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THE DEVELOPMENT OF A FULL-DIGITAL AND NETWORKABLE MULTI-MEDIA BASED HIGHWAY INFORMATION SYSTEM, PHASE I

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THE DEVELOPMENT OF A FULL-DIGITAL AND NETWORKABLE MULTI-MEDIA BASED HIGHWAY INFORMATION SYSTEM, PHASE I

Final Report

Submitted to

Mack-Blackwell Transportation Center

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PROJECT ABSTRACT

This report covers the development of a Multimedia Based Highway Information System (MMHIS). MMHIS extends the capabilities of current photo logging facilities. Photographic logging systems used by highway agencies provide engineers with information in the analysis of traffic accidents, design improvements, and highway pavement management. However, there exist limitations for such systems in the areas of accessibility, search capability of the image library, and synchronization of the video data with traditional engineering site data. The analog nature of the video signals also presents difficulties in integrating the visual information with other types of data. This report presents the development of a multimedia service that can be applied in a state highway department environment. This Multimedia-based Highway Information System (MMHIS) utilizes state-of-the-art technologies in digital video, high-speed networking, and the video server. A data-synchronization algorithm was developed to dynamically display digital video frames along with traditional engineering data sets that contain information such as as-built data, pavement condition and performance, traffic safety, geometric features, and other infrastructure data. Geo-referencing capabilities were also developed into MMHIS, so that multimedia data is location-referenced in the databases.

REPORT SUMMARY

Visual information is frequently used in highway departments for traffic engineering and infrastructure management. Another type of information is tabulated site data organized in traditional engineering databases on pavement history and layer information, pavement width/type, average daily traffic (ADT), accident history, signing and marking inventory, and others. These two types of information (roadway images and traditional engineering database) can be of daily benefit to the needs of various divisions in state highway departments.

Highway departments would have much greater access to data if these two information sources could be combined into one comprehensive database that could be accessed simultaneously. However, most existing photo logging systems used by highway departments are analog based and located at specific location(s) within the department. Traditional engineering site data are contained separately from the video databases, and simultaneous multiple accesses to the video data are not possible. Searching for site data is a cumbersome process.

A few studies have attempted to exploit new technologies to improve the accessibility and usability of video information collected from the photo logging process. Wang et al. [1] presented general concepts and design issues for the development of a distributed multimedia based highway information system (MMHIS) and discussed the economic and technical feasibility of using digital video and new networking technologies for such a system. It was concluded in that study that the latest technology allows such a system to be developed cost-effectively.

The present report summarizes the studies in the areas of high-speed networking, video server technology, and data synchronization that are essential for the implementation of an MMHIS. To implement the MMHIS in an operational environment, a high-performance network and a powerful video and storage server are necessary. In addition, for simultaneous and instant access to the MMHIS data, the application of new technologies such as Asynchronous Transfer Mode (ATM) or FastEthernet, and Redundant Arrays of Inexpensive Disks (RAID) are needed. A plausible alternative to building a wide area network may be to install a high-performance network system in the headquarters of a highway department and distribute hard copy videodisks to remote district offices. For example, the maximum capacity of a new kind of CD, the Digital Versatile Disk (DVD), is 18.8 gigabytes, which can hold 400 lane-miles of video information at MPEG2 quality. This report describes the working system already developed for the Arkansas Highway and Transportation Department (AHTD), which has a user intuitive interface. The report also includes a guide on how to use this system.

We believe that the technologies associated with the implementation of MMHIS are mature and that the costs of implementation are continuing to come down. The cost-effectiveness of using the MMHIS is evident not only in greater office productivity but also in the actual cost savings resulting from reduced travel for site inspections. Preliminary highway site inspection normally involves two people and can take as much as two or more days. If the number of such trips can be reduced through the use of the MMHIS, a highway department can realize substantial savings in travel and labor costs in just one year.

As MMHIS is technology-driven, additional features can be built into MMHIS over time. New features of Geographic Information System and high-resolution 3-D terrain data will be useful for an integrated highway management and design. When statewide terrain data in the MMHIS are updated with Digital Elevation Models (DEM) of sub-meter resolution, it is possible to conduct preliminary engineering design of cut-and-fill and planning for new transportation systems.

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INTRODUCTION

Visual information is frequently used in highway departments for traffic engineering and infrastructure management. Another type of information is tabulated site data organized in traditional engineering databases on pavement history and layer information, pavement width/type, average daily traffic (ADT), accident history, and signing and marking inventory, and others. These two types of information (roadway images and traditional engineering database) can be of daily benefit to the needs of various divisions in state highway departments. In order to improve data accessibility in a highway department, it will be very beneficial to combine these two information sources into one comprehensive database that can be accessed simultaneously.

However, most existing photo logging systems used by various highway departments are analog based and located at specific location(s) within the department. Simultaneous multiple accesses to the video data are not possible. Searching for site data is cumbersome. Traditional engineering site data are contained separately from the video databases. There were a few studies in an effort to exploit new technologies to improve the accessibility and usability of video information collected from the photo logging process. Wang et al. [1] present general concepts and design issues for the development of a distributed multimedia based highway information system (MMHIS) and discussed the economic and technical feasibility of using digital video and new networking technologies for such a system. It was concluded in that study that the latest technology allows such a system to be developed cost-effectively. This report summarizes the studies in the areas of high-speed networking, video server technology, and data synchronization that are essential for the implementation of an MMHIS. It is demonstrated that a future digital video-based highway information system will be efficient and productive through use of technologies such as Asynchronous Transfer Mode (ATM) and state-of-the-art video server devices.

A working system has already been developed for the Arkansas State Highway and Transportation Department (AHTD). The system has a user intuitive interface. A guide on how to use this system is also given in this document.

History of Photo-logging System and Basic Requirement of MMHIS

Problems with Existing Photo-logging Systems

Current existing photo-logging systems use data collection vehicles to collect data on pavements and roadside structures and to take videos of the right-of-way. The video information used by highway agencies is stored in analog format and located at specific locations. The storage media include tapes, films, and laser disks. Engineering site data are stored in separate databases. Video playing devises are used to play the highway videos. This is shown in Figure 1. Special-purpose software is used in some existing systems to retrieve and present site data tables to the user. The data in the database, however, are not well organized. Some systems require the user to use general-purpose DBMS software to open the table and query information. Others use file processing instead of database management. The limitations of existing systems are exhibited in the areas of accessibility, search capability of the video library, and synchronization of video data with traditional engineering site data. Users who are interested in a section of a road when viewing the video have to go to another location to look for the corresponding site data. The existing systems also lack multiple-user access capability. Due to the analog nature of the video signals, it is difficult to integrate the visual information with computer databases. It is a time consuming process to look up and reassemble the video and site data in different formats and from various sources.

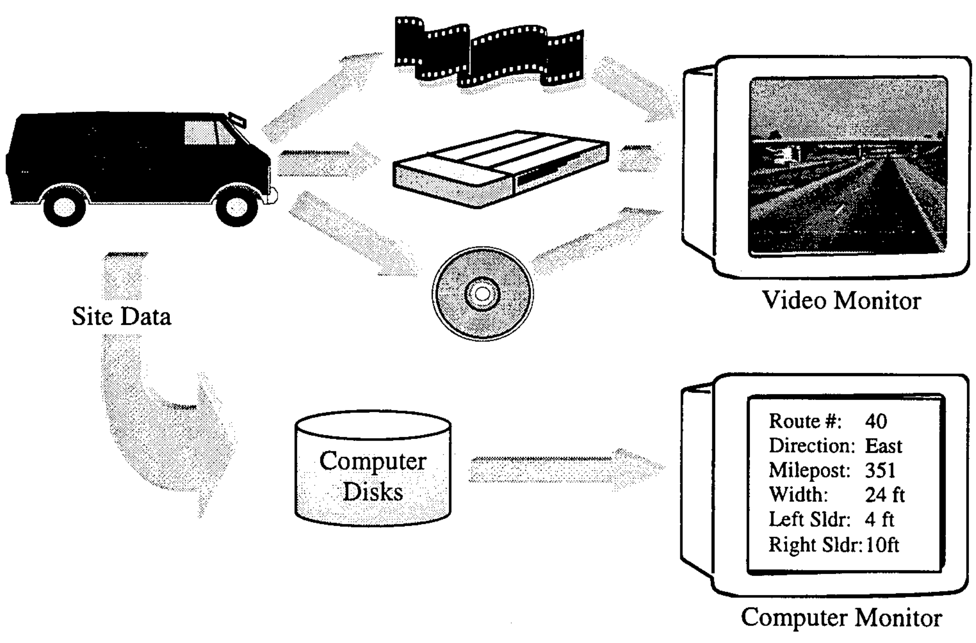


Figure 1 – The Existing Photo-logging System Data Flow

Basic Features of MMHIS

A new system – Multimedia-based Highway Information System (MMHIS) – was developed in this project to solve the problems in existing photo-logging systems. Technologies used in the new system include digital video, high-speed video server, ATM networking, relational database management system, and 3D-map rendering. MMHIS also uses a data synchronization algorithm to synchronize the highway motion video with the display of other data – engineering site data, roughness and rutting graphs, and location on the 3D-map. A high-speed network links workstations with the MMHIS server so users can look at the photo-logging video and the synchronized data sets without leaving their offices. Because the engineering site data are stored in computer databases, MMHIS can be easily customized to fit the need of different departments.

Apart from easy data accessibility, data presentation in MMHIS is more flexible than the old systems. An integrated environment hosts various views that are used to display data from various sources. The views can be customized to display a certain collection of fields in the data set. It can display the data in either categorized or user-defined format. Users can choose whether to use metric or imperial units in the data display. When using the user-defined format, the order of the data fields can also be customized.

With the technology advancement of satellite imagery and remote sensing, vast amount of 3D earth surface data is readily available. Because all inventory data from photo logging are location-specific and have spatial characteristics, a terrain visualization interface was constructed for MMHIS. Users can interact with a 3D digital map for the area of interest and visually select data queries from this map. This visualization interface allows users to rotate, zoom in and out, and pan around the terrain surface of the area. The picking operation for the 3D map was implemented using a specially designed picking algorithm. The 3D map can be rotated freely within a certain range. The picking algorithm guarantees that users can always click on the road in the rotated map and get the correct location information. The 3D-map shows the terrain surface relief when rotated to a low angle. In most cases, however, users view the map from a right angle. In such cases, MMHIS uses special algorithms to render the map so that the zooming, panning, and rendering operations can be conducted with a very fast speed.

The Querying database in MMHIS is object-oriented. There are several different ways to conduct a query in MMHIS. It does not require users to be familiar with any general-purpose DBMS products. Users need only to specify the location on a road by specifying the route number, direction, and milepost, or by clicking on the map offered by MMHIS. MMHIS provides highway engineers an efficient and effective tool in analyzing road and roadside structures with instant accessibility to the multimedia databases. This tool is not available to any highway department in the United States at this time. The core technologies developed for this system can be used in future generations of highway information systems in any highway department.

NEW TECHNOLOGIES OF DIGITAL VIDEO AND GEO-REFERENCING

Digital Video for MMHIS

The video quality associated with consumer TV and video tapes, including video from Super VHS and laser disks, is determined by the analog video standards set by the National Television Standard Committee (NTSC) in the early 1950s. Even though an analog video signal can be transmitted and copied through narrow bandwidth, it is difficult to manipulate, copy, and distribute without introducing electronic noise into the original signal, resulting in the deterioration of image quality. Without the use of high-end video production equipment, the integration of analog video with other types of data, such as text and graphics, is very difficult.

Additionally, in an MMHIS, multiple users need simultaneous and random access to video data. For data stored in an analog system, multiple and unsynchronized access to video data is a problem. For instance, it is difficult to view two different sections of the same videotape simultaneously, and then decide to freeze one while running the other. Routing of multiple analog video data to users is also complicated. If the video signal is presented in digital format, like the digital sound in compact disks, it can provide much better image quality, can be easily duplicated and can be incorporated into other media without introducing artifacts or losing fidelity. Because digital video data is stored in disk files, it is possible to allow simultaneous multiple accesses to the same digital video files through computer networks. Digital video is necessary when high fidelity, fast and multiple user accesses are required of the MMHIS.

Data Collection, Compression and Decompression (CODEC)

Presently the visual data is collected in a vehicle, such as a van, with video capturing equipment. Normally, the visual data is recorded onto a Y/C signal based tape (S-VHS or Hi-8mm) or laser disk. The video signal is analog based with luminance and chrominance information separated. The perceivable vertical resolution of the video data is about 400 lines. The recorded media are then categorized for viewing in the office. To prepare the video for the MMHIS, the analog based video data is digitized and becomes digital data sets that are directly manageable with computers. The digital video is generated through a process called encoding with source video data, such as tapes. One full color (8-bit for each of red, green, and blue) digital image with a NTSC TV resolution (640 x 480) requires approximately 0.92 megabyte of data storage, resulting in about 27 megabytes of storage space for one second of motion video. In addition, the input and output bandwidth of modern microcomputers are not generally capable of processing this amount of data per second. Therefore, data compression is needed to reduce data storage requirements on the one hand, and to improve the data flow rate on the other.

The amount of compression ranges from 2:1 to 200:1, depending on the type of algorithm, the implementation of the algorithm, the level of video quality, and the presence of hardware assistance. Most compression algorithms are "lossy", meaning that some information is lost during the compression of the data, due to the fact that the compression ratio based on lossless encoding algorithms is low, around 2:1. The objective for most applications is to retain visually faithful representations of the original images and discard any visually insignificant information. The process of compression and decompression (for playback) is called CODEC for encoding and decoding. Some approaches require more operations to be performed in encoding than in decoding. This type of CODEC is referred to as asymmetrical. If both processes require the same amount of processing, it is called symmetrical CODEC.

Motion JPEG (Joint Photographic Experts Group) and MPEG (Motion Picture Experts Group) are the two dominant types of digital video CODECs, both of which are used in this MMHIS research. The Joint Photographic Experts Group (JPEG) developed the JPEG compression algorithm for still images based on Discrete Cosine Transformation (DCT), the quantization approach and Huffman encoding. The standard was then widely adopted as Motion JPEG for video sequences, each frame of which is compressed based on the JPEG standard. Motion JPEG allows easy random access to any frame in a digitized sequence. Compression for Motion JPEG is conducted exclusively on redundant data in individual frames without condensing any data between frames. Hardware based JPEG CODEC's can capture full-screen, 30 frame per second video in real time. When a high compression ratio (over 20:1) is not required, this symmetrical CODEC is very effective in preserving the details and fidelity of single video frames.

