoint is at the location of the center of the earth and the direction of the view is facing the position with the longitude of east 90 degrees and the latitude of 0 degree (equator), shown in Figure 5 (a). At this point of view, the area of Arkansas cannot be viewed at the initial viewpoint. Therefore, transformation of the model, area of Arkansas, is necessary in order to let the viewpoint to have complete view coverage of the area object.

The world coordinate system is always fixed as (X, Y, Z). In order to make the terrain map viewable and also perpendicular to the user, first, the model has to be moved, or translated away from the center of the world coordinate system forming a local coordinate system (*x*, *y*, *z*) with the earth's center as the local origin, shown in Figure 5 (b). In this translation, the earth is translated back along the negative Z-axis. For convenience, the moving distance is equal to the radius of the earth.

In order to view the area object perpendicularly, the earth is then rotated along the local x-axis counterclockwise when viewed at negative x direction. The rotating angle is equal to the latitude degrees of the point to be viewed, shown in Figure 5 (c). Afterwards, the earth is rotated again along the local y-axis counterclockwise when viewed at negative y direction. The rotating angle is equal to the longitude degrees minus 90, as the projector goes from positive Z-axis to the negative Z-axis. At this time, the position of the area of interest is perpendicular to the Z-axis and to the viewer at the viewpoint, shown in Figure 5 (d). Therefore, the position of the terrain map of Arkansas is perpendicular to the user's view. However, the position of the viewpoint and the center of the terrain map are approximately at the same location, considering that the earth is not a perfect ball and the terrain has varying elevations.

To view the terrain map from a distance, the model is then translated again by the radius of the earth along negative direction of the Z-axis. The area of interest is therefore fully viewable to the user. When MMHIS is launched along with the terrain map utility shown in Figure 1, the program conducts the above modelview transformations, so that user can immediately view the complete terrain map.

Adjustment of the Viewing Angle: View Transformation

When the user adjusts the viewing angles with the sliders in Figure 1 to view the terrain map from a different position, the viewpoint is logically moved. Internally, OpenGL moves the model to achieve the same result. In this scenario, two parameters, α and β, are used to customize the viewpoint position and projector direction, shown in Figure 6. The angle α controls the vertical position of the viewpoint, while the angle β controls the horizontal position of the viewpoint. The two sliders of angle control are shown in the zooming utility at the bottom-right corner of the terrain map in Figure 1.

To view the new terrain area defined by two parameters, α and β, the whole model is reset to the world coordinate system. The viewpoint at the center of the world coordinate system also becomes the center of the earth. Based on the values of α and β, and the illustration in Figure 6, the viewpoint is logically transformed from the center of the world coordinate system to the selected position on the surface of the earth. Thereafter, the complete modelview transformation sequences follow the exact steps shown in Figure 5 (b) to Figure 5 (d).

Modelview Transformation with the Presence of α and β

After the user selects a new viewing position with α and β, logically setting the new viewpoint location is a process of creating a viewing transformation matrix based on current viewpoint, a reference point indicating the center of the map, and an up vector. The matrix of view transformation resets the reference point of the center of the map and the viewpoint point to the origin, as shown in Figure 5 (a). When a typical projection matrix is used, the center of the scene therefore maps to the center of the whole view area, or Arkansas in MMHIS. This whole view area is referred to as viewport in OpenGL. Similarly, the direction described by the up vector projected onto the viewing plane is mapped to the positive y-axis so that it points upward in the viewport. The up vector can not be parallel to the projector.

The following procedure illustrates the initial transformation for the model similar to the step from Figure 5 (a) to Figure 5 (b) to prepare for the additional transformation from Figure 5 (b) to Figure 5 (d). However, Figure 5 (a) and Figure 5 (b) only show a special case of the transformation, that is when α=0 and β=0.

The following view transformation is based on Woo, Neider, and Davis (1997). Assume the viewpoint location is given by $EYE = (eyeX, eyeY, eyeZ)^T$; the center of scene is given by $CENTER = (centerX, centerY, centerZ)^T$; the up vector is given by $UP = (upX, upY, upZ)$. The projector vector is:

$$PJ = CENTER - EYE = \begin{bmatrix} centerX - eyeX \\ centerY - eyeY \\ centerZ - eyeZ \end{bmatrix} \quad \text{.................................} (1)$$

The vectors are normalized as follows:

$$P = \frac{PJ}{\|PJ\|} \quad \text{.......... (2)}$$

$$UP' = \frac{UP}{\|UP\|} \quad \text{.......... (3)}$$

Finally, let $S = P \times UP'$, and $U = S \times P$, forming a new local coordinate system defined by three unit vectors, S, U, and P.

