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Final CRADA Report
for
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DEVELOPMENT OF A GEOGRAPHIC VISUALIZATION AND COMMUNICATIONS SYSTEMS (GVCS) FOR MONITORING REMOTE VEHICLES

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Abstract

The purpose of this project is to integrate a variety of geographic information systems capabilities and telecommunication technologies for potential use in geographic network and visualization applications. The specific technical goals of the project were to design, develop, and simulate the components of an audio/visual geographic communications system to aid future real-time monitoring, mapping, and managing of transport vehicles. The system components of this feasibility study are collectively referred to as a Geographic Visualization and Communications System (GVCS). State-of-the-art techniques will be used and developed to allow both the vehicle operator and network manager to monitor the location and surrounding environment of a transport vehicle during shipment.

NOTE: Project Complete 9/95, Information Contained Within Dated From The 1995 Time Frame.

CRADA Objectives

This research project was to integrate existing technologies including geographic information systems, image mapping, geographic positioning systems, satellite tracking, transportation networks, multi-media communications and graphic workstations. The intent was to develop and simulate the system components that would allow video, audio, digital map, and image information to be communicated and displayed in a geographic context by the network manager in conjunction with a transport vehicle. For example, images from a video camera mounted in the vehicle would be conveyed via satellite communications to a command center or remote centers for display on a graphic workstation. This would allow the network manager to monitor the surrounding environment of the vehicle, assess trouble spots, and better plan "safe havens" or alternate routes that might be needed. Television broadcasts (e.g., weather forecasts, accident problems, etc.) or even video from aerial platforms (traffic reports) could also be incorporated as video input. The video imagery might be recorded on laser videodisks at a center or as digital compressed video for playback and analysis. Audio communication was to be provided between the vehicle operator and network manager. A major part of the effort was to determine which technologies are most useful, how they should be incorporated from a communications, logistics, and systems standpoint, and establish priorities for demonstrating "proof-of-concept" for the most important components.

DOE Benefits

The current DOE Transportation Tracking and Communications System (TRANSCOM) system can provide locational tracking and vector-based mapping of the vehicle on highway, rail, or barge networks. Locational tracking and communications from the transport vehicle is performed through the commercial Qualcomm system. By adding satellite imagery or aerial photographs as a master background behind the vehicle position, information on the surrounding environment is greatly enhanced. By incorporating GIS techniques, databases can be maintained and queried on the map features, vehicle contents, transportation network and trouble spots. A possible scenario might be the question of delaying, placing shipment in a "safe-haven" or re-routing a truck shipment of hazardous material while in-transit. Television maps of upcoming severe storms may be recorded on the workstation. The manager might view current conditions at the vehicle, compare the recorded storm maps with the planned route, review pre-stored satellite terrain images overlaid with "safe-haven" or alternate routes, especially in urban areas, discuss options with the truck driver, and study impacts on time schedules. Integrating all these different types of information on the workstation greatly enhance the decision-making capabilities of the network manager. A laptop computer within the truck could provide first hand spatial information to the driver to aid "on-the-road" assessment.

Technical Details

Section 1: Introduction

Background

Monitoring of vehicles remote from the observer is a topic of considerable interest in a wide variety of applications. Truck dispatch centers want to know the geographic position of each vehicle to keep their customers informed and to schedule new shipments. Shippers of hazardous materials are particularly interested in informing each jurisdiction of the arrival time of such materials in their state and to schedule emergency response actions in case of an event. Emergency response and law enforcement agencies need to rapidly dispatch the appropriate vehicle(s) to a location. Each of the applications requires the geographic position of all vehicles of interest to be transmitted over wireless communication linkages to some type of command or control center.

Although geographic position of the vehicle is of primary interest, other characteristics of the vehicle and its environment may also be of considerable interest to the control center staff. For instance, the state or "health" of the vehicle or its cargo may be of vital importance. The temperature of the engine and velocity of the vehicle may be two parameters of interest. Verbal communication from/to the vehicle operator may also be of interest. Finally, images of the vehicle's surrounding environment or a specific local item may be of immediate interest to the control center.

The purpose of the CRADA was to design, develop and simulate the components of an audio/visual geographic communications system to aid in future real-time monitoring, mapping, and managing of transport vehicles. The system components of this feasibility study are collectively referred to as a Geographic Visualization and Communications System (GVCS). State of the art techniques were used and developed to allow both the vehicle operator and the network manager to monitor the location and surrounding environment of a transport vehicle during shipment.

Components of Vehicle Monitoring

A vehicle monitoring and communication system is composed of several major components: core display/query system, telecommunication infrastructure, and positioning and sensor related data collection equipment. Each of these components is a collection of sub-components, but are integrated into a separate system.