Unlike JPEG, which condenses information only within each frame, the standard developed by the Motion Picture Experts Group, MPEG, compresses information based on data within a frame and frame to frame motion. It should be noted that the compression within frames in MPEG is also based on DCT and related algorithms.

MPEG allows compression ratios over 100:1 while still retaining good visual quality. Due to its high compression ratio, MPEG is a desirable delivery format for applications that require narrow bandwidth transmission, such as CD-ROM and video networks. However, due to the asymmetric nature of MPEG, the encoding process requires very high computing power. For example, a state-of-the-art MPEG encoding device can consist of over a dozen RISC based compression processors. The decoding process of MPEG needs relatively less computing power. At similar levels of video quality, a Motion JPEG stream will require a much higher data rate than an MPEG compressed stream. Current available MPEG systems are classified into the categories of MPEG1 and MPEG2 with MPEG1 being used for CD storage and the Internet, and MPEG2 being used for studio quality video and satellite digital TV systems.

Geo-referencing Technologies

The 3D map interface of the MMHIS uses a geo-referenced map to show the location of the video on the map and allows users to query data on any point on the map. The information about the location of any point on the map is displayed in a pop-up window when the point is clicked with the right button of the mouse. In addition, if the clicked point is near a road, the route number, direction, and milepost of the road at that point are also shown.

The 3D map of MMHIS is rendered based on information stored in the 3D-map database. Separate files are used to store different data in the 3D-map database. These files are listed in Table 1.

Database File	Description
DEM	The digital elevation model that is used by MMHIS to render the terrain surface
2D surface map	3D map viewed from a right angle
2D coordinate maps	Coordinate maps that are used for 2D picking operations
2D zoom surface map	Map used to show the zooming interface
2D zoom coordinate maps	Coordinate maps that are used for zooming interface picking operations
Raster map	Map that shows surface features
Shape	Rendered shading for the terrain surface
Location	File that stores route number, direction, and milepost information

Table 1 – MMHIS 3D Map Databases

3D Database File Structures

Digital Elevation Models (DEM) are essential to the rendering of the 3D surface of the earth. The DEMs used in the MMHIS were obtained from the United States Geological Survey (USGS). They were then converted to MMHIS specific file formats to provide for fast information retrieval. The conversion is based on the understanding of the original USGS DEM file format. Several utility programs were developed to aid this conversion. The USGS DEM file format is a general format that is suitable for a variety of different DEMs. Because MMHIS only uses one type of DEM, it makes sense to simplify the file format and make access to the data more efficiently. In the mean time, the file size can be reduced to the minimum size possible and hence save storage space on the host computer. Twenty-four 1-degree DEMs are needed to cover the whole State of Arkansas. Instead of using 24 separate DEM files as the data source, MMHIS combined all 24 DEM files into one file. There are three different records in the combined 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 (southwest corner coordinates) in degrees. The second record contains integers representing the number of grid points along both the longitude and latitude lines. The third record contains the elevations in meters along the profiles organized from south to north and from west to east. The numbers are stored in the internal integer format of the host operating system.

The rendering of a 3D map is time consuming on high-end desktop computers. Users of MMHIS normally want to scan the whole map quickly, locate the spot on the map, and then decide to see details of the terrain surface of that particular area of interest. To reduce the time for rendering the map and still offer the power to show the 3D-terrain surface, MMHIS treats the special case of 2D rendering separately. This requires a separate database to be setup to store the 2D surface map. Windows has powerful Device-Independent Bitmap (DIB) manipulation API functions built in. To take advantage of that, MMHIS stores the 2D surface map in Windows DIB format.

The 2D coordinate maps are saved in two files—one for longitude, one for latitude. These files are used to implement the picking operation in 2D special cases. The longitude and latitude of any point on the map can be identified by querying the above two files.

The 2D zoom surface map is similar to the 2D surface map file. It is used to speed up the zooming control in the MMHIS's map interface. The file is in Windows DIB format. The 2D zoom coordinate maps are similar to the 2D coordinate maps. These files are used in the zooming control to implement the picking operation.

The raster map of Arkansas is used in a texture mapping process to project the 2D map to the 3D-terrain surface. This file records the intermediate result of this mapping. The file contains three records. The first record stores the origin of the area. Two floating-point numbers are used in this record to give the longitude and the latitude of the origin. The second record stores the number of grid points along the longitude and latitude lines. The file uses the same grid system as the DEM. The third record stores the texture mapping results. It is an array of red, green, and blue (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.

MMHIS renders the 3D-terrain surface with different shades, showing the shape of the surface with light effects. With real-time rendering, the shading process is very slow. Because the terrain surface shape is fixed, the shading of all points in the area is saved to an intermediate file so that the data do not have to be generated each time the scene is rendered. The shape information file is used for this purpose. The file's structure is similar to the raster map information file. The only difference is that instead of saving an array of three bytes representing RGB values in the third record, this file saves a byte array. Each element of the array represents the corresponding shading of the grid points.

Note that this file does not record things such as hidden surface information. MMHIS deals with the issue of hidden surface removal using other tools. To show 3D objects' positions, real-time rendering is conducted when the map is displayed. The real rendering process uses a less computation-intensive lighting model so that the scene can be efficiently rendered.

The route numbers, directions, and mileposts of grid points on roads are saved in the location file. MMHIS uses this information to decide the query location of a point on the map. There are three records in this file. The first two records are the same as those in the shape information file. The third record contains an array of integer pairs representing the route and milepost of each grid points. The route is the `RowID` field value in the state master table (refer to later sections for database structures).

Generating the 3D Map Database

The conversion from USGS 1-degree DEMs to the MMHIS DEM file requires two steps, utilizing two special utility programs developed specifically for this purpose. These two programs are not built into the MMHIS integrated environment because the conversion takes place only once. The first step converts individual USGS 1-degree DEM files into individual MMHIS DEM files using a vertical scale factor of one. The second step combines these small files into the final large DEM file.

The 2D surface map is a special case of viewing the 3D surface map from the right angle. The 2D surface map is generated by rendering the 3D surface map using the right angle. It is saved in the DIB format to the 2D surface map file.

The 2D coordinate maps are rendered using the more general technique of rendering the 3D coordinate map with a viewing angle of 90° (right angle). The rendered map is saved in the DIB format to the 2D coordinate map files.

The process of creating these two files is the same as the process of creating the 2D surface map and the 2D coordinate maps; with the use of different parameters. The resultant files are saved to appropriate files.

MMHIS uses a 2D map that was scanned from a paper map as the basis for the features of the 3D map. Information from the 2D map is used in the final rendering of the 3D map. It is also used in the road digitizing process. The resolution of this map is smaller than the resolution offered by the DEM.

The creation of the raster map involves a texture mapping (or projection) process. The projection algorithm is described below.

- Loading the 2D map and the DEM

  This step loads the 2D map into memory. The raw data of the image is separated to simplify the projection process. The MMHIS DEM file is also loaded for use in the rendering process.

- Matching the 2D raster map with the MMHIS rendered region

  In this step, the longitude and latitude lines are rendered and overlaid to the 2D map. The purpose is to find out the correct transformation factors so that the rendering results match the corresponding lines on the 2D map. During the matching process, transformation factors are interactively adjusted and the longitude and latitude grids are rendered after each adjustment. The result is shown on screen and is visually compared with the lines on the 2D map. The process stops after a satisfactory match is reached.

- Rendering the 3D-terrain surface using lighting effects

  Using the results from the previous step to conduct the transformation, the 3D-terrain surface is then rendered to a buffer that has the same dimension as the 2D-raster map. Because of the large size of the area, a memory mapped file kernel object is used as the virtual memory for the rendering buffer. DEM data are used in this step.

- Reading the DEM records and match each grid points to the results in the previous two steps

  In this step, the DEM records are scanned and the view-port coordinates for the grid points are calculated with the OpenGL raster position functions. The view-port coordinates are used to get the colors of corresponding pixels in both the 3D-terrain surface rendering buffer and the 2D-raster map. These colors are used to fill the records of the raster map and shape information files.

Roads on the 2D-raster map are digitized and saved in the location information file. The digitization is an interactive process. The following steps are used in this process.

- Prepare the 2D-raster map and the longitude and latitude grid buffers

  The digitization process uses the 2D-raster map to show the location of roads. It requires the user to interactively specify points on the road on the 2D-raster map. The map is loaded into one buffer of the program. Two other buffers containing the corresponding longitude and latitude grid information can either be rendered directly or loaded from disk files (if one has already been created). These two buffers are used to get the grid coordinates of points on the 2D-map.

- Define points of a new road

  A temporary file is created in this step to save the coordinates of points on the road. The program checks for mouse click messages after the above file is created. The points clicked by mouse are then linked to form a line representing the road. Because points clicked by the mouse does not cover all points on the road, Windows dynamic data analysis function `::LineDDA()` is called to retrieve all pixels on the road. The view-port coordinates of all pixels on the road are saved into the temporary file.

- Correlate mileposts with grid coordinates

  The coordinates saved in the above file are checked against the pixel information in the two grid coordinate buffers to get the longitude and latitude of the points. The results are saved in the same file.

- Specify mileposts for key points

  Similar to the video frame index building process, this step allows users to interactively specify the milepost of certain points (called key points) on the road. These points will be matched exactly to the mileposts specified.

- Update database

  Linear stretch is used to calculate the mileposts of every grid points and the result is saved in the last two fields of the fixed data table corresponding to the road.

Picking Operations

The map module allows users to click on the map and shows a small popup window with location information in it. If the point clicked is a point on a highway section and is registered in the database, it also displays a menu showing the point's corresponding route number, direction, and milepost. The operation is called *picking*. The picking can happen anywhere on the map.

MMHIS creates two buffers for picking operations. Instead of rendering the same scene to two different buffers and specifying the names of the objects, the MMHIS renders the main scene only once. The MMHIS specific C++ class `cmaptools` handles rendering the picking buffers in a simplified way—it renders the location information directly into the picking buffers. `cmaptools` does not use name stacks as normal OpenGL programs do. It uses *colors* to represent longitude and latitude grid numbers in its picking buffers. When a point on the map is clicked by the user, the corresponding two points in the two picking buffers are checked. The coordinates of the clicked point can be obtained by decoding the colors of the corresponding points in the picking buffers. This decoding process is the reverse of the rendering process. `cmaptools` does not use any lighting effects when it renders the picking buffers. This ensures the color of each pixel in the picking buffer is the one specified during the rendering process. The `cmaptools` does not render anything on the screen. This ensures that the actual color depth of the display device does not affect the color depth requirement of the picking buffers. Figure 2 shows MMHIS's picking mechanism.

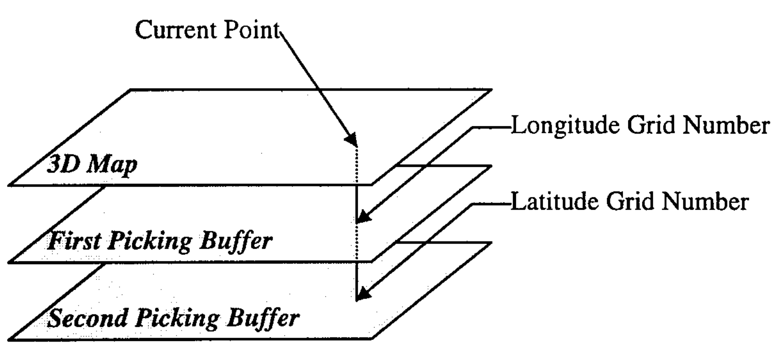


Figure 2 – Picking Operations

After the coordinates of a point on the map are obtained, MMHIS obtains the elevation of the point from the DEM data file and displays the location information in a small pop-up window. The program then checks all the points in the vicinity using the data in the location information file. The route (represented by the `RowID` field of the state master table) and milepost can be obtained from this file if the point is registered in the digitizing process. With this information in hand, the direction information can be queried out from the state master table. The returned data is used to construct a context menu to show the position of the point.

Location Synchronization with Video and Site Data

When a query is going on, a location indicator (a small flashing red dot) is displayed on the map to show the current vehicle location. The location indicator goes along the highway on the map as the video plays. The synchronization timer handler queries the current vehicle location from the fixed data table and passes the query result to the 3D-map sub-module. The map module then finds the screen coordinates of the current vehicle location. MMHIS maintains a 3D position in window coordinates. (This is handled internally by the OpenGL engine.) This position, called the *raster position*, is used to position pixel and bitmap write operations. It is maintained with sub-pixel accuracy. The current raster position consists of three window coordinates (x, y, z), a clip coordinate value (w), an eye coordinate distance, a valid bit, and associated color data and texture coordinates. The w coordinate is a clip coordinate, because w is not projected to window coordinates. MMHIS converts world coordinates to window coordinates by calling appropriate API functions. The converted window coordinates are used to display the location indicator on the map.

DATA SYNCHRONIZATION ALGORITHMS AND IMPLEMENTATION

The Preparation of Video Frame Index

Video frame indexes were created with the MMHIS Index Building module. The index building process is divided into the following steps.

- Obtaining information. In this step, necessary information is collected in the *Building Index* dialog box. The fields are listed in Table 2.

Field	Explanation
Video File Name	The name of the video file for which frames will be indexed
Video Start Frame	Frame number corresponding to the beginning milepost
Video End Frame	Frame number corresponding to the ending milepost
Route Number	Route number of this section
Direction	Direction of this section
Start Milepost	Starting point of this section
End Milepost	End point of this section
Key points	Mileposts of points that corresponds to known frame numbers
Turning points	Destination route numbers, directions and mileposts of turning points

Table 2 – Index Building Module Input

- The key points specified by the user are used to define subsections of the highway section covered by the current video. Each subsection begins at one key point and ends at the next key point. That is, in each subsection only the first milepost and the last milepost have corresponding video frame numbers specified. Video frame numbers corresponding to the rest of mileposts are calculated by using the linear interpolation method. The speeds of the vehicle when it took the video are recorded into the main data table. The speed data are used as the determining factors.

The above method guarantees that key points are exactly indexed with the frame number specified. This is especially useful when the speed data is not accurate enough to be used as the sole factor to interpolate values. If the total accuracy is guaranteed, only the starting point and end point of the whole section need to be defined as key points.

