

# Design Considerations for Distributed, Multimedia-Based Highway Information System

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Two types of data commonly used in highway management systems are video/film images and tabulated data such as pavement width/type, construction/rehabilitation history, layer thicknesses and types, condition data, accident data, traffic history, and signing/markings inventory. Tabulated data can be stored readily in a database, making general access reasonably feasible. However, access to the video/film images has been limited by technology, and the simultaneous access to both data types from a single medium has not been possible. A multimedia-based Highway Information System (MMHIS) is described in this paper that merges the two data types into a single access system that displays moving video images and the corresponding tabulated site data. The system displays the video image and corresponding data on a conventional desktop computer monitor. The MMHIS is installed on a centralized file server, and any PC or workstation networked with the server has access to the images and data. MMHIS has broad applications in highway engineering and management. A state highway agency with a statewide computer network would have access to the entire database from any office on the network. The latest video images and data would be available to field engineers, maintenance superintendents, design engineers, traffic analysts, and planners. Through the use of overhead projection panels, top management meetings regarding specific sites could include the viewing of those sites without leaving the conference room. This paper discusses the design of a low cost MMHIS and identifies the technology associated with the implementation of such a system.

For many years, highway agencies have used 16-mm film and, more recently, broadcast quality video to capture and view visual information for their traffic engineering and infrastructure management. The Connecticut Department of Transportation was the first highway agency to adopt analog-based laser disc systems for pavement video inventory (1). Recently, other states, such as Arizona and Arkansas, started using laser disc or Super-VHS (S-VHS) video for their roadway video inventory. These images are used for pavement management, highway signing and marking improvement, and accident analysis. A potentially significant use of these images is pavement surface distress identification and classification; however, there has been limited success in automating the process of surface distress identification and classification.

Another type of information is the tabulated site data contained in traditional engineering databases. These data sets include information on construction and rehabilitation history, pavement layer information, pavement width/type, average daily traffic, accident history, signing/markings inventory, and others. Engineering information in the databases regarding specific roadway sections can be accessed through microcomputer-based local area network (LAN). 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. However, the facilities used

for the two types of data are traditionally managed through separate groups within the agency. Simultaneous access to both visual information and engineering data is presently not possible. The visual images are analog-based and are located in specific offices. To view specific roadway sections, users must go to offices equipped with special, expensive equipment. Even though the benefits for combining these two information sources is evident to highway agencies, the high cost of implementation and the complications associated with the technology required to implement such a system has prevented it from becoming a reality.

The introduction of high performance, low cost microcomputers has ushered a new information age that is affordable to a large number of users. An important feature of this capability is digital video and audio at the desktop, commonly called "microcomputer-based multimedia." The development of a low cost combination of visual data with traditional highway engineering databases has become a viable option. This paper describes available technologies and design considerations for a multimedia-based highway information System (MMHIS) with digital and networkable capabilities.

## THE REQUIREMENTS OF A MMHIS

To justify the cost and effort of development, a MMHIS must have a distinct advantage over today's nonnetworkable photolog systems and separate engineering data tabulations. To have the needed advantage the following requirements are identified as being practically achievable based on the capabilities of the latest information technology and the current practices of state highway agencies:

1. A dynamically synchronized combination of tabulated data sets with the appropriate visual images so that the images and corresponding data can be viewed simultaneously,
2. Usability in multiple agency functions, including traffic studies, pavement management, highway design, and other information needs,
3. The ability to incorporate and use to the fullest extent possible existing network, hardware, and software to make use of past investments,
4. The ability to accommodate multiple users simultaneously accessing the same images and databases,
5. The ability to view a highway section through text or graphical query and the ability to capture the video images for incorporation into a word-processing document,
6. Sufficient flexibility that the MMHIS can be integrated into a geographic information system (GIS) such as Intergraph's MGE system,

7. Initial video quality to be at S-VHS level, with scalability of incorporating higher resolution video, such as high definition television (HDTV), and

8. Optional capabilities of the (a) ability to store audio comments embedded either in the video or tabulated data files and (b) incorporation of teleconferencing capabilities.

For traffic safety information management, with a MMHIS, each accident data record can be indexed to video frames of the actual accident scene, possibly including pictures of the vehicles involved. This capability will provide more insight into the causes of accidents and will result in better decisions on geometric, signing, or marking improvements. It can also serve as a tool for the legal and insurance systems.

The digitizing of pavement surface images will lend itself to the development of automated surface distress surveys. Although efforts to develop such capability has met only limited success to date, the development of high resolution MMHIS will greatly expand the opportunities and potential for successful development and implementation.

MMHIS will be quite useful in roadway design that involves improvement of existing roadways. The preliminary examination of geometric features can require many hours (or days) of travel time for field trips. With MMHIS the preliminary examination can be performed in the office either individually on a computer monitor or by a group viewing images projected onto a screen.