In OpenGL, all positions are defined with four values, x, y, z, and a fourth value, which is normally one, forming a homogeneous coordinate. Considering the presence of α and β, the model is rotated based on the following matrix:

$$R = \begin{bmatrix} S[0] & S[1] & S[2] & 0 \\ U[0] & U[1] & U[2] & 0 \\ -P[0] & -P[1] & -P[2] & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{.......... (4)}$$

The model is then translated based on the position of the viewpoint $EYE = (eyeX, eyeY, eyeZ)^T$:

$$T = \begin{bmatrix} 1 & 0 & 0 & -eyeX \\ 0 & 1 & 0 & -eyeY \\ 0 & 0 & 1 & -eyeZ \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{.......... (5)}$$

Therefore, the combinational modelview matrix factor is

$$M = T \times R = \begin{bmatrix} S[0] & S[1] & S[2] & -eyeX \\ U[0] & U[1] & U[2] & -eyeY \\ -P[0] & -P[1] & -P[2] & -eyeZ \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{.......... (6)}$$

After the above transformation, the projector projects to the origin of the local coordinate system. The up vector for the viewpoint is the tangent vector of the meridian at the center of the viewing region and pointing to the north. To be viewed correctly, the model can then be further transformed based on the sequence from Figure 5 (b) to Figure 5 (d).

Rendering of 2-D and 3-D Terrain Maps

After the completion of necessary modelview transformations and before the terrain map is rendered and displayed on the screen, a process of sub-sampling takes place to the map. As the map in memory and the map shown on the screen window have different sizes, sub-sampling presents the correctly sized terrain map on the screen through filtering out unnecessary grid lines. Sub-sampling only occurs to 3-D rendering, as sub-sampling in 2-D is automatically handled by the operating system.

2-D Rendering

Even though the 2-D raster image does not present any lighting effect by itself, MMHIS uses OpenGL functions to create lighting effects for the projected raster image perpendicular to the user. Two disk-based picking buffers are used for this rendering. When displaying in the 2-D case, it simply loads the raster and displays the image using Win32 API function `::StretchBlt()`, which conducts the sub-sampling automatically. This approach is shown in Figure 7.

3-D Rendering

3-D map rendering occurs when the viewing angles are not perpendicular to the terrain map. In MMHIS's 3-D map rendering, there is a limitation in using memorized 3-D commands and data in system memory, or display lists of OpenGL. When user changes the zooming factor or the viewing angles, the data sub-sampling has to be re-applied to the map, resulting in the frequent updating of the display lists. This makes display lists of OpenGL useless, as their purpose is to speed up rendering by saving the commands the memory. Therefore, in MMHIS, a new technique was derived to efficiently render the 3-D terrain map.

Rendering results are first saved in an internal buffer, and copied to the screen window for display. Based on our test, the copying operation is much faster than executing display lists by OpenGL. In addition, MMHIS has the ability to specify a memory-mapped file kernel object in the hard disk as its virtual memory, which cannot be achieved with OpenGL's display lists. The size of an OpenGL display list can also become very large when rendering a 3-D map with millions of vertexes and triangles in system memory. The use of hard disk based virtual memory to store the intermediate results alleviates the high physical memory requirement by display lists of OpenGL.

MMHIS uses a triangular mesh for the whole area and calls OpenGL rendering functions to draw the 3-D map surface. The partition for a complete 1 × 1-degree region with no grid line filtered out is shown in Figure 8. The actual rendering first filters out some of the grid lines based on the size of the screen window, a sub-sampling process. For each adjacent pair of sub-sampled profiles (lines along the latitude direction), a triangle strip is rendered based on sub-sampled samples (lines along the longitude direction). Both profiles and samples here are USGS conventions for DEMs. The rendering order is from low latitude location to high latitude location. The color of each vertex is calculated according to the elevation of the point, the lighting effects, and the color of the corresponding point on the 2-D map. OpenGL smooth shading is used in the map rendering.

Picking Operation

MMHIS allows users to click on the 3-D map and shows 3-D location information specific to the clicked point on the map. The process to identify the point being clicked on the 3-D map is called *picking*. Each point on the 3-D map can be uniquely specified by giving its longitude and latitude values. The map application allows users to click on the map and, if the point clicked is a point on a highway section and is registered in the database, displays a menu showing the point's corresponding route numbers, directions, and mileposts. Picking can happen anywhere on the map. An example of picking operation is shown in Figure 1.

OpenGL is designed to support interactive 3-D graphic applications. Such applications allow the user to identify objects on the screen and then to move, modify, delete, or otherwise manipulate those objects. Since 3-D objects are drawn on a 2-D surface, picking can be difficult to achieve. OpenGL provides a selection mechanism that automatically records the objects drawn inside a specified region of the viewport. This can be utilized to implement general purpose picking operation.