To describe the above algorithm mathematically, suppose for a subsection the starting milepost is s, which corresponds to frame number fs, and the end milepost is e, which corresponds to frame number fe. The number of mileposts in this subsection n can be calculated as

$$n = \frac{e-s}{step} + 1,$$

in which *step* is the distance between consecutive mileposts. In the current database, the value of step is 25 meters. Suppose the speed value for milepost i (i is $1 - n\text{-}1$) is *speed(i)*. The corresponding frame number is *frame(i)*. The traveling time for the video to cover this subsection T is calculated as

$$T = \sum_{j=1}^{n-1} \frac{step}{speed(j)}.$$

The frame numbers for the rest of mileposts are calculated as

$$frame(i) = \frac{(fe - fs)}{T} \sum_{j=1}^{i} \frac{step}{speed(j)} + fs.$$

Database updates are involved in the index building module. Because the Microsoft Access ODBC driver supports database updates, it is just a simple matter of calling the appropriate update functions with proper SQL commands to finish building the index. The index building process is shown in Figure 3.

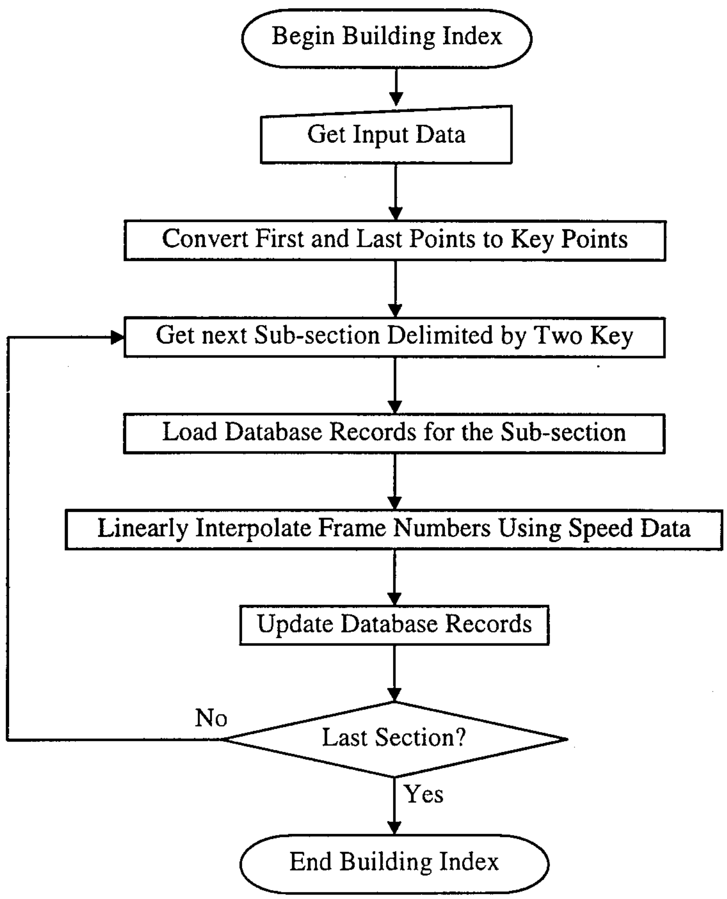


Figure 3 – Index Building Flowchart

The Synchronization of Video and Site Data Display

When MMHIS is started with a query, the information displayed is all synchronized. That is, when the video is playing, data displayed in all other windows change dynamically with the video frames. The view window of the MMHIS control module has a timer set up at creation time. This timer, called the *synchronization timer*, is used to synchronize the display of site data with the video. The synchronization timer handler in the MMHIS control module does not actually find the correct data and display them. Instead, it acts as a director to orchestrate all sub-modules of MMHIS.

The synchronization process uses a frame range to check if the current frame of the video is still in the range for the current milepost. The range is updated when the site data and the video frame are synchronized. The first time a query is started, this range is set to an impossible range to guarantee that the synchronization operation is applied upon initialization. The synchronization process is shown in Figure 4.

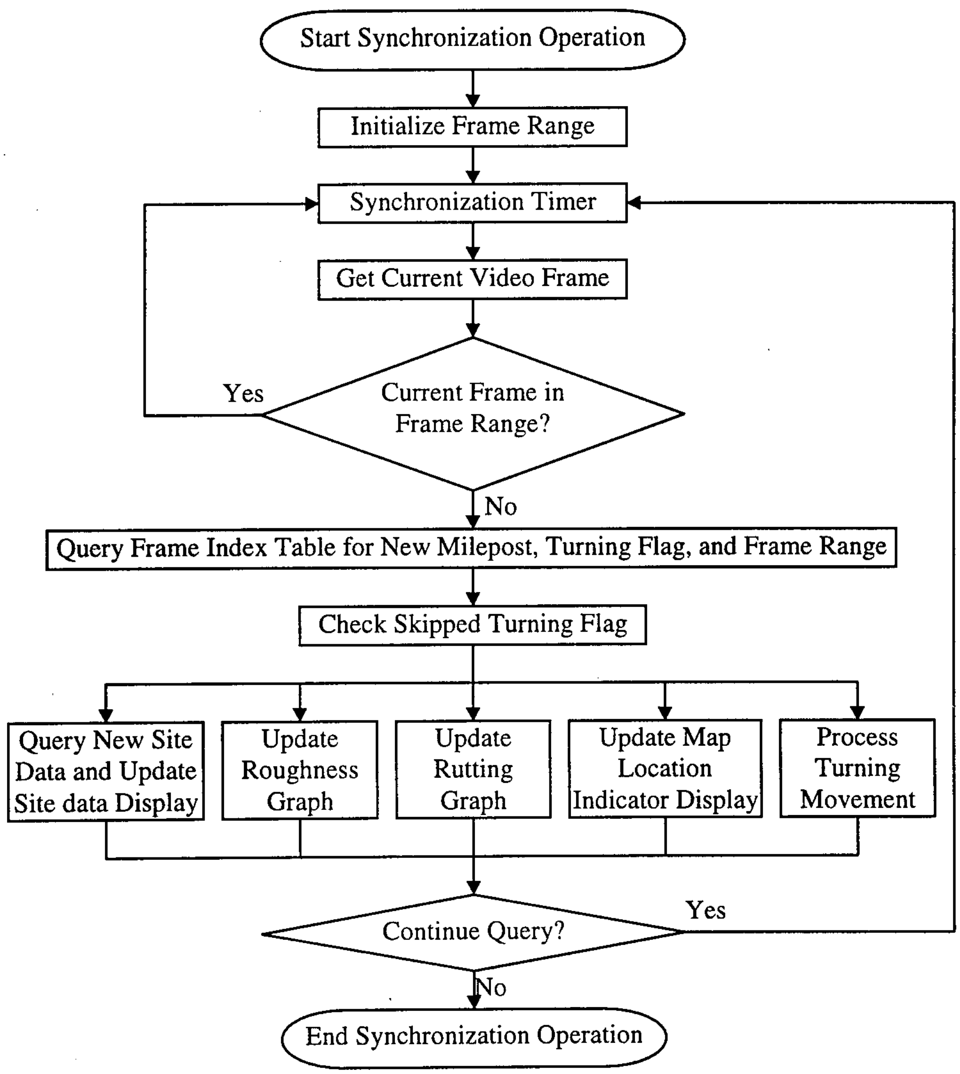


Figure 4 – The Synchronization Process Flow Chart

DATABASE STRUCTURES OF MMHIS

There are four database layers in the MMHIS. The first layer contains the state registration table. The second layer contains the state master table. The third layer contains tables that store engineering site data, frame index, turning movement information, and the data display format. The fourth layer contains the yearly data table. These tables are used to store data collected in different years for the roads. This layered structure is shown in Figure 5.

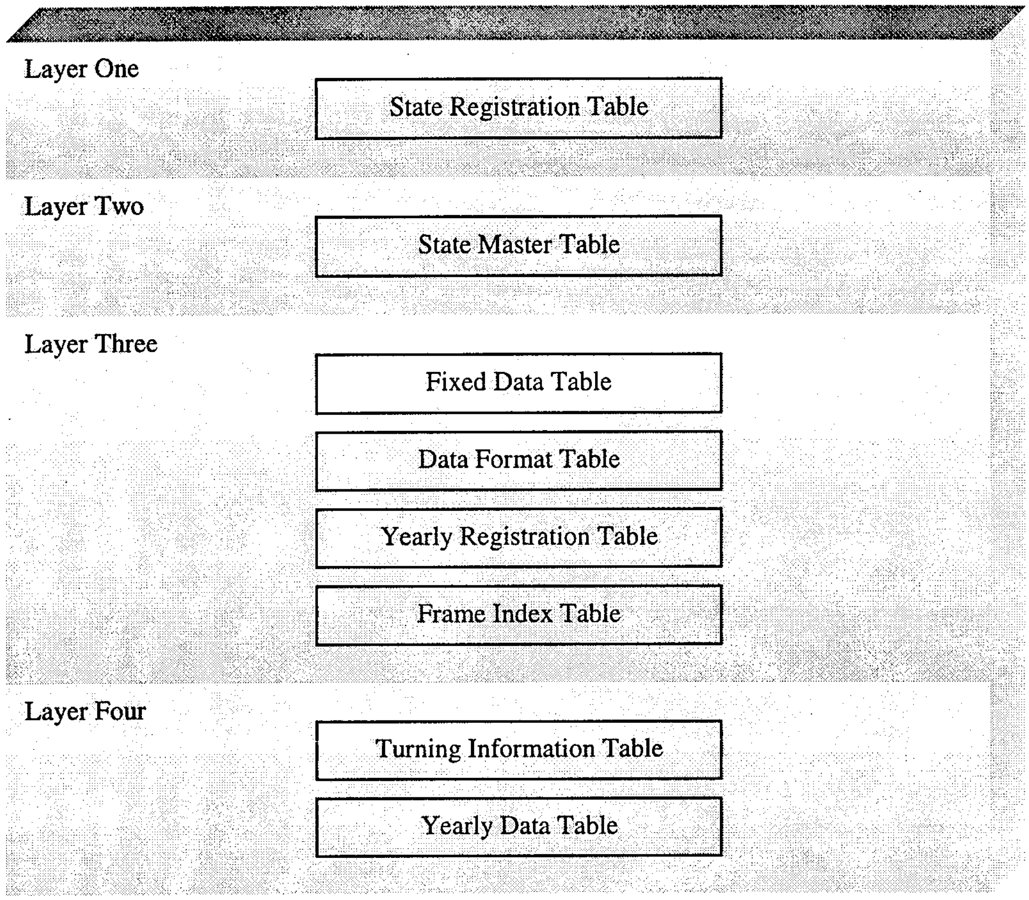


Figure 5 – The Layered Database Structure For MMHIS

The State Registration Table

The state registration table is used to register all the states in the US. Each state has a record in this table. The structure of this table is listed in Table 3. The primary key for this table is `StateName`. The field `StateMasterTableExist` determines if a corresponding table (state master table) in the second layer exists for the state. Other fields specify the map database (which is saved separately from the database for engineering site data), and basic attributes of the map.

Field Name	Data Type	Short Description
StateName	Text	State Name
StateShortName	Text	Abbreviation of State Name
StateMasterTableExist	Boolean	Yes if the state has a master table; No if not.
MapPath	Text	Path for all the files relating to map rendering
DemFileName	Text	Name of the digital elevation modal file
MapFileName	Text	Name of the raster map file
ShapeFileName	Text	Name of the rendered terrain shape file
LocationInfoFileName	Text	Name of the file that contains location information
FlatMapFileName	Text	Name of the 2D map file
FlatXFileName	Text	Name of the 2D x-coordinate file
FlatYFileName	Text	Name of the 2D y-coordinate file
ZoomMapFileName	Text	Name of the zoom map file
ZoomXFileName	Text	Name of the zoom x-coordinate file
ZoomYFileName	Text	Name of the zoom y-coordinate file
InitZoom	Number	Zoom factor for the whole state
InitCenteri	Number	Initial x-coordinate of the center point
InitCenterj	Number	Initial y-coordinate of the center point
FlatMapWidth	Number	Width of the 2D map
FlatMapHeight	Number	Height of the 2D map

Table 3 – The Structure of State Registration Table

The State Master Table

The state master table registers all the roads in the corresponding state. Each record in this table represents a unique route. The structure of this table is shown in Table 4. The field `RowID` (`RoadID` attribute of the entity `ROAD`) is the primary key for this table. The values of `RouteNumber` and `Direction` can also uniquely identify a record in this table. They are also used as keys for this table. Other fields represent the existence of other tables in the third layer.

Attention should be paid to the `DatabaseFileName` field. This field specifies the actual database that hosts the corresponding tables in the third layer. As pointed out later, the MMHIS uses Microsoft Access® DBMS as the physical implementation platform of the database system. The Microsoft Access database has a limitation on the number of tables in each database. Putting all of the tables in one database may cause problems since the total number of tables may well exceed the limit.

Including the `VideoFilePath` field allows the system to put video files for different states to different locations and makes it easier to manage the video files.

Field Name	Data Type	Short Description
RowID	Number	Record serial number
RouteNumber	Text	Route number
Direction	Text	Direction
FromMilePost	Number	Start milepost of the road
ToMilePost	Number	End milepost of the road
FixedDataTableExist	Boolean	The existence of the fixed data table
FrameIndexTableExist	Boolean	The existence of the frame index table
TurningMovementTableExist	Boolean	The existence of the turning movement information table
YearDataRegistrationTableExist	Boolean	The existence of the yearly data registration table
SiteDataFormatTableExist	Boolean	The existence of the site data format table
DatabaseFileName	Text	Database file name for all the above mentioned tables
VideoFilePath	Text	Path for the video files for the current route

Table 4 – The Structure of the State Master Table

Fixed Data Table

This table stores the basic information for each route. The data stored in the table normally remain the same for a certain period of time. The table only stores the latest values for the fields. The fields `LongitudeGrid` and `LatitudeGrid` are used to store the spatial location for each milepost. This is used in the MMHIS to mark the location of the current point on the map. In this table, the `MilePost` field is the primary key. The structure of this table is listed in Table 5.

Field Name	Data Type	Short Description
MilePost	Number	Milepost
Lane	Number	Number of lanes
PavementWidth	Number	Total width of the pavement
LeftShoulder	Number	Width of the left shoulder
RightShoulder	Number	Width of the right shoulder
District	Text	District
Area	Text	Area
Region	Number	Region
ADT	Number	Average daily traffic
ADL	Number	Average daily load
GrowthFactor	Number	Growth factor
StructureNumber	Number	Structure number of the pavement
Project	Text	Project
Year	Number	Year
Layer1	Text	Layer 1 Material
Thickness1	Number	Thickness of Layer 1
Layer2	Text	Layer 2 Material
Thickness2	Number	Thickness of Layer 2
Layer3	Text	Layer 3 Material
Thickness3	Number	Thickness of Layer 3
Layer4	Text	Layer 4 Material
Thickness4	Number	Thickness of Layer 4
Layer5	Text	Layer 5 Material
Thickness5	Number	Thickness of Layer 5
Layer6	Text	Layer 6 Material
Thickness6	Number	Thickness of Layer 6
Rate	Number	Rate
Speed	Number	Speed of the vehicle when the data was collected
LongitudeGrid	Number	Longitude coordinate of the current point
LatitudeGrid	Number	Latitude coordinate of the current point

Table 5 – The structure of fixed data table

The Data Format Table

The table contains information on the format of the site data display. Users can modify the contents of this table to change the output format of the site data. The primary key for this table is `FieldName`. The values of this field correspond to the fields in the fixed data table and the yearly data table (mentioned later). MMHIS can use two unit systems to display site data. To allow users to decide what to display for the units, several fields are included in this table specifying the name of the unit and the conversion factor for the unit. The structure of this table is listed in Table 6.