## REVIEW OF AVAILABLE TECHNOLOGY

It was difficult to put TV quality video in computer networks. In recent years, the technological advancement of low-cost equipment resulted in performances at the advanced workstation level. Now the good quality of capturing and playback of digital video can now be achieved in 486 and Pentium level computers with some hardware assistance. Network technologies were also improved in the last couple of years. The following discussions relate to today's video technologies essential for the implementation of a MMHIS.

### Analog or Digital

Until recently, computers and television existed in two separate worlds: digital for computers and analog for television. This difference between digital computer display and the consumer video world reflects the fundamental difference between computer images and television images in the way they are handled and displayed. Information in computer displays is comprised of digital data and is stored as sequences of negative and positive charges that the computer reads or writes as the digital numbers 0 and 1. Images in television-based video (including video-form broadcast, VCR, and laser disc) are stored and manipulated as analog information. Analog information is stored in smooth, continuously variable electronic signals that can have an infinite number of possible values. Although a large amount of analog data can be easily stored in tape or laser disc, they are difficult to manipulate, copy, and distribute without introducing electronic "noise" into the original signal. Therefore, the quality of the video image is degraded during the process. In addition, the access to analog video images is also restricted in a number of areas. For example, it is impossible to let multiple users simultaneously access one laser disc. Because digital video can be reduced to a series of numbers, it can be edited,

stored, and played back without ever losing any of the original signal fidelity. Digital video can also be easily integrated with other information on the computer to form new types of communications media that will be hybrids of text, computer graphics, and motion video. The data format of digital video is similar to regular computer files in many aspects, so multiple access to the same digital video files is possible. More importantly, speedy random access is an important property of digital data stored in hard drives or optical discs. Therefore, digital video is necessary when high fidelity, fast, and multiple-user access are required of the MMHIS.

## Compression and Decompression

The generation of multimedia data (video and/or audio) is conducted through a process called "capturing" from analog sources, such as tape, laser disc, or camcorder. Then the data can be stored and played back on desktop computers. One full color digital image with a NTSC TV resolution ( $640 \times 480$ ) requires approximately 0.92 megabyte of data storage. A full motion video has about 30 frames in 1 second. As a result, about 27 megabytes of storage space are needed for just 1 second of uncompressed motion color video. In addition, the input and output bandwidth of modern microcomputers (disc, bus, and video subsystems) are not capable of processing dozens of megabytes of a huge data stream per second. Therefore, data compression is needed to reduce data storage requirement on the one hand and to improve data flow rate on the other.

With custom chips and compression algorithms, a capture card residing in the computer bus takes in video frames, compresses them, and passes the compressed data onto the computer's storage. The amount of compression ranges from as little as 2:1 to as much as 200:1, depending on what algorithm is used and what level of quality is required. Most image compression algorithms are "lossy," meaning information is lost during the compression of the data. The stored digital data (video and/or audio) can be played back through decompression to give a visually faithful representation of the original image. The same process applies to audio decompression. This entire process is called CODEC for compression and decomposition, sometimes referred to as encoding and decoding. The general rule is: the more compression you use, the poorer the quality of the played back image is. However, quality of compressed video data also depends on the CODEC algorithm and whether hardware-assisted CODEC is used. The following is a brief introduction of the popular formats.

### Motion Joint Photographic Experts Group

The Joint Photographic Experts Group (JPEG), an industry standard-setting committee, first developed this compression algorithm for still images, but the standard has been widely adopted for video sequences because the JPEG compression chips are relatively inexpensive. The motion JPEG is based on the original JPEG algorithms and allows easy random access to any frame in a digitized sequence. JPEG compression is conducted exclusively on redundant data in individual frames, and many other CODEC algorithms use inter-frame compression, resulting in a higher compression ratio. JPEG compression is fairly fast. Hardware-based JPEG CODEC can capture full-screen, full-rate video in real time. The image degrades noticeably if the compression exceeds 20:1. When high compression ratio is not required, this CODEC algorithm is very effective in preserving the details and fidelity of single video frame, which is very important in applications in medical analysis and military targeting.

## Motion Picture Experts Group

Unlike JPEG, which only condenses information within each frame, the standard developed by the Motion Picture Experts Group (MPEG) compresses information between frames, such as background information that does not change. This allows video digitization and playback at compression ratios as high as 160:1 while still retaining fairly good quality. Because of its high compression ratio, MPEG is a desirable delivery format for applications that require the digital video stream to be transferred over narrow bandwidth systems such as CD-ROM, video networks, and video conferencing. The forthcoming HDTV is based on a new MPEG CODEC, called MPEG-2 because of its high compression ratio and high quality of motion video. However, because of the asymmetric nature of MPEG, the required high computing power makes it difficult to conduct the compression (encoding) process. The decompression (decoding) of MPEG is relatively easy to implement.