However, OpenGL's implementation of picking requires the program to render the same scene twice. OpenGL establishes a data record in the background for each object on the surface. After rendering, the name of an object is determined when that object is selected. However, names of all objects need to be input before the rendering in the programming process. Therefore, OpenGL's picking implementation could not be directly used for MMHIS, as the terrain surface in MMHIS is formed by using possibly millions of small triangles and this naming convention could not be directly used. Instead MMHIS uses a simplified mechanism to achieve picking. It does not let OpenGL manage the name stack and the background buffer. Rather, MMHIS creates two buffers for picking operations. Instead of rendering the same scene to two different buffers and specifying the names of the objects, MMHIS renders the main scene only once. MMHIS renders the location information directly into the picking buffers and does not use name stacks. *Colors* are used to represent longitude and latitude grid numbers in its picking buffers. When a point on the map is clicked by the user, the same point in the two picking buffers are checked and the coordinates of the point can be obtained by decoding the colors of the same point in the picking buffers. This decoding process is the reverse of the rendering process. Lighting effects are not produced when the picking buffers are rendered. This ensures the colors of each pixel in the picking buffers are those specified during the rendering process. Nor is anything on the screen rendered, which ensures that the actual color depth of the display device does not affect the color depth requirement of the picking buffers. Figure 9 shows MMHIS's picking mechanism.

Because the same 3-D coordinates are used for rendering both the map and the picking buffers, hidden surface removal is identical for the map and the picking buffers. This ensures accurate picking operation for the 3-D map. After the coordinates of a point on the map are obtained, the program checks all the points in the vicinity using the data in the location information file. The route number and milepost can be obtained from this file if the point is registered in the digitizing process. The route number is in fact the value of the *ID* field in the master database table. With this information in hand, the direction information can be queried out from this table. The returned information is used to construct a context menu to show the position of the point. The process of picking is shown in Figure 10.

CONCLUSIONS

Currently, the data sources for MMHIS are from an existing highway data vehicle and USGS. It requires less than a full-time personal to maintain the operation of MMHIS. However, a computer network and workstations are needed to support a multi-user environment, as digital video files have to reside in a central location due to their large sizes. Video decompression of MPEG-2 support is also necessary of the workstations. This feature is becoming a standard for many new computers. 3-D visualization hardware is recommended for the workstations, but not required. 3-D rendering can be conducted by the CPU, but with slower speed than a computer can do with dedicated 3-D hardware.

MMHIS provides multimedia data viewing capabilities to highway engineers. It allows a highway agency to examine road and roadside structures without taking certain field trips. In addition, MMHIS in a computer network environment can be used in communicating design and improvement ideas among engineers and managers, and to the general public. Future work includes the use of higher resolution data from satellite imagery vendors and USGS.

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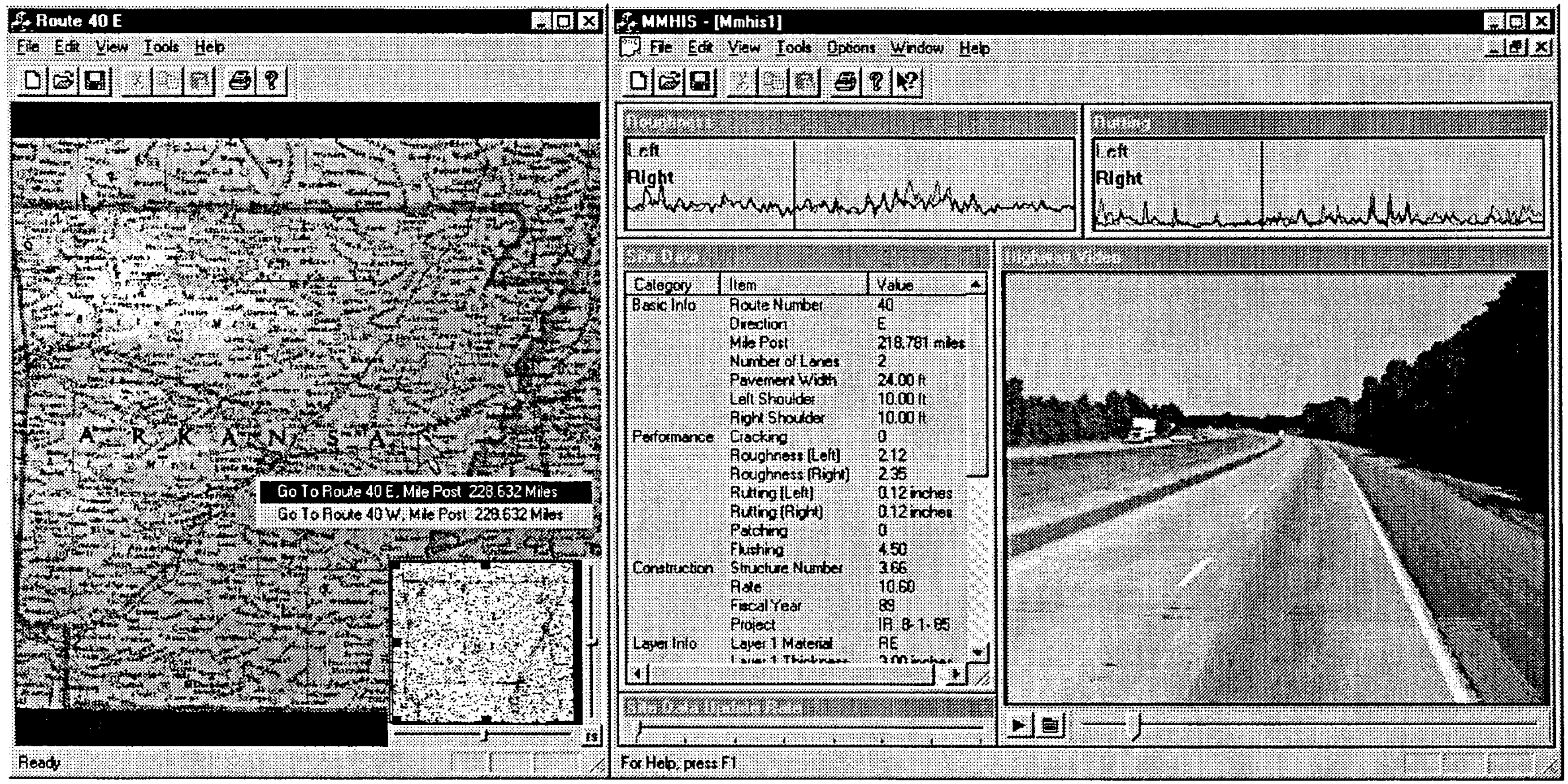