Field Name	Data Type	Short Description
FieldName	Text	Field name in the database tables
Caption	Text	Field caption shown in the site data view
Type	Text	Data type of the current field
Unitless	Boolean	Whether or not the field has a unit
MetricsUnitName	Text	Unit name for the field when metric unit system is chosen
MetricsConverter	Number (single)	Multiplier for converting the field value to metric system values
ImperialUnitName	Text	Unit name for the field when imperial unit system is chosen
ImperialConverter	Number (single)	Multiplier for converting the field value to imperial system values
Format	Text	Format specifier for the field data
GroupName	Text	Name of the category to which the current field belongs
DefaultDisplayOrder	Number (integer)	Default order to display the fields
SourceTable	Text	Name of the table to which the current field belongs

Table 6 – The Structure of the Data Format Table

The Frame Index Table

The frame index table contains the synchronization information that is used to synchronize the site data display with the video display. The `MilePost` field is used as the primary key for this table. Since on the Windows NT ® operating system there is a limit on the size of video files, multiple video files are normally needed for a road. The `VideoFileName` field is used to store the file names for the videos. The structure of this table is shown in Table 7.

Field Name	Data Type	Short Description
MilePost	Number (long integer)	Milepost
VideoFileName	Text	Name of the video file
StartFrameNumber	Number (long integer)	Start frame for the current milepost
EndFrameNumber	Number (long integer)	End frame for the current milepost
TurningMovementFlag	Number (byte)	Flag for turning movement

Table 7 – The Structure for the Frame Index Table

The Turning Movement Information Table

The turning movement information table contains information on the location and destination of turning points. The structure of this table is shown in Table 8.

Field Name	Data Type	Short Description
MilePost	Number (long integer)	Milepost
LeftState	Text	Left turn destination state
LeftRowID	Number (long integer)	Left turn destination route
LeftMilePost	Number (long integer)	Left turn destination milepost
ThroughState	Text	Through destination state
ThroughRowID	Number (long integer)	Through destination route
ThroughMilePost	Number (long integer)	Through destination milepost
RightState	Text	Right turn destination state
RightRowID	Number (long integer)	Right turn destination route
RightMilePost	Number (long integer)	Right turn destination milepost

Table 8 – The Structure of the Turning Movement Information Table

The Yearly Registration Table

The year registration table has one record for each year that has yearly specific data. Each record in this table has a corresponding table in the fourth layer. The structure of this table is listed in Table 9.

Field Name	Data Type	Short Description
Year	Text	The year number
LogFromMilePost	Number (long integer)	Starting log milepost
LogToMilePost	Number (long integer)	End log milepost

Table 9 – The Structure of the Yearly Registration Table

The Yearly Data Table

The yearly data table contains each year's data. The structure of this table is shown in Table 10.

Field Name	Data Type	Short Description
MilePost	Number (long integer)	Milepost
Cracking	Number (single)	Cracking value
RoughnessLeft	Number (single)	Left wheel roughness
RoughnessRight	Number (single)	Right wheel roughness
M	Number (integer)	Field taken from Arizona database
RuttingLeft	Number (single)	Left wheel rutting
RuttingRight	Number (single)	Right wheel rutting
Patching	Number (integer)	Patching
Flushing	Number (single)	Flushing
ADT	Number (long integer)	Average daily traffic

Table 10 – The Structure of the Yearly Data Table

Functional Dependencies of Databases

The functional dependencies are shown in Figure 6. The above database schema design conforms the normalization criteria 1NF, 2NF, and 3NF. It has dependency preserving and lossless join properties.

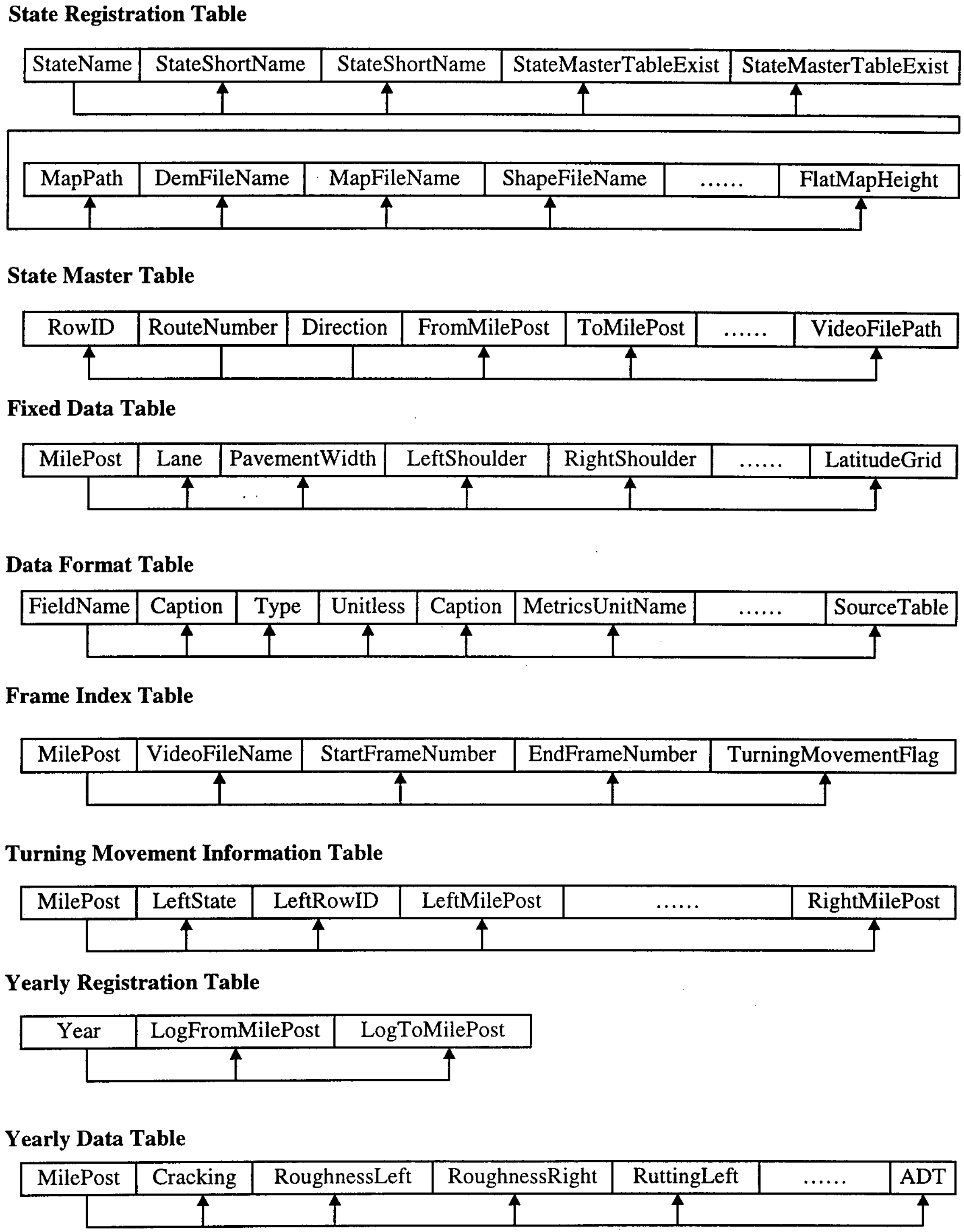


Figure 6 – Functional Dependencies of Databases in MMHIS

Database Indexes

MMHIS uses database indexes to speed up queries. The primary key in each table is automatically indexed. Additional indexes are added to each table according to the needs of queries. The indexes for the database tables in MMHIS are shown in Table 11 – Table 18.

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	StateName	Ascending	Yes	Yes	No
StateShortName	StateShortName	Ascending	No	Yes	No

Table 11 – State Registration Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	RowID	Ascending	Yes	Yes	No
RouteNumber	RouteNumber	Ascending	No	No	No
RouteNumberAndDir	RouteNumber	Ascending	No	No	No
	Direction	Ascending			

Table 12 – State Master Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No
LatitudeGrid	LatitudeGrid	Ascending	No	No	No
LongitudeGrid	LongitudeGrid	Ascending	No	No	No

Table 13 – Fixed Data Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	FieldName	Ascending	Yes	Yes	No
DefaultDisplayOrder	DefaultDisplayOrder	Ascending	No	Yes	No

Table 14 – Data Format Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No
EndFrameNumber	EndFrameNumber	Ascending	No	No	No
StartFrameNumber	StartFrameNumber	Ascending	No	No	No
VideoFileName	VideoFileName	Ascending	No	No	No
VideoAndFrame	VideoFileName	Ascending	No	No	No
	StartFrameNumber	Ascending			
	EndFrameNumber	Ascending			
MilePostAndFrame	MilePost	Ascending	No	No	No
	StartFrameNumber	Ascending			

Table 15 – Frame Index Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No

Table 16 – Turning Movement Information Table Index

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	Year	Ascending	Yes	Yes	No

Table 17 – Yearly Registration Table Index

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No

Table 18 – Yearly Data Table Index

MMHIS Network Performance Requirements

A single digital video stream based on the National Television Standard Committee (NTSC) standard has a data rate of about 200 kilobytes per second for MPEG1, 0.5 to 2 megabytes per second (MB/s) for most MPEG2 signals, and 3 to 5 MB/s for Motion JPEG. Common networks based on Token Ring or Ethernet have the shared data bandwidth of 16M bit/sec and 10 M bit/sec (2 MB/s and 1.25 MB/s) respectively. The effective actual bandwidth available to a station can be much less than the specified rate of 16 Mb/s or 10 Mb/s, due to (1) the nature of bandwidth sharing for both Ethernet and Token Ring, (2) network overhead. In addition, the two types of networks are optimized for carrying packet and burst data, and do a poor job of carrying full-motion video that requires guaranteed bandwidth. In order to provide multiple streams of video data (more than 10), the throughput of the traditional network needs to be improved and the bandwidth for individual stations needs to be guaranteed. Furthermore, it is required that video streams be delivered in a particular order with very small and consistent latency. Otherwise, frame drop and un-synchronization would occur. Ethernet, Token Ring, and Fiber Distributed Data Interface (FDDI) use shared-medium and are not capable of carrying motion video in a timely fashion. Therefore, the challenge is to design a proper network to both provide high bandwidth and guarantee video delivery.

The MMHIS capable computer network should be able to carry a number of services, including low speed data transmission for regular data sets and mail, medium speed data transmission for CAD design files, and high speed data transmission for the distribution of high quality video footage of highway sections. Therefore, the network system cannot be designed specifically for one service. Figure 7 shows a range of services with an estimated bit rate of a few bit/s up to some hundreds of Mb/s. The holding times (continuous transmission period) vary from seconds to hours.

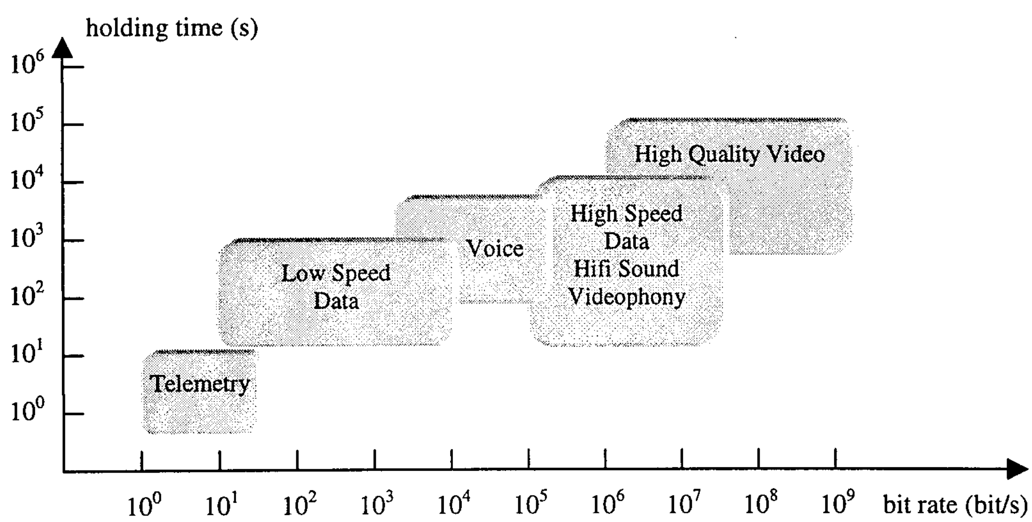


Figure 7 – Range of Services in a Multimedia Network [3]

Ethernet and Token Ring technologies are limited in their bandwidth and capabilities of ensuring timely delivery of multimedia data. Recently, switched Ethernet has become a cost-effective approach to increase the available bandwidth from a station to a server. In a switched Ethernet based network, every station has a dedicated bandwidth of 10 Mb/s to the switch, which has a bigger data pipe to the server with 100 Mb/s bandwidth. The 100 Mb/s Ethernet link from the server to the switch is called fast Ethernet. Although data throughput is increased in the switched Ethernet, the inherent limitations of Ethernet still remain in area of time transparencies. For instance, when an MPEG2 video stream at 4 to 8 Mb/s is requested from a client, and at the same time a CAD file gets transmitted from the server to another client, there is no guarantee that the video stream will be delivered uninterrupted. Most likely jitters will occur to the video stream at the client station. In reality, there could be many data transmissions underway at a particular point of time in the network. Apparently, even switched Ethernet is not a good solution to the problem of providing guaranteed bandwidth for the MMHIS system or any types of distributed multimedia services with a high video quality requirement.

In the last decade, tremendous research has been conducted by both telecommunication and computer network industries in the area of providing high quality data service with guaranteed bandwidth in computer networks. A technology called Asynchronous Transfer Mode (ATM) has emerged as the dominant approach to solve wide and local area data transmission problems by providing very high speed connections with guaranteed bandwidth for various types of services, including the bandwidth hungry video/audio transmissions.