## Indeo

Developed by Intel for its i750 chip (used on the ActionMedia II capture board), Indeo-based video can now be played back via software as well as with Intel hardware. Indeo combines both lossless and lossy algorithms. The compressed information with the lossless algorithm can be decompressed to its originality with 100% fidelity. Indeo produces good image quality but fairly low compression ratios (about 10:1). Indeo has been licensed for Macintosh, Windows, and OS/2. Based on prototyping work conducted by the authors, when the compression is conducted in a 486 or Pentium computer, the quality of the playback video based on the i750 chip is not even close to the S-VHS quality that is a requirement for described MMHIS. However, if the compression of the video data is carried out in a super computer through a highly specialized repetitive process, the quality of playback in a 486 computer is very good.

## Microsoft Video 1 and IBM Ultimotion

Both Microsoft Video 1 and IBM Ultimotion are software-only compression schemes. Video 1 was developed by Media Vision

under the name Motive and was licensed by Microsoft in its Video for Windows. The current maximum video size ( $160 \times 120$ ) and quality provided in Microsoft Video for Windows are not adequate for use in a MMHIS.

From video capturing to play back, the CODEC in Ultimotion included in 32-bit IBM OS/2 is conducted in the computer's central processing unit (CPU). Therefore, the quality of video is compromised, and the cost of obtaining full motion video is kept to a minimum. Currently Ultimotion is only available in the OS/2 environment. Unless an extremely powerful CPU is used, software-only CODEC will not provide the full motion frame rate at or over the S-VHS resolution required for a MMHIS.

## Digital Video in a Network

Putting digital video on a network is a complex task; the difficulty is in determining how to keep multimedia data from straining every computer and network component to the utmost. The factors of storage capacity, processor power, network data rate, and networking software determine the availability and quality of the video on the desktop. Any one of these factors can become the bottleneck to the video flow, as shown in Figure 1. Even with compression, VHS-quality digital motion video requires about 2 M bit/sec (Mbps) of bandwidth. Advanced digital video, such as HDTV, could use over 30 Mbps bandwidth after compression (2). Common networks based on Token Ring or Ethernet have the shared data bandwidth of 16 Mbps and 10M bps, respectively. In addition, the two types of networks are optimized for carrying packet data and do a poor job of carrying full-motion video. It is clear that to allow multiple access to the video files (more than 10), the throughput of the traditional networks need to be drastically improved. Furthermore, it is required that video streams be delivered in a particular order with very small latency. Otherwise, frame drop and unsynchronization would occur. Therefore, the challenge is to design a proper network that provides the highest data bandwidth and at the same time takes advantages of the existing network capabilities.

It is possible to use Ethernet or Token Ring to carry a limited number of simultaneous streams at S-VHS quality (e.g., less than five users) by using specially designed management software ensur-

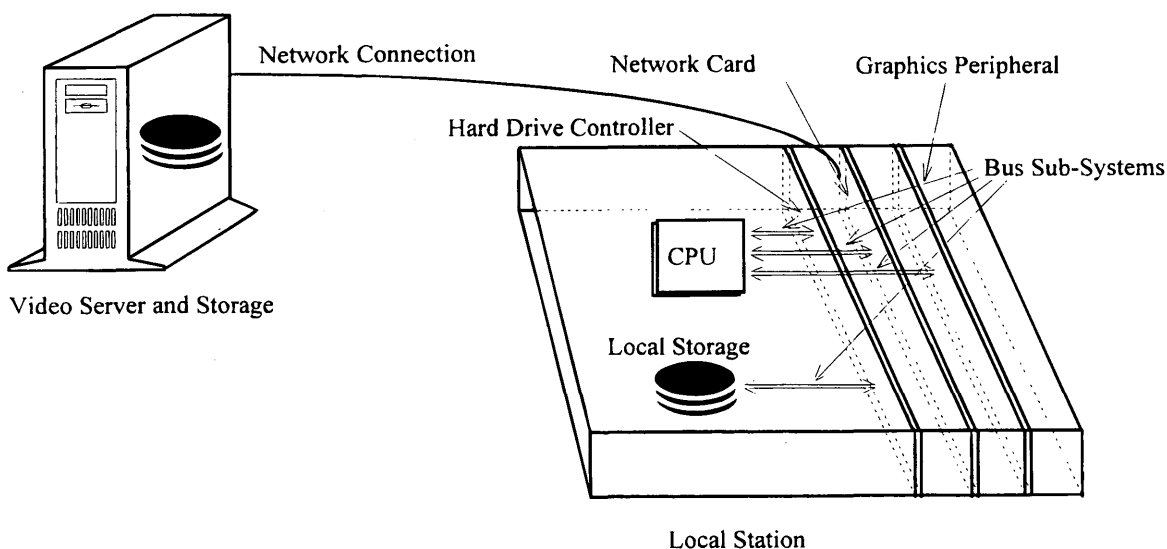


FIGURE 1 Bottlenecks of video data flow in the video server and station. (All identified items are potential bottlenecks).

ing free flow of video/audio data. However, for carrying higher fidelity video/audio for a larger number of users, new and more expensive technologies need to be used, such as asynchronous transfer mode (ATM) and the fiber distributed data interface (FDDI). ATM is a short-packet protocol based on individual connections, and FDDI can be used in a 100-Mbps, shared medium LAN.