FIG. 1. 3-D Map Interface for MMHIS

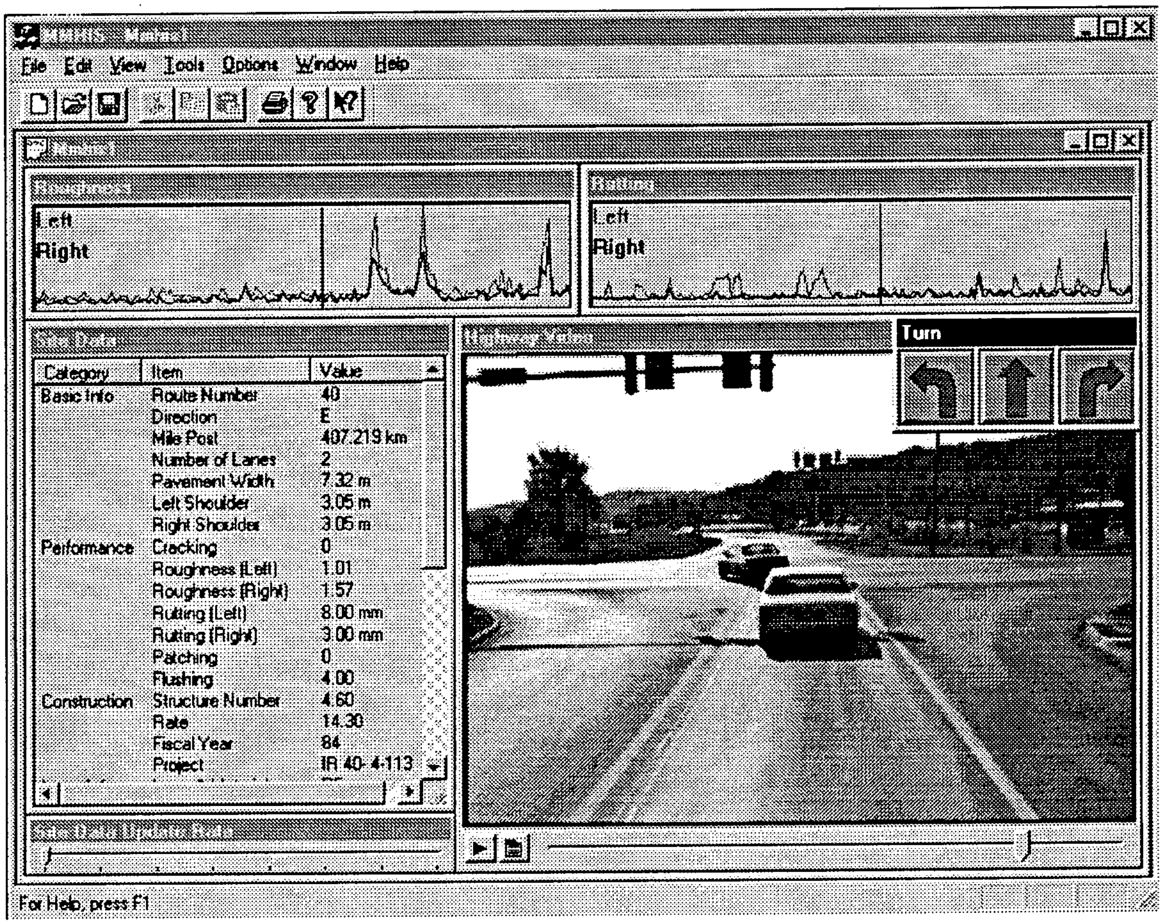


FIG. 2. User Selectable Turning Movements

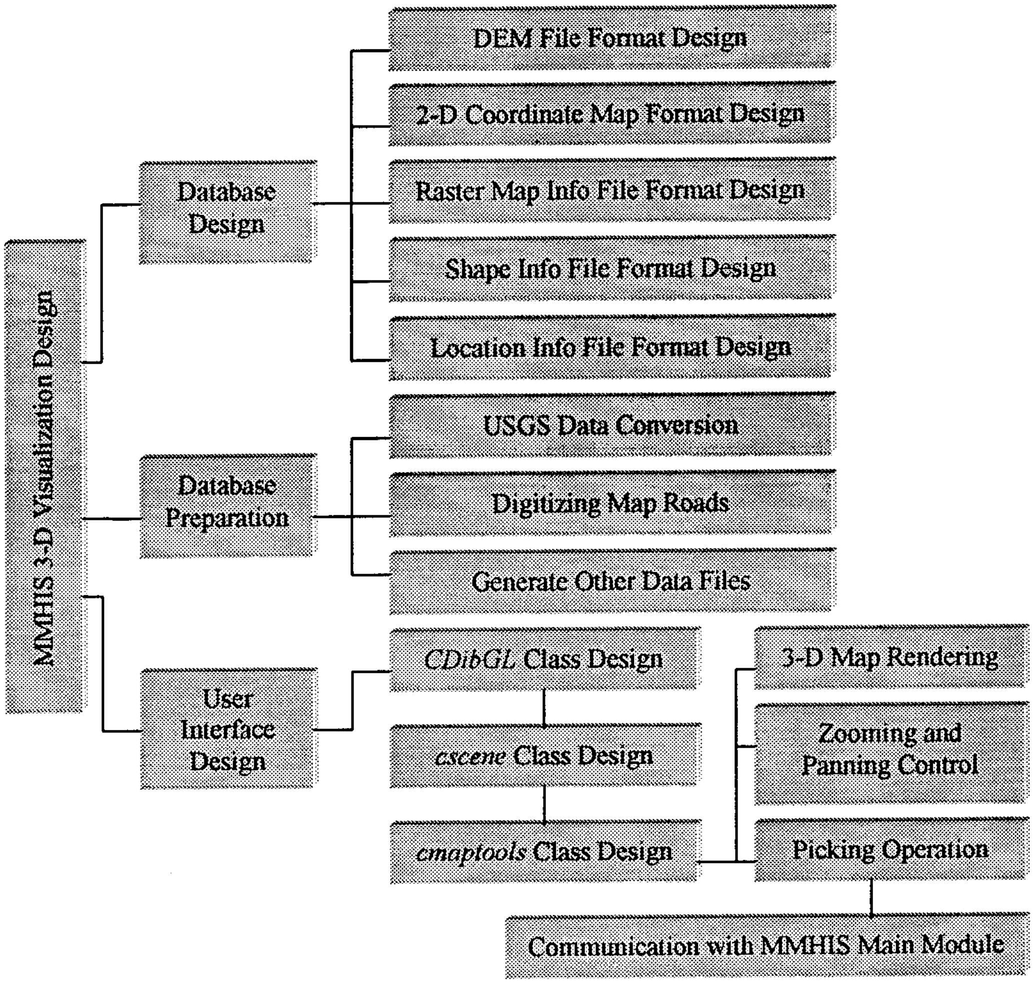


FIG. 3. System Level Design for MMHIS