Scope Of CRADA

We sought to build a prototype vehicle tracking system with capabilities for the transmission of not only positional data, but also audio, video stills, and other measurements of onboard sensors. Rather than building an entire system from scratch, we wanted to use of the existing telecommunication technologies infrastructure. It was also highly desirable to design a modular system, so that individual components, such as the wireless technology, positioning method, display drivers, WWW access, could be easily replaced as the technologies evolved. The primary goals of the system were for it to be:

- modular, allowing hardware or software components to be easily replaced,
- portable across hardware platforms,
- visual integration of cartographic, remotely sensed imagery,
- dynamic graphics, and
- expandable with user-defined functionality.

TEXCOM, Inc. has proposed the establishment of a Cooperative Research and Development Agreement (CRADA) with the Oak Ridge National Laboratory to integrate a variety of geographic information system capabilities and telecommunication technologies for potential use in geographic network and visualization applications.

The Computing Applications Division (CAD) of Martin Marietta Energy Systems has been involved in the development and application of Geographic Information System (GIS) technology, transportation network models and data bases, multi-media graphic workstations, and remote sensing technologies for over two decades.

TEXCOM, Inc. is a minority-owned small business specializing in telecommunications support services. In support of the federal government and commercial organizations, TEXCOM provides services in project management, systems engineering and integration, network management, and product design, engineering, assembly and installation. TEXCOM, founded in 1982 by Mr. Clemon H. Wesley, is headquartered in Landover, Maryland with offices in Virginia, New Jersey, and Michigan.

This CRADA integrates the strengths of both organizations to benefit the DOE activities in transportation of hazardous materials and the interests of TEXCOM in telecommunication networks and systems engineering as applied to geographic network applications. The advanced geographic visualization and communication methods described in this proposal will also bring additional strength to DOE for future use in spatial applications.

It is anticipated that the results will help establish technical directions for future DOE improvements over the next 3 to 5 years. This effort will also help position TEXCOM, Inc. as a telecommunications leader in the application of vehicle tracking capabilities.

This CRADA has integrated existing technologies including geographic information systems, image mapping, geographic positioning systems, satellite tracking, transportation networks, multi-media communications and graphic workstations. The original intent was to develop and simulate the system components that would allow video, audio, digital map, and image information to be communicated and displayed in a geographic context by the network manager in conjunction with a transport vehicle. The final phase of this CRADA went beyond a mere simulation by actually collecting and transferring position and imagery in near real-time to the control center.

For example, images from a video camera mounted in the vehicle might be conveyed via satellite communications to a command center or remote centers for display on a graphic workstation. This would allow the network manager to monitor the surrounding environment of the vehicle, assess trouble spots, and better plan "safe havens" or alternate routes that might be needed. Television broadcasts (e.g., weather forecasts, accident problems, etc.) or even video from aerial platforms (e.g., traffic reports) could also be incorporated as video input. The video imagery might be recorded on laser videodisks at a center (i.e. from a workstation) or as digital compressed video for playback and analysis. Audio communication might be provided between the vehicle operator and the network manager.

By adding satellite imagery or digital aerial photographs as a raster background behind the vehicle position, information on the surrounding environment is greatly enhanced. By incorporating GIS techniques, data bases can be maintained and queried on the map features, vehicle contents, transportation network characteristics and trouble spots.

A major part of the effort will be to determine which technologies are most useful, how they should be incorporated from a communications, logistics, and systems standpoint, and establish priorities for demonstrating "proof-of-concept" for the most important components.

Phase I (Months 1 - 8)

The CRADA was conducted in two phases. The first phase resulted in a design concept, detailed definition of project tasks/subtasks, identification of a project study area, determination of appropriate hardware, software and relevant geographic databases, and interface standards of audio/video data transmission. The design included a review of available technologies and specifications for an operational system. Tasks and subtasks for 1) a simulated real-time system (i.e. without real-time collection, interactive capabilities and feedback to the transport vehicle) and 2) an operational real-time system with interactive capabilities and feedback to the transport vehicle will be defined.

During phase I (i.e. conceptual design and system configuration), Martin Marietta Energy Systems (MMES) will take the lead on reviewing and testing technologies for audio/visual computer-related hardware, software, display, locational data collection, geographic data (including data models and file structures), GIS techniques, and the user interface. MMES will also provide technical oversight and coordination with TEXCOM's effort. TEXCOM, Inc. will review and test technologies for audio/visual data collection and telecommunications, electronic and satellite interfaces for audio/visual and digital data, including the appropriate hardware/software components, data compression methods, data paths, and interface standards.

Phase II (Months 6-13)

The second phase will carry out the tasks/subtasks for the simulated real-time system using the computer systems, software, databases, and other resources within the ORNL GIS Center, along with system and communication resources at TEXCOM, Inc. TEXCOM will assist in acquiring special hardware components on a temporary basis from appropriate vendors. Acquisition and geo-referencing of improved transportation and remote sensing data for the Oak Ridge study area will be done during this phase. Audio/video and locational data collected from a moving vehicle will be transmitted via satellite and telecommunication linkages to a remote site. These data will then be transferred to the ORNL GIS Center for incorporation in the simulated system. TRANSCOM capabilities and data will be incorporated in the development. Development and adaptation of software, algorithms (e.g., data compression), and communications protocols and interfaces will be done.