## ATM

ATM is an extremely fast, high bandwidth, packet-switching technology. ATM technology was invented by the telephone industry. Its connection approach is similar to telephone switches; each telephone has full data bandwidth to the called telephone when connected. This approach is best suited for video and audio transmission (2). ATM breaks all traffic (voice, video, or data) into equally 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. 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 622 gigabits/sec (3), which is adequate for any type of application in the foreseeable future. The resulting bandwidth is available from each station to a server or another station, which poses a big advantage over the shared bandwidth technology in Token Ring and Ethernet.

Integrated Service Digital Network (ISDN) is the digital successor to the analog-based telephone communication technology. It is widely used in video conferencing systems for both video and voice transmission, such as the recently announced ProShare system from Intel. However, ISDN operates at the speed of 64 K bit/sec/channel, which is not suitable for carrying high traffic loads between LAN. ATM is derived from ISDN technologies, so it is sometimes called broadband ISDN.

## FDDI

FDDI is based on the same token-passing technique as Token Ring. But it is a more sophisticated implementation, with timing devices enabling data to be transmitted at the higher speed of 100 Mbps, which is 10 times greater than that of Ethernet. Today's FDDI no longer requires fiber optical cable at the desktop. Recent advances in data transmission technology enable the full speed of FDDI to be sustained over standard twisted pair copper cabling over short distances up to 100 m. For many existing applications, FDDI is used as a backbone network, connecting different LANs together within a building or a site, such as a university campus. Individual computers are not connected through FDDI mainly because of cost considerations.

The main advantages of FDDI over Token Ring and Ethernet are performance and reliability. FDDI supports multiple tokens, meaning that many different packets of data can be transmitted over the LAN simultaneously. In addition, FDDI can be implemented over a pair of rings, which has certain fault-tolerant features in case faults occur. The fact that FDDI can run on optical fiber ensures the immu-

nity from electrical interference. The main advantages of FDDI over ATM is its lower price and proven interoperability between products. However, FDDI's price advantage over ATM is disappearing as ATM standards are being set, and the prices of its devices are falling fast. In addition, FDDI has the similar disadvantages of using shared medium as Token Ring and Ethernet do. Recently, 100-Mbps Fast Ethernet has been proposed based on the existing Ethernet technology. How successful the Fast Ethernet will be remains to be seen.

## The Video Server and Data Storage

When traditional data are traveling in the network, the data stream is not continuous and steady; rather it is sent in a batch mode resulting in inconsistent delays between batches. This type of data is also called short and bursty data. A dedicated video server can help eliminate the compromises that ordinary servers make between controlling short, bursty data and optimizing large streams of data. The video server along with a proper network protocol for video bypasses the democratic contention scheme and acts as a real time system that ensures reliable data flow. To efficiently manage the multiple simultaneous video streams, multiple processors can be used in the video server. For example, the database maker Oracle uses a massive, parallel n-Cube super computer in its video demand implementation, which is capable of managing thousands of simultaneous consumers. In a MMHIS, simultaneous users would be limited because of its engineering nature, so a low-cost symmetrical computer with a few Pentium processors would provide adequate power to drive 10 to 50 users at the same time.

Storage is another important issue in the video server design. For a MMHIS, a minimum of a few dozens of gigabytes of storage is needed for a highway network of a few thousand miles. A Redundant Array of Inexpensive Discs (RAID) system can be used to ensure the availability of data at all times. A common technique in RAID is stripping, meaning splitting data into multiple drives. The resulting effective sustained data rate can be drastically improved.

All of the above technologies were designed to handle traditional data access, in which short, random, burst transfers that leave gaps in the data stream are common. These gaps last up to 800 milliseconds, which are used to perform drive calibration and error correction tasks. The burst transfer pattern is similar to the traditional data transmission in a network. In a MMHIS scenario, multiple users may access video frames of highway sections in the state highway system. Therefore, a new type of storage device is needed to provide multiple simultaneous data streams and at the same time keep latency as small as possible. Recently, Micropolis Corporation and Pinnacle Micro, Inc., introduced storage products that are specifically designed for applications requiring multiple video stream delivery. The Micropolis AV magnetic hard drives use a proprietary AV management system, providing 30 milliseconds of worst case data access with an average latency of 5.6 milliseconds and a minimum sustained data rate of 3.0 megabytes/sec (MBps). The Pinnacle product is an 5.2-gigabyte optical disc system called ORRAY, which has four removal bays containing four 1.3-gigabyte magneto-optical discs. ORRAY uses the multi-head and multi-platter approach of traditional hard drives. However, its multi-channel architecture allows four-channel reading and writing of data simultaneously to four optical platters. Another important feature of the ORRAY drive is that it has virtually unlimited storage capacity because each optical drive is removable. The sustained data rate is

from 5.0M Bps to 8.0 MBps, which excels at the best performing Winchester hard drive on the market. The technology in ORRAY allows all active surfaces to be read or written independently and simultaneously without requiring complex spindle synchronization or rotational position locking as required in magnetic drives. This feature is especially helpful in the multiple access environment in a MMHIS. As computer storage technologies evolve rapidly, the sustained data rate of AV ready storage is increasing at a very fast space. For example, Seagate just introduced a high capacity drive with data rate of 8 MBps.