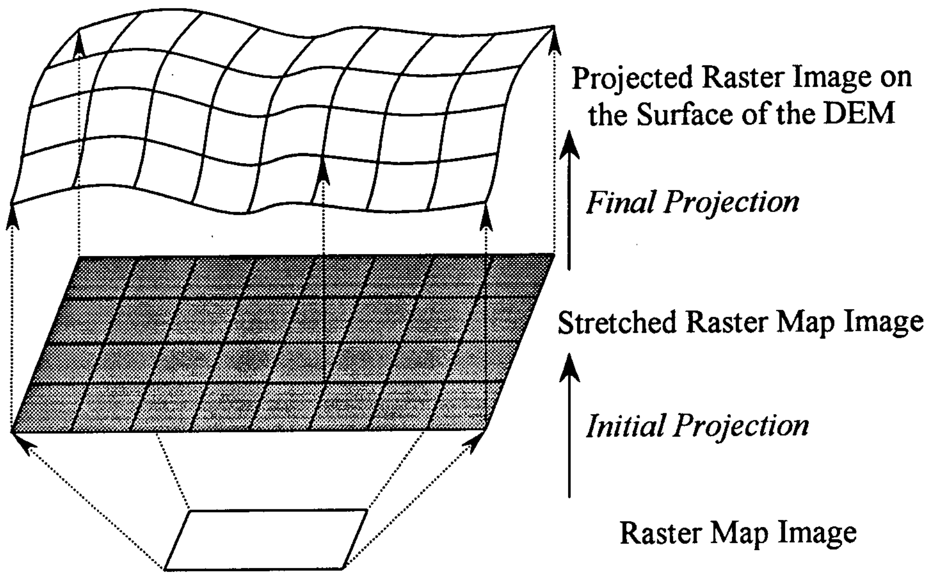
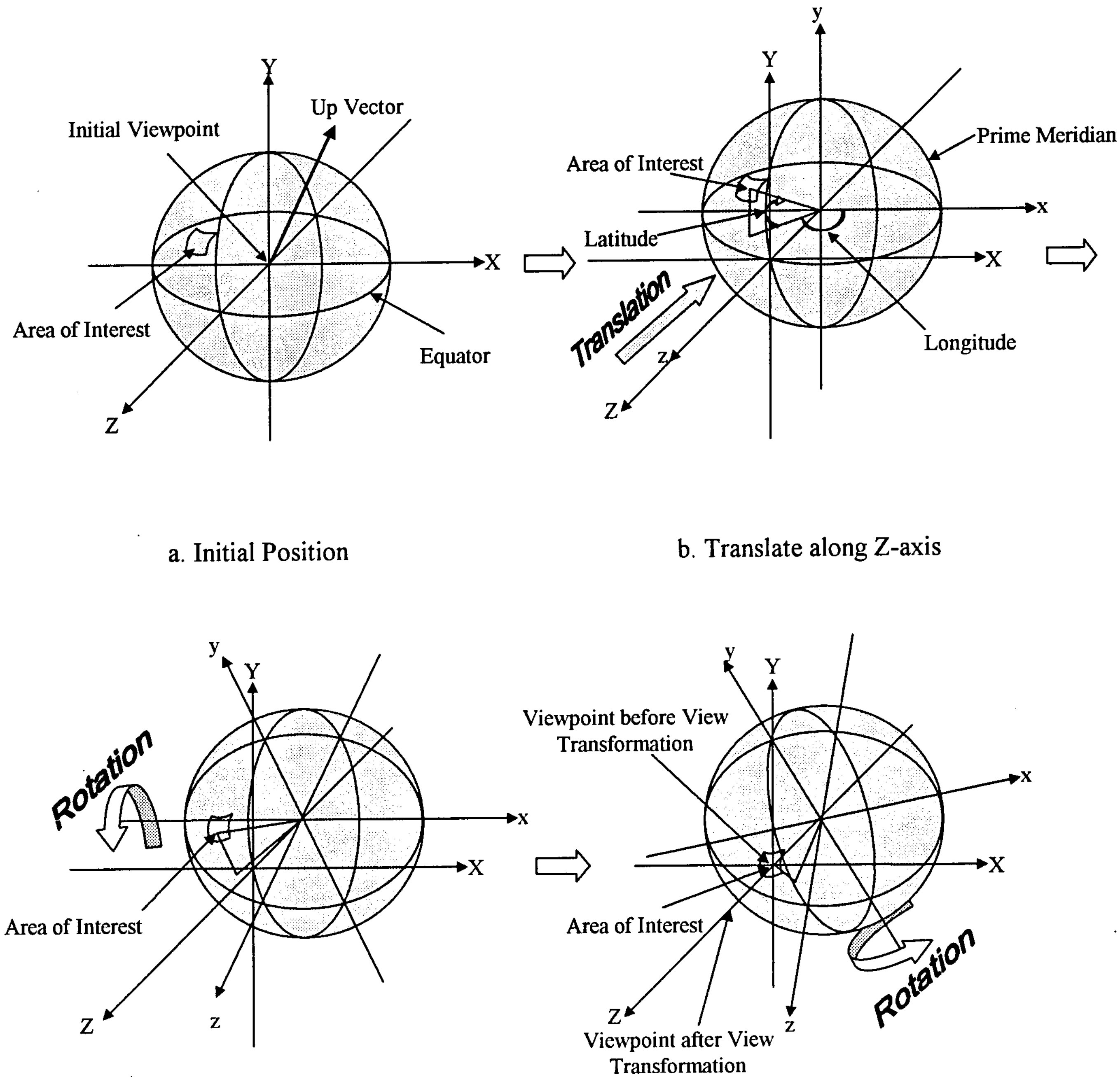


FIG. 4. Illustration of Projection of the Raster Image onto the Terrain Surface



a. Initial Position

b. Translate along Z-axis

c. Rotate along X-axis

d. Rotate along Y-axis

Note: X, Y, and Z represent the world coordinate system.
x, y, and z represent the local coordinate system.