Asynchronous Transfer Mode (ATM) and Gigabit Ethernet

ATM is an extremely fast, high bandwidth, packet-switching technology created by the telecommunication industry. In an ATM environment, computers are connected through adapter cards and network wire to a central ATM switch. ATM breaks all traffic (voice, video or data) into equal sized 53-byte short packets, known as cells. Each cell has a 5-byte header. Therefore, the user data in each cell amounts to 48 bytes or 90% of the total data. The size of 48-byte information field in the ATM cell was determined through compromise by the two industry groups in Europe and the US, which preferred a 32-byte size cell and 64-byte size cell respectively. In return for the 10% overhead, ATM brings two benefits. First, its short, fixed length cell makes ATM better than frame relay and existing LAN protocols, which all use variable length packets, for carrying real-time data and multimedia applications. Second, ATM's short packet format enables the cells to be formed and routed almost entirely in hardware. This hardware capability is likely to allow far faster network speeds than are possible with today's multiprotocol routers, which rely on software to handle the bulk of the switching task. More importantly, ATM's speed is scalable up to many gigabits/s [2]. The resulting bandwidth is available from each station to a server or another station, which provides a big advantage over the shared bandwidth technology in Token Ring, Ethernet and FDDI. "Asynchronous" in ATM comes from the fact that cells headed to a destination appear at varying intervals. Therefore, it is allowed to perform asynchronous operations between the sender clock and the receiver clock. The difference between the clocks can be solved by using empty cells that do not contain useful information.

When an ATM connection is established, the sender's information is segmented into 53-byte cells and transmitted through the network. The receiver then reassembles the cells into the original format. The 5-byte header carries information about the Virtual Channel (VC) and Virtual Path (VP) in use, the payload type, and prioritizes cell loss. A VP is a group of VCs. The channels and paths are referred to as virtual because many channels and paths can be established simultaneously in the network. A VC carries information of application specific services. The VP aggregates VCs destined to the same destination to properly allocate transmission resources. The flexibility and reliability of the network can be improved by dynamically modifying VP/VC capacity and routing.

The ATM Adaptation Layer (AAL) inserts payload data into the 48-byte information field of the ATM cell. The AAL provides the flexibility to carry different types of services with the same format. The network's task is to use the information in the packet's header to route the cell from one point to another. With some AAL types, up to four bytes of the payload type may be used by the adaptation process itself, leaving 44 bytes for the user data.

ATM Performance Characteristics

Neither error protection or flow control is provided on a link by link basis in an ATM network. The links in ATM networks have a very high quality, or low Bit Error Rate (BER). The omission of error correction protocol improves data transmission efficiency. In addition, ATM operates in a connection-oriented mode, which allows the network to guarantee a minimal cell loss ratio, and therefore provide maximum quality. As a result, the flow control that is used frequently in other computer networks is not needed for ATM. At call set-up, if enough resources in the network are available, the connection is then initialized. When the connection is established, the probability of overflowing the network is very small, less than 10^{-8} [3].

Delay issues in time transparency are mainly applicable to real time services such as the MMHIS. Other computer data transmissions are not particularly sensitive to delays, such as CAD file transmission. In addition, due to the lack of error correction protocols in ATM, three sources of error determine the overall BER in an ATM network: (1) error in the information field in the ATM cell, (2) error in the header field in the ATM cell and, (3) queuing overflow resulting in loss of cell in the switch.

In a Local Area Network (LAN) based ATM environment, the delay times include (1) the distance dependent Transmission Delay (TD), (2) Packetization Delay (PD) at the sender end, (3) Depacketization Delay (DD) at the receiver end, and (4) Switching Delay (SD). The size of ATM cell affects the overall network delay, the transmission efficiency, and the implementation complexity. It is shown [3] that when the size of the ATM cell (packet) is fixed to 53 bytes, the total delay is limited, which is an advantage for real time services.

Quality of Service (QOS)

Properly implemented ATM networks solve the major problems of existing popular networks in the two areas of high speed interfaces and multimedia support with video, voice, and data in one transfer. Constant Bit Rate (CBR) and Variable Bit Rate (VBR) are typically for the transmission of voice and video respectively. Unspecified Bit Rate (UBR) and Available Bit Rate (ABR) can be used for regular data traffic. Each traffic type requires a different quality of service (QOS) with properties such as the amount of bandwidth reserved, delay tolerance, and variation.

QOS of a connection is a general indicator relating to cell loss, delay, and delay variation incurred by the cells belonging to that connection in an ATM network. It represents user perception of service quality at the receiving end of the network. It is a function of terminal capability (bit rate) and network performance such as cell-loss ratio and bit errors in a cell payload [4]. The bit rate ranges from videophone at a very low rate of 64 Kb/s (Kilobits per second) to High Definition Television at over 20 Mb/s. The bandwidth management, key to the support of multiple services on ATM, guarantees QOS for high priority, delay sensitive CBR and VBR traffic, while providing bursty UBR and ABR traffic with fair access to the remaining network bandwidth. For example, ATM switching ensures the integrity of CBR and VBR connections through connection admission control algorithms. Flow control and intelligent buffering are used in the ATM switch to optimize the bandwidth available for data traffic (UBR and ABR). Flow control detects congestion in the network and informs the sending device to slow down.

Gigabit Local Area Networking for MMHIS

In an MMHIS, a number of computers connected through a network medium are used to transmit and receive high quality video streams and regular engineering databases. The MMHIS needs to be scalable to accommodate the data rate of future digital television standards. For instance, one uncompressed High Definition Television (HDTV) stream carries a data rate of over one Gb/s (gigabit per second). The compression ratio for an HDTV signal can be from 20:1 to 50:1. Based on a study by Kinoshita et al. [5], the peak rate can be 65Mb/s and an average 10 to 20 Mb/s for one HDTV stream transmission in an ATM network. Based on communications with a State Highway Agency (SHA), the possible number of simultaneous users accessing video and data streams can be as high as 50. Therefore, the aggregated data rate in an MMHIS network will well exceed one Gb/s when HDTV level video streams are used.

A gigabit LAN is a LAN for which the physical communication medium has a peak bandwidth on the order of one Gb/s or higher, and for which an end user is able to realize this gigabit performance [6]. Clearly, an MMHIS based network will be a gigabit LAN. In high speed networks, the specification for transmission protocols follows the SONET (Synchronous Optical Network) standards based on the base signal rate of 51.84 Mb/s, which is commonly referred to as OC-1. The higher speeds are OC-3, OC-12, OC-24, and OC-48 with the speeds of 155.52 Mb/s, 622 Mb/s, 1.244 Gb/s and 2.488 Gb/s respectively. ATM adapter cards at OC-3 speed are widely available. Many LAN based ATM switches have aggregated data rate at or over the OC-48 specification.

The Video and Storage Server

Transmission of multiple digital video streams requires very high consistent data throughput for every sub-system in the MMHIS that processes the streams. The sub-systems include the desktop CPU's, bus and display cards, the networking devices (adapters and switch), and the video server and storage mediums. Special attention needs to be focused on the capabilities of the video server and the video storage. For example, a traditional uniprocessor based server is not able to handle multiple video streams. Virtually all video servers are based on the powerful symmetrical multiprocessing structure with multiple microprocessors. Multimedia also requires huge amounts of data storage and a very high sustained data rate. Storage size and sustainable speed are two critical factors for the implementation of a storage server for the MMHIS.

Issues Related to Multimedia Oriented Network Operating Systems

In a multimedia application, it is required that large blocks of digital video/audio data be transferred simultaneously and continuously in order to ensure the high degree of consistency in picture frame and synchronization with audio or other data. The dominant network operating systems used today do not have the capability to coordinate video data flow sufficiently to ensure video quality on the clients' desktops. The current network management software emphasizes data integrity through error control protocols. Therefore, it is imperative to ensure that video/audio data steams flow at consistent latency in the network and no traffic clogs for video/audio data occur. It should be noted that even though many ATM standards have been set, some important standards regarding QOS and MPEG2 video transmission are not ready yet.

Protocols are software layers in the network, which ensure that data arrives without errors, and traffic flows are regulated properly. For video/audio data, a special video protocol is necessary to make sure there is a highly reliable connection for an uninterrupted stream of data. The flow of regular data can be conducted through the normal protocols. With this parallel protocol approach, video/audio data will have priority over other data flows. Normal data flows yield right of way to video/audio data. The challenge in developing a continuous-media software solution for video lies in the management of a large number of data streams leaving the server. A critical technique in developing such a solution is through the use of a set of ATM specific Application Programming Interfaces (APIs). The new WinSock 2 specification that includes ATM APIs as standard features will be used in the development of the MMHIS.

Requirements for the Multimedia Storage Server

The MMHIS consists of client stations, one or more storage systems, a high-speed ATM network, real-time-service oriented operating systems and customized applications. The client stations are able to receive very fast ATM cells, repacketize them, and decode the video data and display the motion video to the computer screen with synchronized engineering data sets. The storage system should be able to simultaneously process multiple requests for video and data streams and send the requested data fast enough to the clients through the ATM network.

There are four fundamental characteristics of the storage server for MMHIS:

- *Real-time storage and retrieval of continuous video media.*
- *Large data transfer rate and huge storage space requirement.*
- *Dynamic synchronization with and display of traditional engineering data sets with the video frames.*
- *Multiple simultaneous accesses to the video and data files.*

The storage requirement of video footage at MPEG2 quality (average 5 Mb/s) is about 222 GB for a 5,000-lane-mile interstate system when the video is recorded at the speed of 50 miles per hour. This huge storage needs to be randomly accessed by multiple users at any point of the video footage.

Continuous playback of a video stream consists of a sequence of retrieving video blocks from server disks with scheduled play time. It is possible to fetch the video stream from the server fast enough to be played back at the client station. However, the bursty nature of data retrieval from disks does not guarantee continuous operation of the video display. Quite possibly, there will be disruptions of the display due to inadequate video data. Therefore, a buffer storage needs to be used at the client station or the server to contain the video stream before it is played as shown in Figure 8. Buffering is both expensive and time-consuming. The goal is to design a system that would prevent client starvation for video data and at the same time minimizing buffer space and initialization latency. Employing modest amount of buffering enables conventional file and operating systems to support continuous storage and retrieval of isolated video streams.

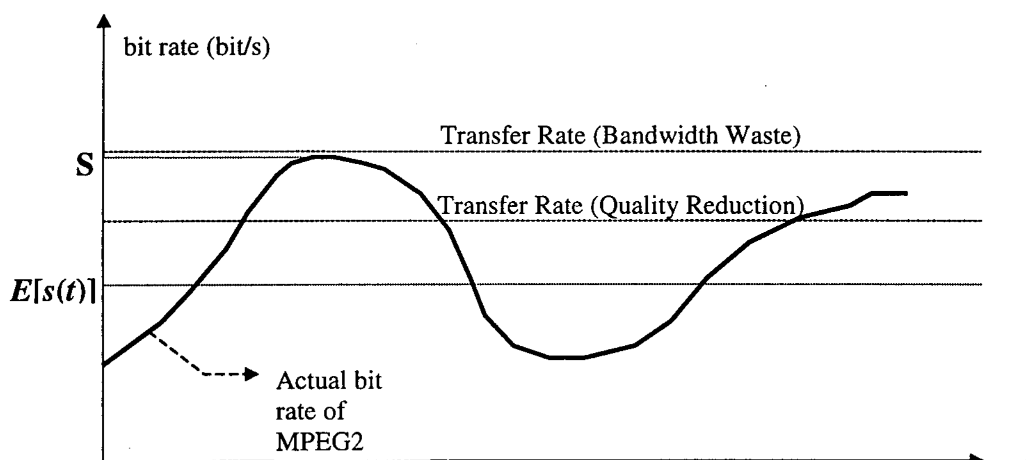


Figure 8 – Buffering Scheme for Video Stream Playback

The multimedia storage server has to process requests from several clients simultaneously. More often than not, different clients may request to view different locations of the highway video footage.

File System for the Server

The following factors need to be considered for the server storage:

- *simple, hierarchical directory structure,*
- *efficient use of low-cost, high capacity disk drives,*
- *efficient handling of both large and small file system objects, and*
- *optimization for random access, rather than sequential access.*

In addition, it is not necessary nor possible to optimize access based on a drive's physical geometry. It is not possible to even determine the real drive geometry at all: track and sector sparing, automatic sector reassignment, etc. The actual disk layout is completely hidden from the user and optimized for large sequential accesses. Most new drives have large data buffers and perform read-ahead and write-behind operations. The best way to get optimum performance is to stream large amounts of sequential data similar to a traditional tape drive. Therefore, the filing system for the video server should be able to:

- *lay the disk out so that objects are in large, sequential chunks,*
- *allocate I/O buffers so that transactions are as large as possible, and*
- *minimize the amount of disk seeking.*

The algorithm to be used is straightforward, assuming all new files are going to be large, and disk space can then be reserved accordingly. Therefore, when allocating space for a file, reserve a large contiguous chunk at the beginning, and then use up the reservation as needed. As a video file grows, extra contiguous chunks are reserved. When the file is closed, the unused space is freed. In MMHIS, one large video file can be used to cover a few hundreds of miles of roadway. This file may need to be updated only annually. Therefore, this filing system is applicable for MMHIS. In addition, only read operations are allowed on video files in an MMHIS system, which simplifies the optimization of the file structure due to the infrequent write operations. Although this algorithm may cause the fragmentation of disk space, as the contiguous files are very large with the sizes of multiple gigabytes, the side effect of spare blocks can be minimized through an efficient managing algorithm.

In the task of optimization for sequential access, it is realized that in an MMHIS system, the accesses to video files are read-only operations and sequential in nature. However, the initialization of viewing request is random in nature. For instance, multiple users may request to view any section of the roadway at the same time.

It should be noted that cache strategies used frequently to improve storage performance do not apply to video files. Video files used in MMHIS are gigabytes in size. The application of a cache can only add overhead to a disk streaming operation, and the size of any type of cache is much smaller than a typical video file in MMHIS.

Disk Arrays for the Server Storage

The sustained bandwidth of a single hard drive can be as high as 10 MB/s for sequential access. However, when multiple users access the video file(s) in a single drive, the available bandwidth for individual user's video stream is much less than the average theoretical rate, for example, 10 MB/s divided by the number of users. The overhead is due to head seeking time and disk management. Therefore, the structure of putting a number of drives to a Small Computer System Interface (SCSI) channel will not be able to adequately serve multiple users.