## THE DEVELOPMENT OF THE MMHIS

The Civil Engineering Department at the University of Arkansas has a project supported by the Mack-Blackwell Transportation Center (a US DOT-sponsored research center) and Intergraph Corporation to develop a distributed MMHIS. This project targeted at improving access to state highway agencies' information in their transportation management systems. Most of the efforts will be devoted to network design and software development because standard hardware equipment will be used. Based on the discussions in the previous sections, the following sections represent the design elements, the appropriate technologies required for the development of MMHIS, and the development plan.

### MMHIS Design Elements

The elements of the hardware system include the following sub-systems:

1. Video recording and digitizing,
2. Microcomputer requirement: sub-systems such as I/O, micro-processor, or storage,
3. The video displaying system (frames, resolution, and number of colors),
4. LAN and wide area network,
5. Video and database servers,

The software elements include:

1. Operating systems for both the desktop and server,
2. CODEC algorithm (software only or hardware assisted),
3. Network management software for video/audio data stream,
4. Indexing and displaying engineering data and video frames,
5. Modules for integrating MMHIS in an Intergraph MGE environment,
6. Relational database management software.

### Client Computers, Server Storage, and ATM

Based on current practices of highway agencies and fast growing capabilities of Intel x86 processor and related I/O sub-systems, the hardware platforms for both the video server and clients are Pentium or higher level computers. Capabilities of managing multiple video data streams are critical in a MMHIS, so the video server needs to be symmetrically based with a minimum of two high powered processors so that the management of data streams can be distributed among processors. The bus system for both server and clients will be based on the new peripheral component interconnect

(PCI) standard. The existing version of PCI has a peak I/O bandwidth of 132 MBps. This bandwidth is more than adequate to deliver highest quality video if the graphics subsystem can take advantage of the PCI throughput. Future generations of PCI standard are proposed at the data rate of 264 MBps to 528 MBps, which is likely to be implemented in the next 2 years. The video database will reside in the server, so the storage capability of the server should be large enough to store the video frames. It is assumed that the taping speed is 55 mph and 1 megabyte of compressed video data per second. For a state interstate network with 4,000 lane-miles, it is estimated that the storage needs will exceed 260 gigabytes with full motion (30 frames/sec) and full color at NTSC quality.

ATM devices, including switches and adapter cards, were much more expensive than the rivals, such as Token Ring, Ethernet, and even FDDI. In the summer of 1994, ATM hardware prices dropped to price levels that are competitive to its rivals. Recently IBM announced a \$396, ISA-based ATM adapter card with a speed of 25 Mbps (4). In the beginning of 1995 PCI-based ATM cards with a speed of 155 Mbps already fell below \$900. This lower pricing trend will encourage the wide spread adoption of ATM implementations in LAN connecting Pentium-based computers. Industry groups are setting up standards for the interoperability of ATM equipment from various vendors, most of which will be finalized in 1995. In this MMHIS, ATM will be used in combination with existing networking equipment to increase the overall capabilities of the network's data bandwidth.

### Video Data Management in Networks

Current network operating systems usually do not have the capability to coordinate video data flow sufficiently to ensure video quality on the client's desktops. The existing network management software emphasizes data integrity through error control protocols. Flow control and timeliness of delivery are critical for high quality video/audio data but are secondary in the current network software. Therefore, managing and transmitting digital video/audio data poses two major challenges to the network operating system: dealing with large file sizes and meeting the time-dependent needs of video data stream. In a multimedia application, it is required that large block digital video/audio data be transferred simultaneously and continuously to ensure the high degree of consistency in picture frame and synchronization with audio or other data. It is very difficult to manage random, bursty data along with streaming data in the same LAN. This is because of the democratic scheme in using the CPU power in which bits are bits, regardless of the type of represented information, resulting in the same priority for all applications. The data transmission slows down and speeds up along with the data traffic volume in the network. The resulting phenomenon is either the untimely arrival of the requested data at the desktop or a reduced number of frames and degradation of image quality.

It is imperative to ensure that video/audio data streams flow at consistent latency in the network and that there are no traffic clogs for video/audio data. One way to deal with the bottleneck in the network is to throw away all the software and hardware that cause the traffic jam and replace them with new multimedia capable software and hardware. For example, the existing 10-Mbps Ethernet LAN can be replaced with a ATM system at the expense of losing all investment in Ethernet and purchasing a new system. Another solution is to initially improve the limiting hardware and software so that they can handle more data on the one hand and pro-

vide a separate network management protocol for video/audio data on the other. When the cost to install ATM becomes low enough, the old facilities can be replaced with the new equipment.