FIG. 5. Modeling Transformations in MMHIS

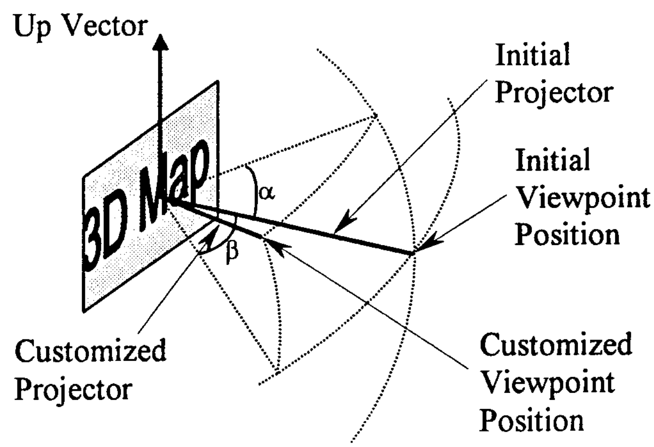


FIG. 6. Customized Viewpoint Position and Projector

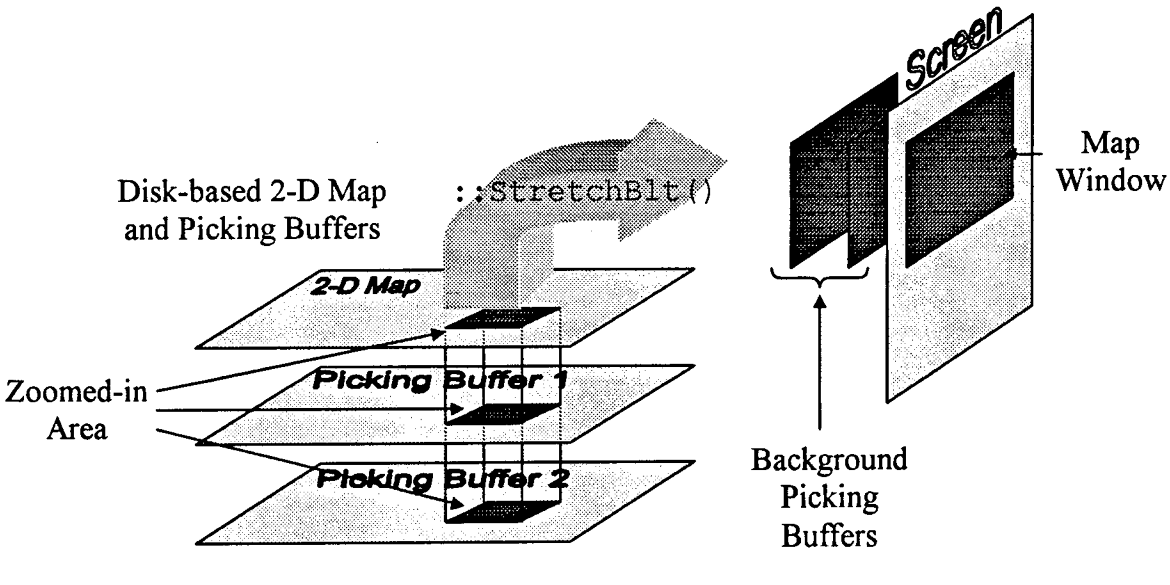


FIG. 7. Map Rendering in 2-D