A technology called Redundant Arrays of Inexpensive Disks (RAID) is widely used to overcome the inherent throughput limitations of a single disk drive. Various RAID configurations are designed to address either performance or reliability. RAID comes in several flavors from levels zero through five. Each level is optimized for various capabilities, including improved performance of read and write operations, and improved data availability through redundant copies or parity checking.

The computer industry's experience with SCSI has brought to light the need for improvements of versatility and throughput. For instance, even in a RAID and SCSI-2 based system, the storage's maximum sustainable rate is about 20 Mb/s. New applications, like video and image processing, have created a demand for huge increases in storage capacity. Some capacity requirements are so large that it is difficult to configure enough SCSI buses to make sufficient drive addresses available to attach the needed number of drives.

One solution is a relatively new technology called Fiber Channel, which is a standard interface adopted by the American National Standards Institute. The existing implementation of Fiber Channel is called Fiber Channel - Arbitrated Loop (FC-AL). FC-AL is used as a direct disk attachment interface for I/O performance-intensive systems. SCSI-3 (Small Computer Systems Interface-3) has been defined as the disk protocol, which is also technically referred to as the SCSI-FCP.

The Fiber Channel interface is a loop architecture as opposed to being a bus - like standard SCSI-2. The Fiber Channel loop can have any combination of hosts and discs up to a maximum of 126 devices and provide 100 MB/s of bandwidth. The maximum cable distance can be as long as 10 kilometers. In addition, FC is a generic, standard interface, supporting many protocols, such as SCSI, Internet Protocol, and ATM. The loop structure enables the rapid exchange of data from device to device. Devices can be removed or inserted without disrupting the operation of the loop. The drives attach directly to the backplane for both signal and power. Neither jumpers nor switches need be set on the drive. The controller determines a drive's address from either the relative position on the backplane or the drives unique IEEE Fiber Channel address.

MMHIS Development

The test data for the MMHIS was collected in a van as shown in Figure 9, which uses Super-VHS or a similar quality system for video recording. The source video is then sent to the compression system for MPEG encoding. Figure 9 also illustrates the multimedia data flow within a state highway department. ATM networking technology is used in MMHIS to link the client stations, the production station, the server and the encoding system.

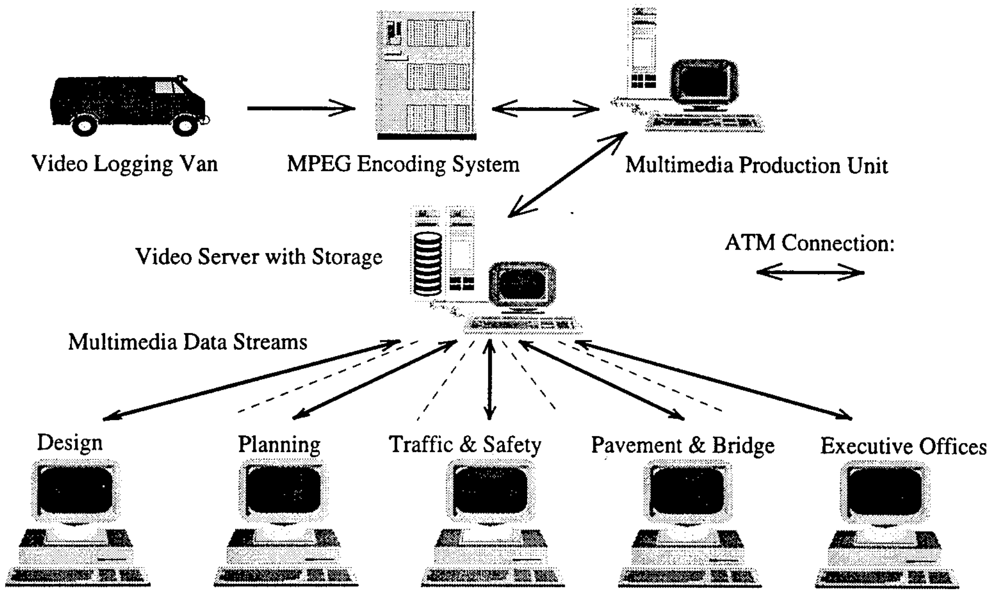


Figure 9 – Video Data Flow In The MMHIS For A State Highway Department

A motion JPEG comparable video stream in MPEG format is normally referred to as a type of high quality MPEG specification known as MPEG2 of Main Profile at Main Level. A combination of profile and level determines the frame rate and size. For example, MPEG2 of Main Profile at High Level Type 1 is to be used for US HDTV with the resolution of 1,152 lines/frame, 1920 pixels/line and 30 frames per second [7]. The current mainstream MPEG2 is Main Profile at Main Level with the resolution of 720 by 480. It is determined that in order to provide useful video information for highway engineering work, high quality digital video for the MMHIS is required. Either MPEG2 or Motion JPEG can provide Super-VHS or higher quality that meets the quality requirement. Even though motion JPEG based CODEC's provide very high quality video, it requires over 5 times more data throughput than a comparable quality MPEG video stream. Therefore, MPEG2 of Main Profile at Main Level is to be used in the actual development of the MMHIS.

The Hardware Structure for the MMHIS

- Client and Server.

Based on current practices of highway agencies and fast growing capabilities of Intel x86 processors and related I/O sub-systems, the hardware platforms for both the video server and clients are going to be Pentium or better computers. The video server is symmetrically based with four or more state-of-the-art Intel processors to distribute the management of data streams among processors. The computer bus is based on PCI with a peak I/O bandwidth of 132 MB/s.

- Storage.

The storage requirement of video footage at MPEG2 quality (average 5 Mb/s) is about 222 GB for a typical 5,000-lane-mile interstate system when the video is recorded at the speed of 50 miles per hour. The sustained throughput for the video storage is one of the critical elements in the MMHIS to ensure timely delivery of multiple video streams to the desktop computers. Fiber Channel and RAID-3 will be used as the server storage technology.

- ATM based networking devices.

This includes adapter cards for each computer and switch(es). OC-3 based 155Mb/s cards and a 2.5Gb/s ATM switch are used in the development.

- MPEG2 encoder

One MPEG2 encoder of Main Profile at Main Level is necessary for development. Only one encoder is needed for a production level MMHIS. An MPEG2 decoder and video card is used for each client station. Many vendors have developed combo PCI based video cards that overlay MPEG quality motion video on the computer screen. New MPEG2 based combo video cards will be used in this MMHIS, which allow us to overlay MPEG2 video on the computer screen of a client station.

Operation of MMHIS

Starting up the System

MMHIS is started by double-clicking the icon of the `MMHISMain.EXE` file. The opening screen is similar to the screen shown in Figure 10.

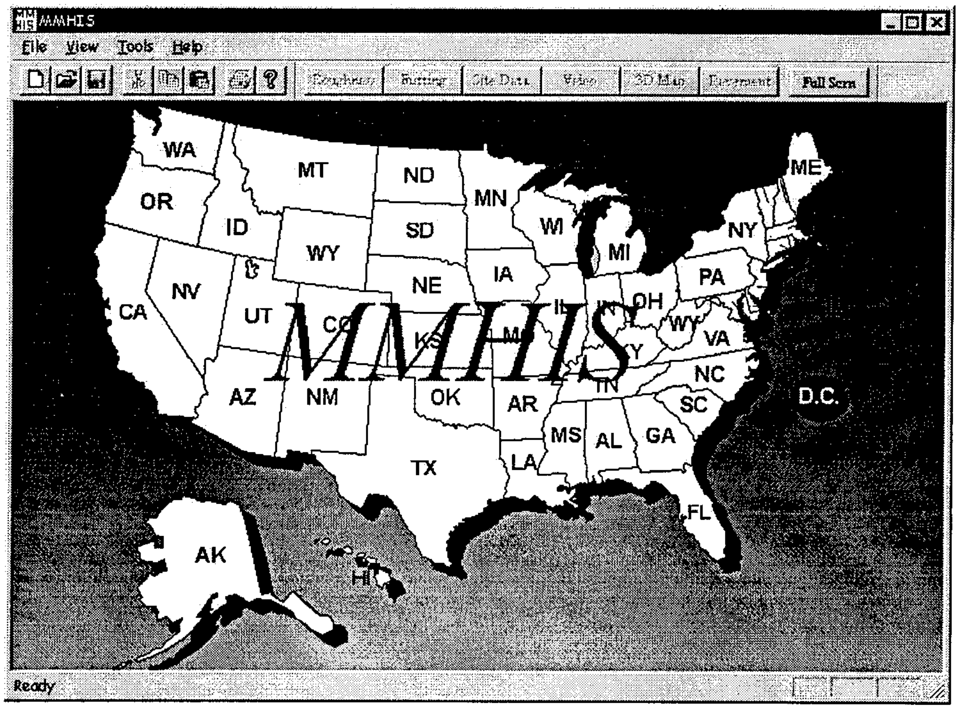


Figure 10 – Startup Screen of MMHIS

Starting a New Query

A main application of the MMHIS is to examine the right-of-way view along with site-accurate location data. The user can start up a query by giving input data on the location of the site: choose *New* from the *File* menu to open the *MMHIS Query Location* dialog box shown in Figure 11.

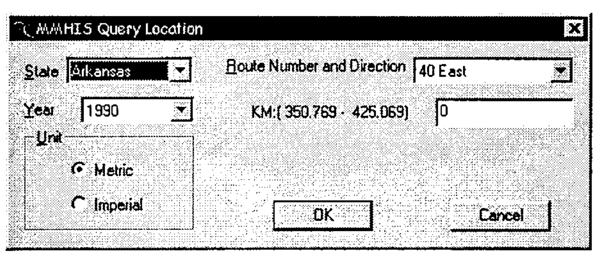


Figure 11 – The Query Location Dialog Box

The user is required to choose state, route number and direction of the highway that is going to be queried, and the year number from the above dialog box. The starting milepost number needs to be input in the above dialog box. Note that the default unit of the milepost number is kilometer. The unit can be changed to mile by clicking on the button shown in the dialog box. After the above information is entered into the dialog box, click *OK* to begin running the query. Please note that MMHIS dynamically loads database information into the system. For instance, when the route number and direction is selected, the available years in the next list box are displayed immediately. When the year number is chosen, the distance range of the particular highway is immediately shown in the third entry. For more information on how to manipulate a query, see the sub-section *Running a query*.

Opening an Existing Query

Queries can be saved into MMHIS query files. When saving a query, the query state, route number, direction, milepost, unit setting, data update rate, window management settings, windows' layout, site data format, font setting, and graphing window zooming factor are all stored to a disk file. The next time MMHIS is run, the user can simply open the saved query and continue doing work on that query. There are two ways to open an existing query. One is to choose the file from the *Most Recently Used File* list on the *File* menu. The other is to choose *Open* from the *File* menu to activate the *Open* dialog box shown Figure 12.

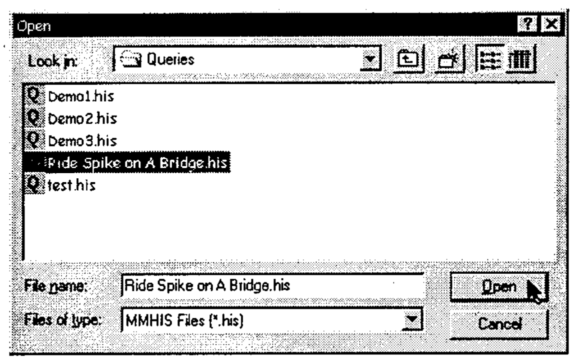


Figure 12 – The File Open Dialog Box

The default extension for the query files is `.HIS` (meaning Highway Information System). To keep every file organized, it is recommended that all query files be put into a common directory, e.g., `C:\MMHIS\QUERY`.

Running a Query

After an existing query is opened or a new query is started, the system is ready to run the query. The application window will look similar to the one shown in Figure 13.

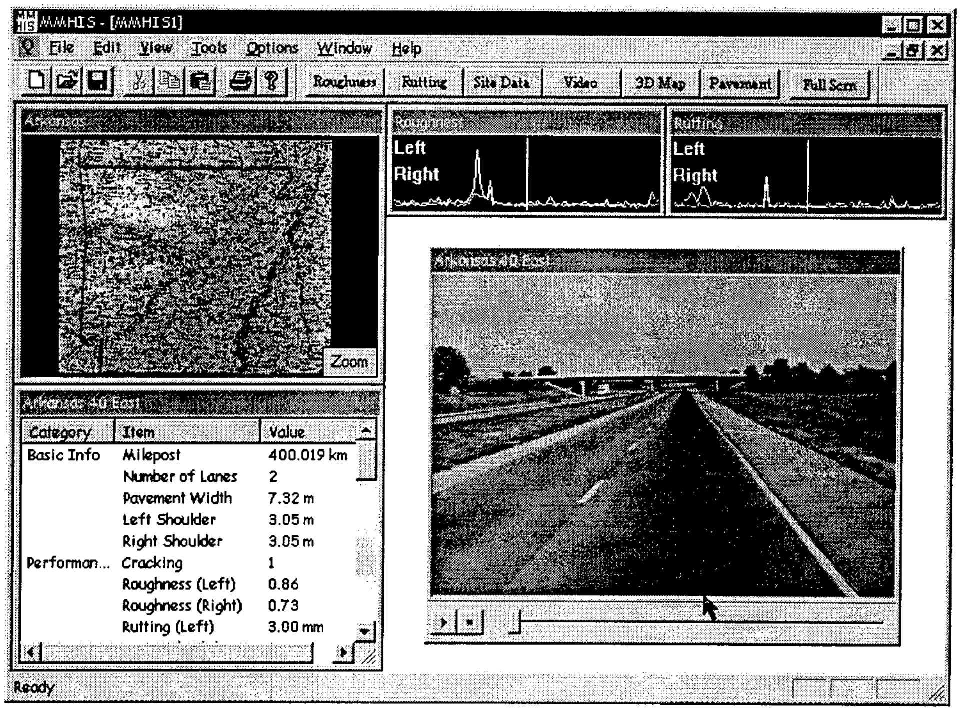


Figure 13 – An Open Query in MMHIS

The highway video is shown at the bottom-right corner of the frame window while the corresponding site data are shown at the bottom-left corner of the window. Two graphing windows are shown at the top-right corner of the frame window. This will be further explained in the sub-section *Dynamic Graphing*. The 3D-map window is shown at the top-left corner of the frame window. The following operations can be conducted on the query.

- Running the video

The button with a small arrow on it on the bottom-left corner of the video window can be used to play and stop the video. While the video is playing, data in the site data window will change accordingly. The video's play speed, the video window's size, and many other factors can also be configured through a context menu offered by the video window.