### Turbocharged Star Structure for Video Data

Modern network bus/ring structure is based on star topology, including the newer Ethernet and all token ring networks, shown in Figure 2a. However, the shared nature of bus or ring networks makes it difficult to guarantee the dedicated bandwidth required for smooth and reliable video/audio delivery due to the 10-Mbps or 16-Mbps bandwidth, even though such a network can be functional in delivering video with limited capacity and quality. One solution is to turbocharge the Ethernet hub to dedicate 10 Mbps for each desktop. The connection from the hub to the server is connected via FDDI or ATM as shown in Figure 2b, providing more than 100 Mbps of bandwidth. The bandwidth may be adequate in this design. This network design is also called "switched Ethernet." However, there is still no guarantee to ensure the timely delivery of digital/audio data in the network in which every application competes with each other on the same level ground to obtain bandwidth.

### Network Protocol for Video

Protocols are software layers in the network, which ensure that data arrive without errors and that traffic flows are regulated properly. For video/audio data, a special video protocol is necessary to make sure that 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 the other data flows. Normal data flows yield right of way to video/audio data. Development of new network protocols for video capable of handling thousands of simultaneous video data streams is a major challenge for the much publicized alliances among large computer companies, telecommunication services, and entertainment consortia.

Microsoft is developing a continuous-media software solution for video in a network. This Windows NT-based network management software for video streams, nicknamed Tiger, purports to enable Intel Pentium chips to control as many as 16 video streams with MPEG-2 quality, plus VCR features like pause and reverse. The challenge in developing the Tiger system lies in managing large numbers of data streams leaving the server. The major advantage of Tiger over other systems being developed is that Tiger fully uses the

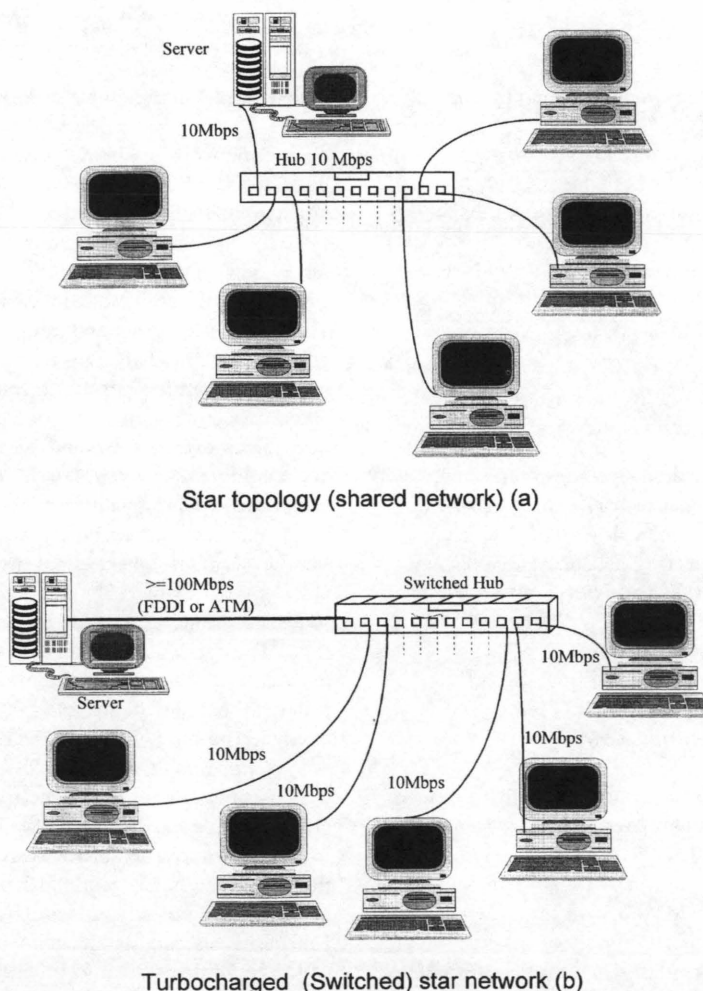


FIGURE 2 Two configurations of the star topology. (a) Star topology (shared network); (b) turbocharged (switched) star network.



power of Pentium-based symmetrical computers, whereas most others take the approach of using proprietary super computer level hardware systems, such as Oracle's venture. In addition, the technologies in Tiger are scalable with the growth of hardware capabilities, meaning that when more powerful processors become available after the current Pentium, Tiger will be able to deliver much more simultaneous video streams and at a higher level quality. Another company, Startlight Networks, has released network management software, StarWorks, for video and audio that takes advantage of the turbocharged start structure shown in Figure 2b. It is claimed that the system can deliver 25 to 50 simultaneous data streams. Most existing products are targeted at the consumer and training markets, so the video quality is expected to be below the requirement of the MMHIS.