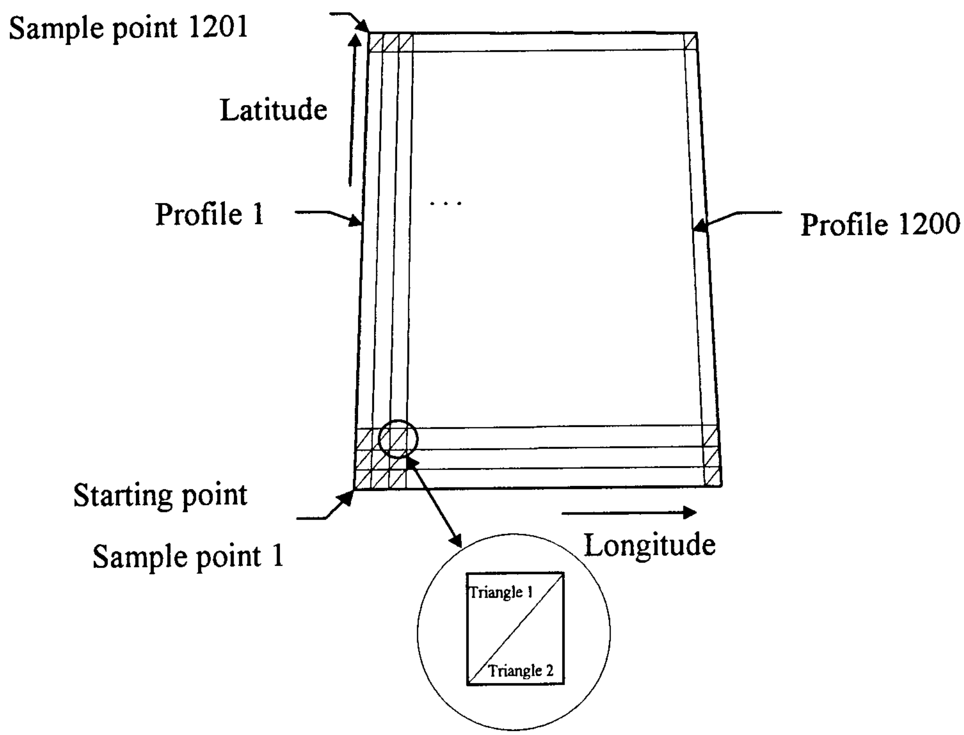


FIG. 8. Partitioning with a Triangular Mesh

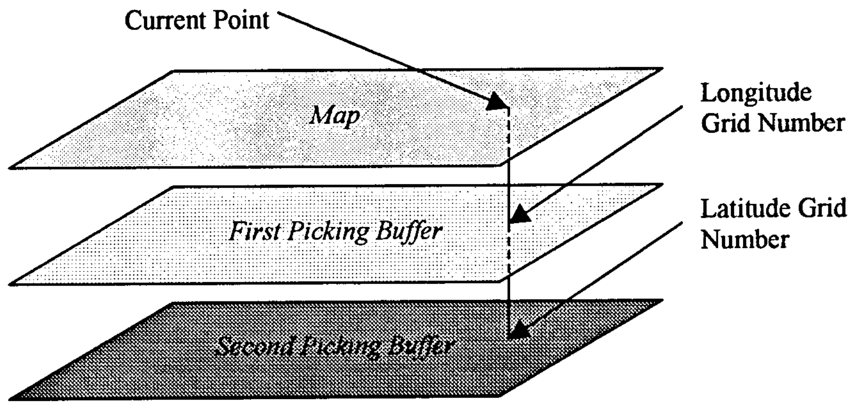


FIG. 9. Picking Operations

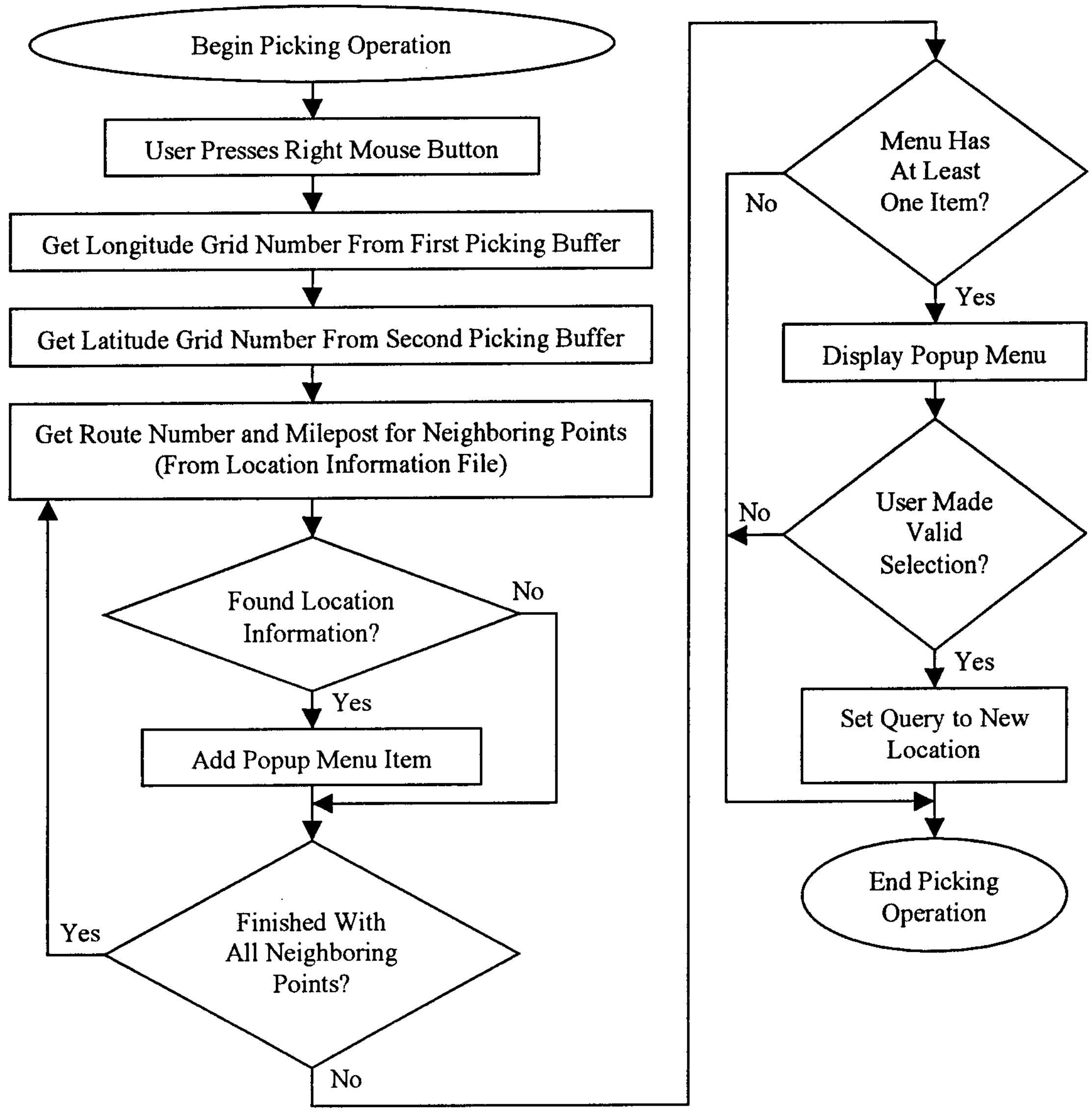


FIG. 10. Picking Algorithm