- Dragging the video to a new location of the highway

This can be achieved by using the mouse to drag the little slider on the slider bar on the bottom of the video window.

- Specifying a new location

A new location can be specified by choosing *Specify Location* from the *Tools* menu. The sub-routine that this menu item activates is the same one used to make a new query. It is shown in Figure 11.

• Changing the font for the site data window

This is achieved by choosing *Choose Font...* from the *Options* menu. The dialog box shown in Figure 14, which is activated by the above menu item, allows users to choose a new font. Note that a context menu is also offered to the site data window. The *Choose Font...* option is also on the context menu.

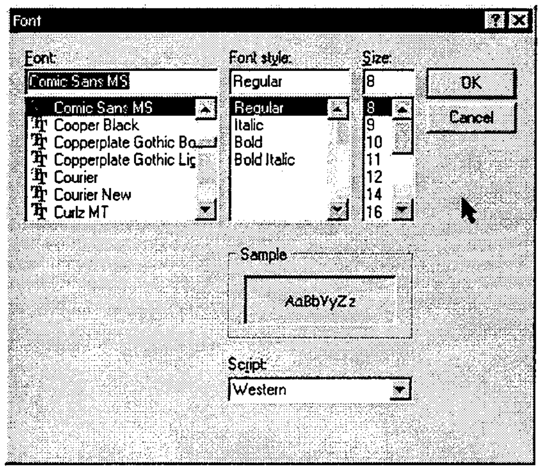


Figure 14 – Font Selection Dialog Box

• Changing the unit for the site data display

The unit used in the site data display in a new query defaults to the Metrics system. It can be changed by choosing *Units* from the *Options* menu. This is shown in Figure 15.

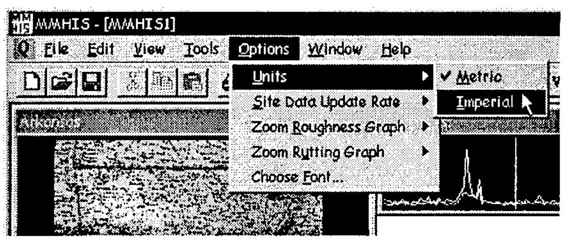


Figure 15 – Changing the Unit Through Menu Selection

• Changing the data update rate for site data table.

The fastest data update rate is every 25 meters. The actual displaying rate and quality of video motion is limited by the machine speed and the distance spacing among adjacent records in the database. Currently the AHTD database contains records for every 25 meters. To change the data update rate, choose *Site Data Update Rate* from the *Options* menu, as shown Figure 16. The option is also offered in the context menu.

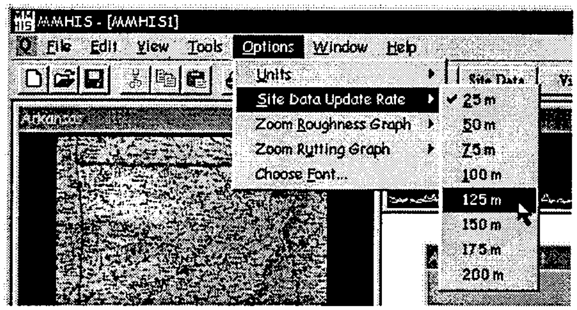


Figure 16 – Changing the Site Data Update Rate

- Opening another query

The current hardware speed does not allow the system to run more than one query (open multiple video/site-data-table) simultaneously at a good quality level. However, the user can still open multiple video windows simultaneously. Windows of each query can be resized and re-positioned so that they can be seen simultaneously on the screen. The system allows the running of one query's video while all the other queries' videos are frozen (i.e. the videos are paused). This is shown in Figure 17.

- Making turns

The system allows users to choose which way to proceed at intersections or exit ramps. When the vehicle approaches an intersection or an exit ramp, the highway video pauses and MMHIS displays arrows to show possible turning movements, as shown in Figure 18. Users can click on one of the arrows to make turns. If none of the arrows is clicked for a certain time (configurable by the user), the system will take the default option (normally the *Through* allow) and continue to play the video.

- Change the site data display format

The site data display format can be changed through the context menu for the site data window. Two formats are offered for the display. One is called categorized format, which is the default. This format shows the site data grouped by categories. The groups can be expanded and collapsed by double clicking on the category name. When a group is collapsed, it is shown in a single line with *<Closed>* as the item name. Shown in Figure 19 is the case with "Layer Info" and "Other Info" groups closed.

The second format is user configurable, where only two columns are shown in the site data window, shown in Figure 20. The user can configure data items and the order of the items to be displayed through the use of a dialog box, shown in Figure 21. In the dialog box, items in the left list box represents those shown in the site data window. Available items are listed in the right list box. An item in one list box can be moved to the other list box by double clicking on it. Items in the list boxes can also be selected first and then moved to the other list box by pushing one of the buttons in the middle of the dialog box. The order of the items in the left list box can be changed with the two buttons at the left of the list box. Default settings can be restored with the *Default* button.

The dialog box shown in Figure 21 is invoked by using the site data window context menu.

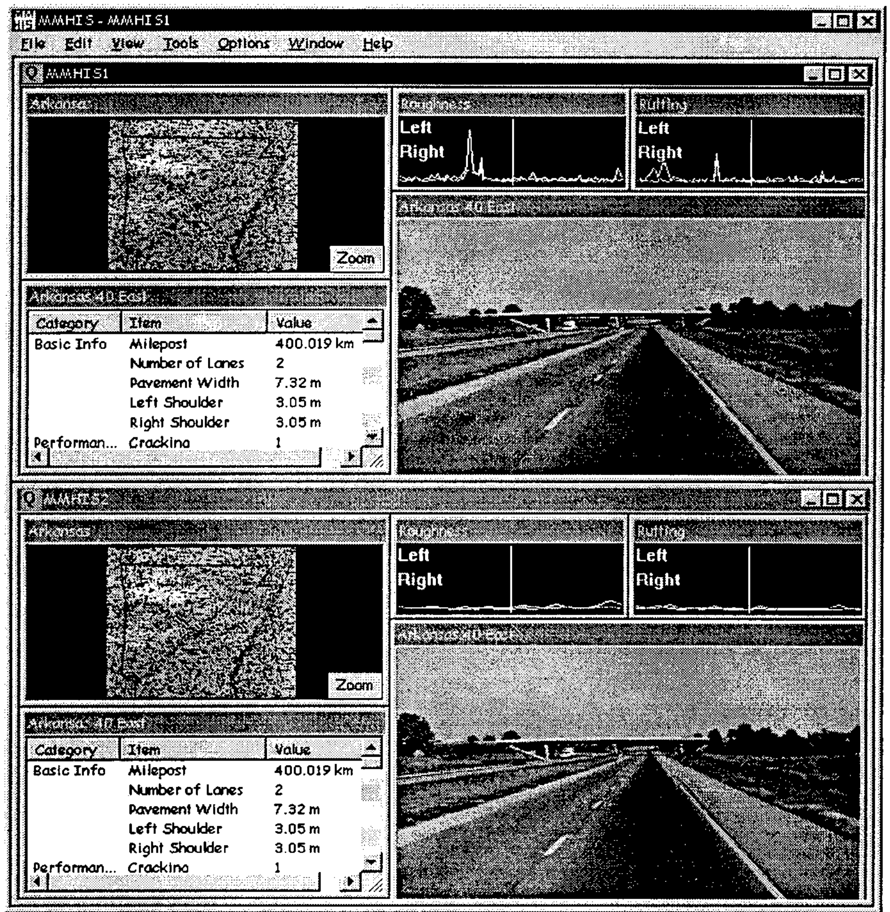


Figure 17 – Two Queries

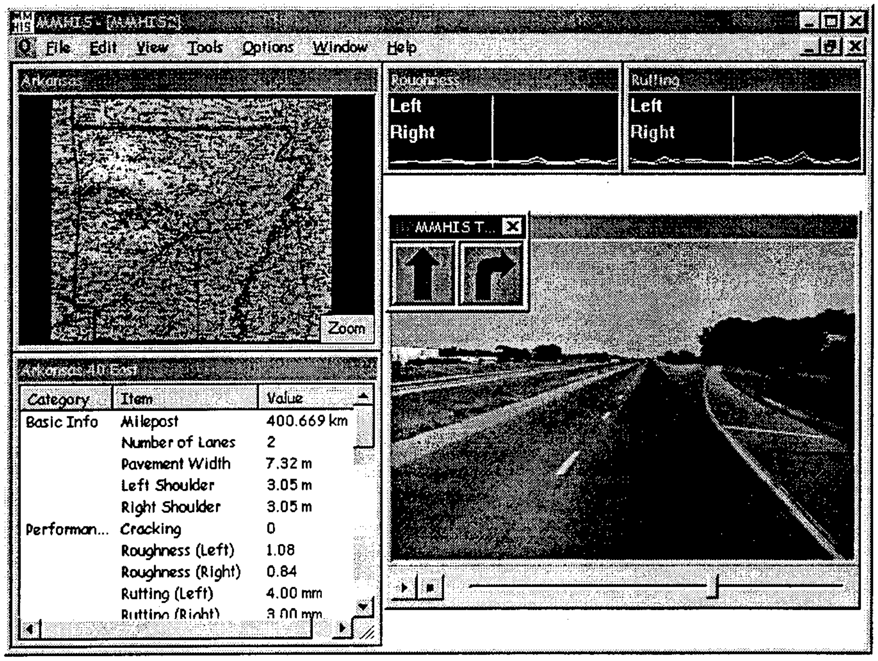
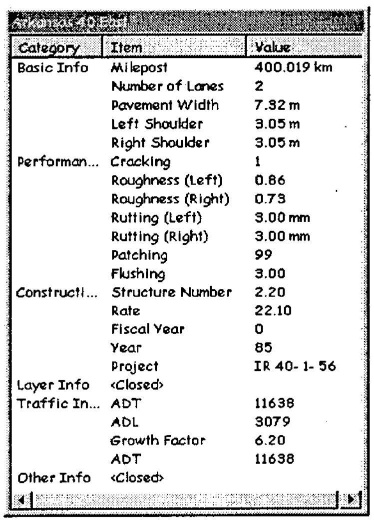


Figure 18 – Making Turns



Arkansas 40 East

Category	Item	Value
Basic Info	Milepost	400.019 km
	Number of Lanes	2
	Pavement Width	7.32 m
	Left Shoulder	3.05 m
	Right Shoulder	3.05 m
Performan...	Cracking	1
	Roughness (Left)	0.86
	Roughness (Right)	0.73
	Rutting (Left)	3.00 mm
	Rutting (Right)	3.00 mm
	Patching	99
	Flushing	3.00
Constructi...	Structure Number	2.20
	Rate	22.10
	Fiscal Year	0
	Year	85
	Project	IR 40- 1- 56
Layer Info	<Closed>	
Traffic In...	ADT	11638
	ADL	3079
	Growth Factor	6.20
	ADT	11638
Other Info	<Closed>	

Figure 19 – Categorized Site Data Format

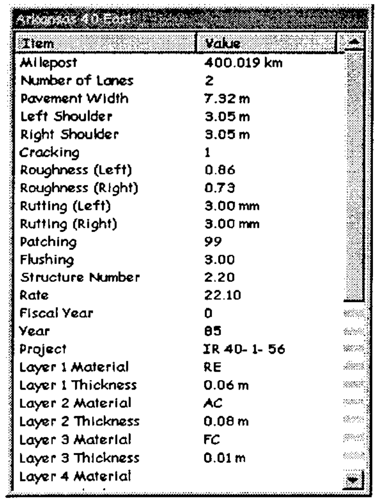


Figure 20 – User-defined Site Data Format

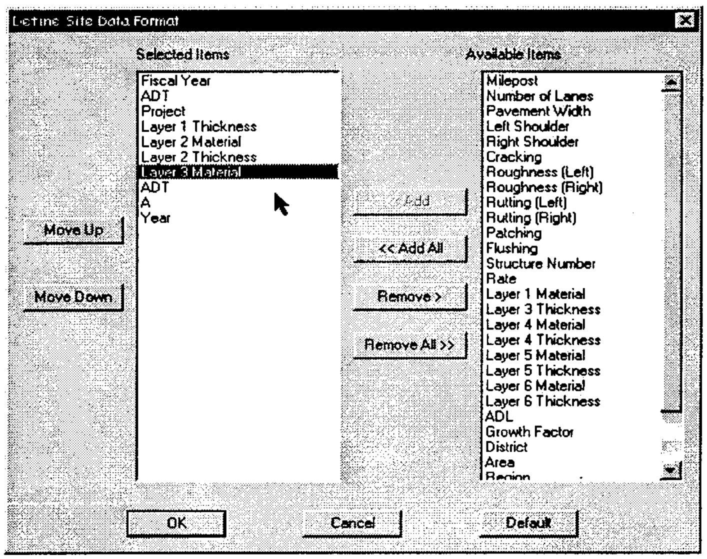


Figure 21 – Dialog Box Used to Define Site Data Format

- Saving a query

To save the query that is currently running, choose *Save* from the *File* menu. For new queries, this will bring up the *Save As* dialog box which asks the user to give a name and location for the query to be saved. For existing queries, the system will save the query without giving user the opportunity to change the name of the query. To save the query using a different name, choose *Save As...* from the *File* menu. The same dialog box that is mentioned above will show up, as shown in Figure 22. Refer to the section *Open an existing query* for more details about what is saved for a query.

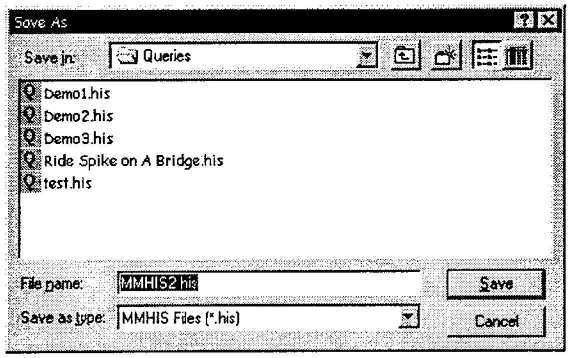


Figure 22 – The Save As Dialog

Dynamic Graphing

An additional capability of dynamic graphing is built into the MMHIS. The data sets shown in the table by the side of the video do not present relative information on the whole section of road. This dynamic graphing capability allows the user to view the values of various attributes, such as roughness and rutting at this particular location against all the values in the road section. The real-time location as the video indicates is shown with a vertical bar on the curves. The ranges that the graph windows show can be set by choosing *Zoom Roughness Graph* and *Zoom Rutting Graph* from the *Options* menu. This is shown in Figure 23.