### Software Issues for MMHIS

For the software environment, the 32-bit Microsoft NT operating system and Tiger or StarWorks video management software will be used as the underlying operating environment for the network. Oracle Relational Database Manager will be used in the development. Intergraph's solution to the Geographical Information System, MGE, will be used as the visual environment for data query of MMHIS.

An important feature of the MMHIS is the dynamic display of a superimposed data table with the video frames. The data table includes any type of information relating to the shown highway section's history, condition, accident records, and even environmental data. The techniques to dynamically link regular database records with video frames are unknown at this time. An efficient linking algorithm will be developed in this project so that computer CPU's resources will not be drained (both server and client) when multiple users access the facility. Figure 3 shows the expected capability of MMHIS to display data along with a video frame in a GIS shell.

### Development Plan

The implementation of the MMHIS includes two stages. The first 2-year stage will use the current Ethernet networking devices with the S-VHS level video quality. ATM will be tested at the later half of the first stage. The second 2-year stage will focus on the delivery of higher quality video at the desktop through an ATM network. The development will utilize Intergraph's GIS solutions (MGE) to incorporate the MMHIS as a seamless module within MGE.

### Data Flow

The data collection for this MMHIS can be conducted in a customized vehicle as shown in Figure 4. Currently, most vehicles use either Super-VHS (Hi-8 mm) or Laser Disk-based storage system, both of which provide NTSC Y/C analog signal connections. Some systems may use the Asian standard PAL-based signal system because of its slightly higher resolution. The tapes or disks can then be sent to the compression system for encoding. The encoding system most likely will be based on the high compression standard MPEG. A selection is needed to be made between two MPEG standards: MPEG-1 and MPEG-2. MPEG-1's source image format (SIF) is  $352 \times 240$  with 30 frames/sec (FPS) in NTSC and  $352 \times 288$  with 25 FPS in PAL. The image quality is important for engineering analysis, so the higher data rate specification of MPEG-2 is needed in this system. MPEG-2 itself includes a set of standards for various resolutions. In the latter half of 1994, IBM, C-Cube, Toshiba, and possibly others introduced cost-effective MPEG-2 encoding chips for main profile at the main level, representing the SIF of  $720 \times 480$  at 30 FPS in NTSC. The data rate for MPEG-2 at this resolution is in the range of 6 to 10 Mbps, and the MPEG-1's data rate is from 1 to 3 Mbps.

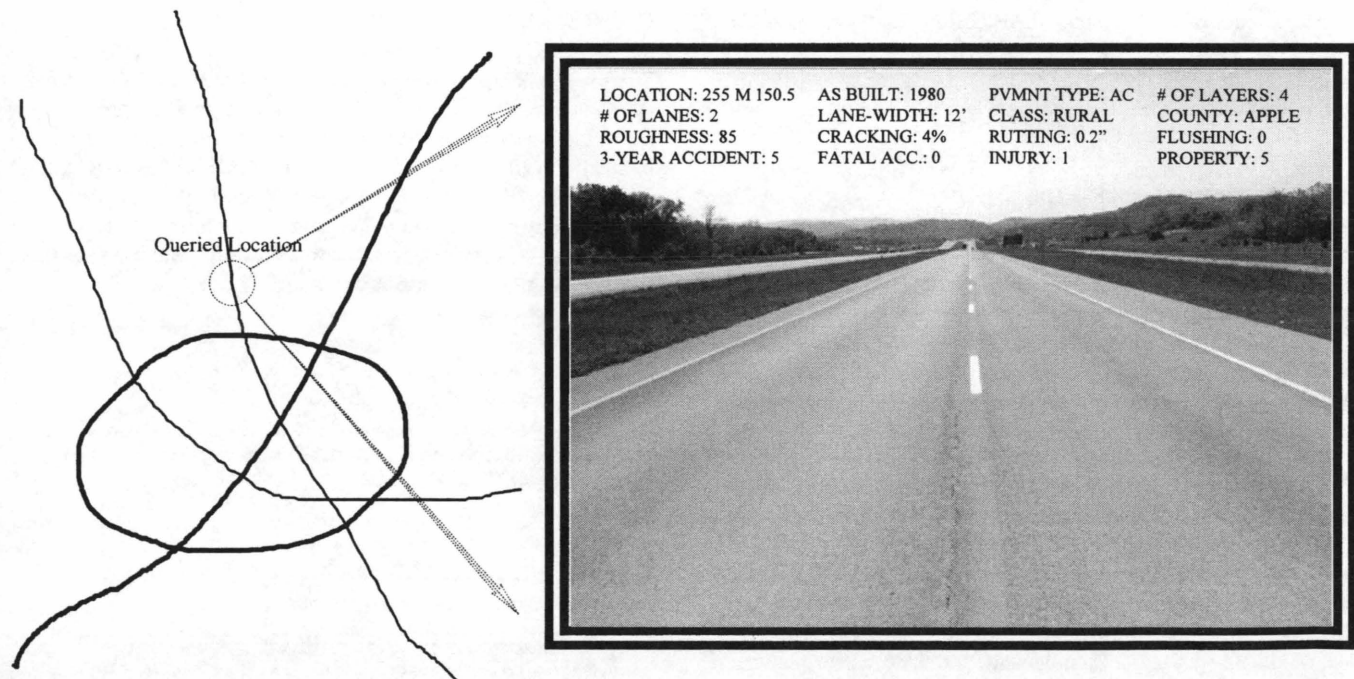


FIGURE 3 An example of the MMHIS in a GIS shell.

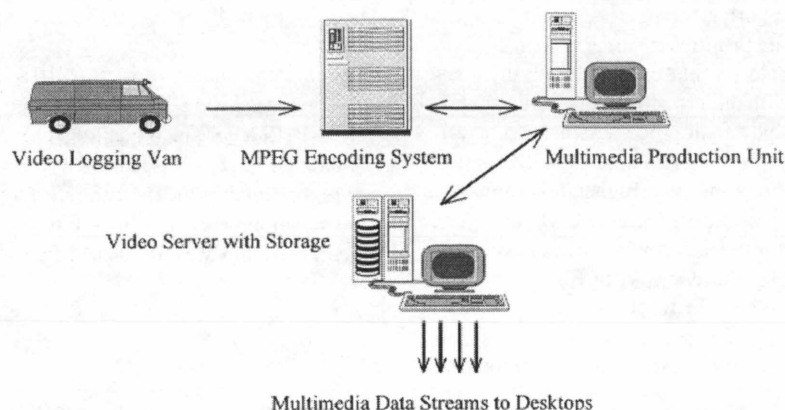


FIGURE 4 Video data flow in the MMHIS for a state highway department.

Figure 4 also illustrates the multimedia data flow within a state highway department. ATM connections are used to link the MPEG-2 encoding system, the production unit, the video server, and desktop computers in various divisions. It is expected that there will be less than 20 simultaneous users accessing the video server for multimedia files. This translates to a maximum total data rate of 160 Mbps at the single stream rate of 8 Mbps for MPEG-2 specification. Therefore, the possible data bottleneck in the ATM-based network is the delivery speed of the hard drives in the video server storage. However, by using techniques of RAID, hard drive stripping and symmetrical processing in the video server, the sustained data delivery rate of 20 MBps (equivalent to 160 Mbps) may be achieved for the network.

Eventually, HDTV will be used in this MMHIS in which effective signing and marking inventory and pavement surface distress survey are needed. The expected data rate for HDTV at the resolution of  $1,920 \times 1,152$  (high profile at main level) is 30 to 50 Mbps after MPEG-2 compression, which falls within the current bandwidth of 155 Mbps speed of ATM. In this MMHIS, all video data are off-line information. In the next few years, a traffic monitoring component can be built into this MMHIS so that real time traffic flows on major arterial highways can be observed with desktop computers.

### Stage One: Ethernet and S-VHS

About 10 Pentium stations with PCI bus will be used in the development of the MMHIS. The stations will use MPEG-2 as the primary CODEC algorithm, and related hardware CODEC devices will be installed. At this stage, the digital video frames will be linked with regular highway engineering data bases so that engineering data can be shown in a superimposed box dynamically with the moving picture.

The current Ethernet network will be experimented at first. Either Microsoft Tiger software or StarWorks is to be installed at this stage. After an 18-month period, one ATM switch and PCI-based ATM adapter cards connecting the desktop computer to the server will be installed, initially providing a minimum 155-Mbps data rate station to station. When the first phase study is completed, the system will be tested by the Arkansas Highway and Transportation Department for testing and implementation. The video quality at that time will be at S-VHS level.

### Stage Two: HDTV and MGE

The second phase targets an ATM-based network and second-generation PCI bus. Over 20 Pentium- and P6-based stations will be used at this stage. Software only CODEC will be tested in the P6 systems because a processor more than twice as fast as today's Pentium may well be able to conduct CODEC in the CPU without any hardware assistance. Using direct digital video technology in the image-capturing process will be an area of study at this stage. In the latter half of the second stage, full digital HDTV technologies will be tested with four times more resolution than the images from the highest possible resolution in the NTSC implementation. In addition, it is expected that tests will be conducted at this phase to automate pavement surface distress survey by using the high resolution images from digital BetaCam or HDTV cameras with proper image-processing algorithms.

### CONCLUSION

The expected capabilities of this MMHIS are based on the technologies in the middle 1990s. The equipment and software used for the implementation are based on open technologies that are commercially available from a number of competing vendors. Therefore, the MMHIS will be nonproprietary, resulting in the realization of a low-cost integration of open software and hardware. MMHIS will provide a highway agency with a powerful tool in its management of the highway infrastructure.

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