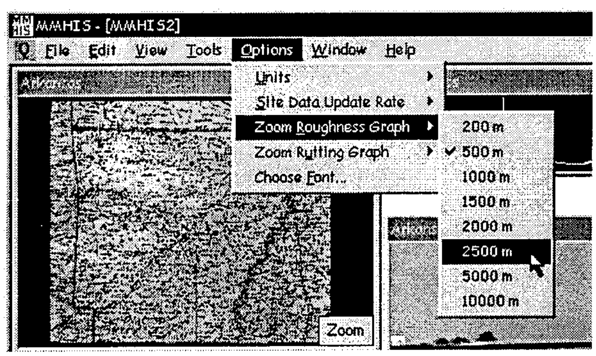


Figure 23 – Changing the Zooming Range for the Graphs

The vertical bar in the graphing window shows the current vehicle location. It can be dragged to a new location. This is shown in Figure 24.

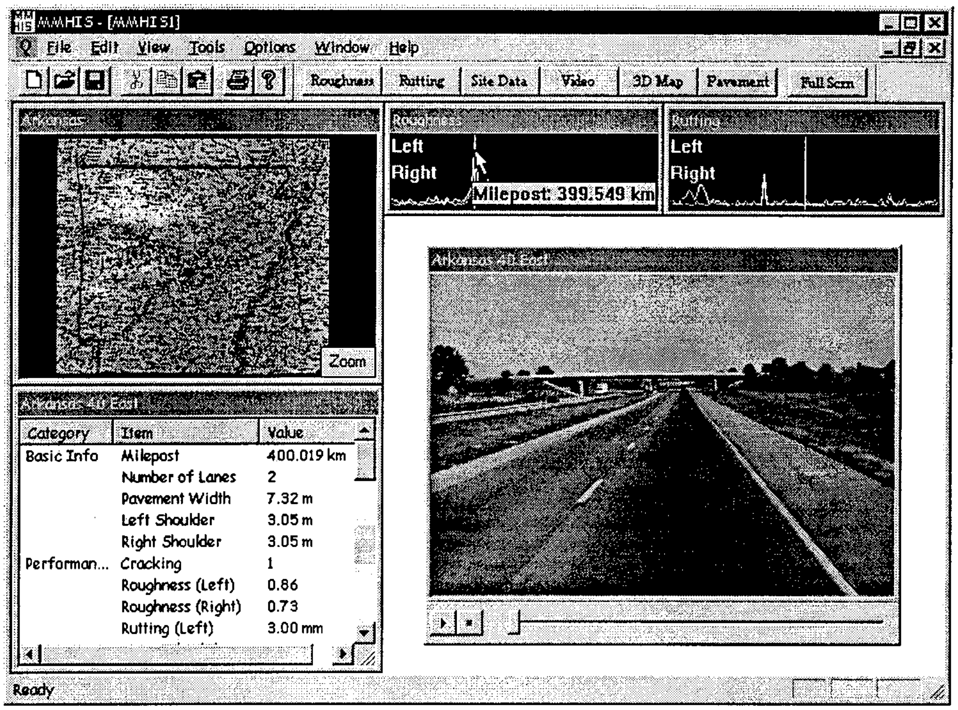


Figure 24 – The Dragable Vertical Bar in Graphing Windows

Using the map

The map interface offers a convenient method to query data through clicking the right mouse button on a point on the map. A small pop-up window will show up with the coordinate information of the point. The road information, if any, will be displayed. Upon the selection of a menu item, the video will go to that location, while the site data display will be updated to reflect the new location information, shown in Figure 25.

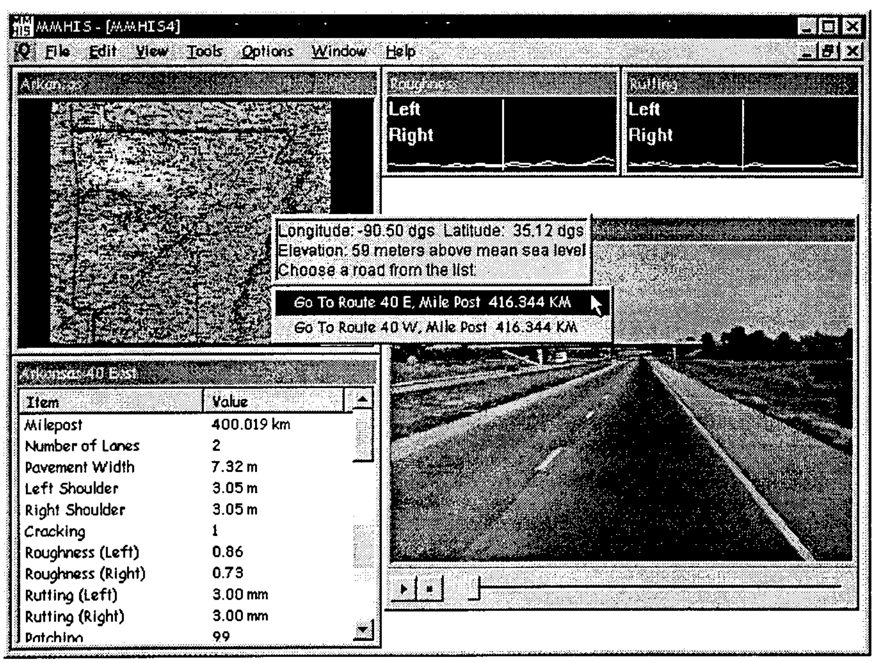


Figure 25 – Getting Information from the Map

Zooming and panning operations are offered in the map window. There are two ways to conduct zooming operations. The first is to conduct a zooming operation directly on the map through clicking the center point of the area and dragging the mouse to define the zooming area, shown in Figure 26.

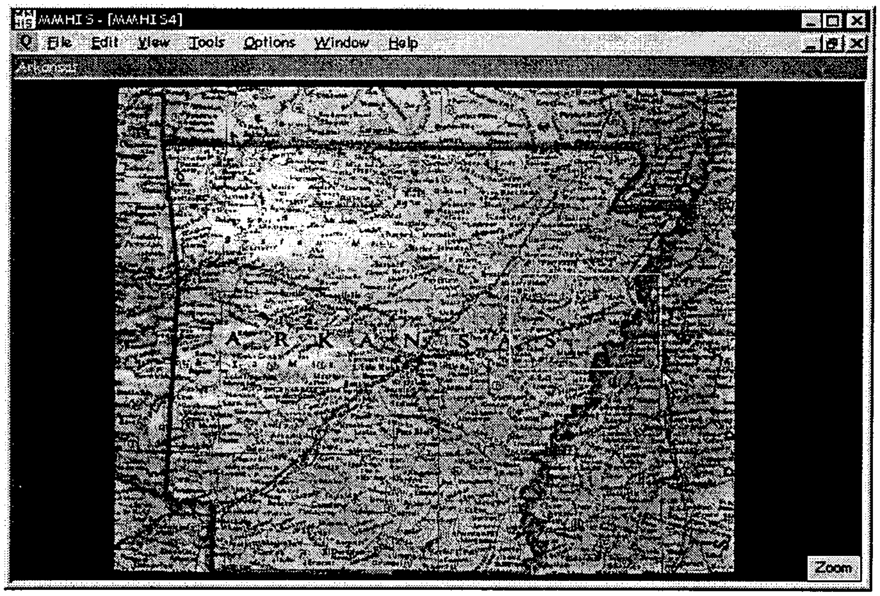


Figure 26 – Directly Zooming on the Map

The second way is to open the zooming window at the corner of the map window and zoom through that window. To open the zooming window, simply click on the *Zoom* button. A resizable rectangle is in the window illustrating the current zooming area. In addition, two slider bars are offered in this window so that the user can use them to adjust the viewing angles. The user can zoom and pan to a specific area by resizing the rectangle and moving it to the destination. When the *zoom* button at the bottom of the zooming window is clicked, the map is updated. An example is shown in Figure 27. The small circle on the road shows the current vehicle location.

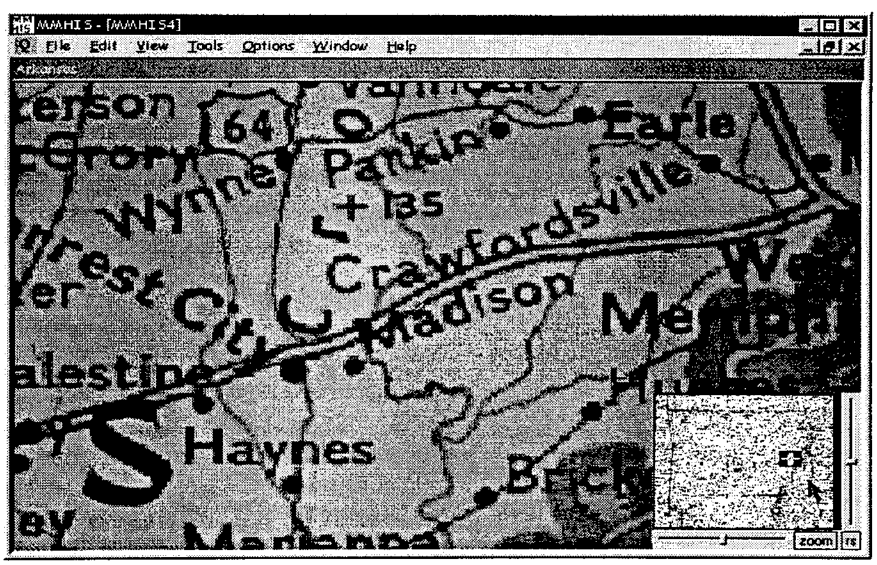


Figure 27 – A Zoomed-in Map with an Open Zooming Window

Building the video frame index

The index building interface is used to build frame indices for the video. With this interface, users first open a video file by specifying the video file name or by browsing the video files from the disk. The global ranges can be specified with the controls in the window. In particular, the start and end frame numbers can be either manually set, or by moving the slider in the video window to the frame and set the frame numbers using the buttons in the window. The state, route number and direction, start and end milepost, and unit can also be chosen. The index-building module uses the vehicle speed data in the database to calculate the frame index. If the speed data in the database is accurate, the above information is enough to calculate the frame index for the whole video. If the speed data is not quite accurate, key points can be used to increase the accuracy of the calculation. In addition, turning points and turning prompts must be set manually because there is no data in the database showing the turning information. Users define key points by moving the video to a specific frame and by specifying the key milepost for that frame. Several search buttons are offered in the window to help the user find the already defined first key point, previous key point, next key point, last key point, previous turning point, and next turning point. Key points can be added or removed by clicking the *Add Key Point* or *Remove Key Point* button. For a frame at an intersection or an exit ramp, a turning point is defined by checking the left turn, through, and/or right turn check boxes and specifying the destination state, route number and direction, and milepost. An option is offered to allow the video frames in the video window to be synchronized with the key mileposts displayed in the window. When this option is checked and the already defined key points and turning points are being searched, the video frame display in the video window is synchronized with the key points. The database is updated after the *Update Database* button is clicked by the user. The index building interface is shown in Figure 28.

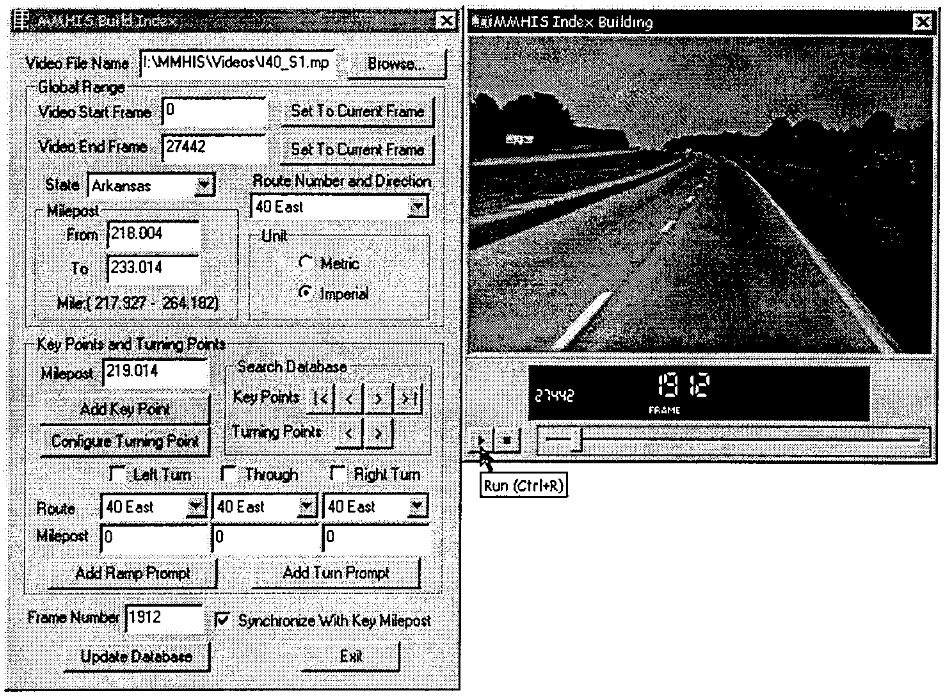


Figure 28 – The Index Building Interface

Conclusion

To implement the MMHIS in an operational environment, a high performance network and a powerful video and storage server is necessary. In order to have simultaneous and instant accesses to the MMHIS data, the application of new technologies such as ATM or FastEthernet, and RAID is needed. In addition to the installation of a high performance network system in the headquarters in a highway department, the distribution of hard copy videodisks to remote district offices may be a plausible alternative to building a wide area network. For example, the maximum capacity of a new kind of CD, the Digital Versatile Disk (DVD), is 18.8 gigabytes, which can hold 400 lane-miles video information at MPEG2 quality. The implementability of an MMHIS needs to satisfy three factors: (1) maturity of hardware and database technologies, (2) acceptable implementation costs, and (3) high video quality and resolution.

We believe that the technologies associated with the implementation of MMHIS are mature and the costs associated with the implementation are continuing to come down. The cost-effectiveness of using the MMHIS is exhibited not only in the form of improvement of office productivity, but also in the actual cost savings through the reduction of travel for site inspections. Preliminary highway site inspection normally involves two people and can take as much time as two or more days. If the number of such trips can be reduced through the use of the MMHIS, the savings of travel costs and labor in just one year for a highway department can be substantial.

As MMHIS is technology-driven, additional features can be built into MMHIS over time. New features of Geographical Information System and high-resolution 3-D terrain data will be useful for an integrated highway management and design. When statewide terrain data in the MMHIS is updated with Digital Elevation Models (DEM) of sub-meter resolution, it is possible to conduct preliminary engineering design of cut-and-fill and planning the development of new transportation systems.

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