In Phase II, TEXCOM, Inc. will provide the video and audio data collected from a recorder onboard the vehicle and transmitted through satellite communications to a receiving center remote from the vehicle. Global Positioning System (GPS) techniques may also be used in the vehicle to record positional information for satellite transmission to the remote center. TEXCOM will also provide conversions and interfacing of the transmitted data into the GIS workstation. The TRANSCOM system can provide geographic locational data to integrate into the simulation demonstration. MMES will implement in a workstation environment the appropriate video, audio, query, and display methods defined in Phase I for geo-referencing with the geographical maps and imagery for the study area. A simulation of the moving vehicle with the transmitted video and audio information will be conducted and a videotape product produced.

The original plan was to produce a simulated demonstration of the GVCS at Energy Systems using video, audio, and locational data previously collected onboard a vehicle and later displayed on a graphics workstation in the second phase. This simulation of the GVCS was not intended to be a real-time operational turn-key system, but rather a demonstration system to prove the utility and feasibility of incorporating advanced communication and GIS techniques in future real-time transportation network applications. A report and a non-proprietary abstract will be produced jointly by Energy Systems and TEXCOM at the conclusion of the project, describing the results and utility of the development efforts.

Although not funded in this effort, a future phase would incorporate the real-time aspect of the technologies described above including real-time data collection, transmission, and display at the command center integrated with other spatial and temporal databases. Such a system would require automatic correlation of video, audio, locational, and other digital data using time-stamps and "intelligent" selection of ancillary information (e.g. weather maps, news reports, etc.) from other databases. Real-time feedback of other audio/visual and digital data may be transmitted back to the transport vehicle. A laptop computer in the vehicle may serve to manage and display information in the mobile unit including locally stored databases. This follow-on phase would be a prototype system using a transport vehicle and command center with the established two-way transmission/communication operating in real-time.

Although not originally planned, the second phase of this project included a real-time one-way collection and transmission of locational, and video still was conducted using cellular telecommunications network.

Deliverables

A variety of products were produced including periodic progress reports, a design/concept paper, system and telecommunication specifications report, graphic and map output products from the system, a demonstration geographic data base for the project study area, and a summary report and demonstration of the final results. It is anticipated that a paper presenting the collaborative efforts may be published in the popular GIS literature. All reports and papers will be produced jointly by Energy Systems and TEXCOM. Each party will develop the sections addressing their specific areas of responsibility. Energy Systems will take the lead on integrating the sections into one document.

SECTION 2: Geographic Positioning

Positioning Characteristics

The basic considerations for selecting a positioning system are the geographic coverage, temporal coverage, and accuracy of the derived location and costs of the equipment and service. Navigational applications may also require velocity measurements. For this demonstration velocity measurements were not deemed essential. There are a number of other minor considerations, such as terrain effects on positioning, differential correction and estimated quality of position. Geographic coverage indicates the geographic areas in which the positioning system is operable. Temporal coverage describes the diurnal or seasonal variations in positioning capability. The accuracy of the estimated position is normally described as the probability distribution of errors in meters, such as circular error. For each positioning system, specific hardware is required and for some systems a service charge is levied. It is assumed that the vertical positioning ability of the technology is not particularly important in this application. The two systems investigated for this project were the Navstar Global Positioning System (GPS) and Qualcomm's Automated Satellite Reporting System (QASPR). Each system offers unique advantages and disadvantages.

Navstar Global Positioning System (GPS)

Development of the Navstar Global Positioning System (GPS) began in 1973 with cooperation from the US Air Force, Army, Navy, Marine Corps, and Defense Mapping Agency (DMA). The goal is to provide military and civilian users with precise position, velocity, and time data. The three major segments of the GPS are Space Segment, Control Segment, and the User Segment. Production of user equipment (i.e. GPS receivers) began in 1986 with an initial contract to Rockwell International. The GPS became fully operational in 1993.

The Space segment consists of the Navstar GPS satellites. Operation of the satellites is the responsibility of the Control Segment. The User Segment focuses on both the production of receivers and dissemination of the information of the GPS signals to the DoD and civilian communities.

The fully operational Space Segment consists of 21 Navstar satellites in six orbital planes. Each satellite is in an orbit of 20,200-km (10,900 nautical miles) altitude with a 12-hour period. The spacing and orbital planes are designed so that at least four satellites will be in view at any moment in time. A full constellation of 24 Block II satellites are now in place. The control segment provides continuous updating of the satellite ephemeris and time data. In the event of a failure, this segment also provides a spare satellite to be moved into position.
The GPS provides several characteristics not available with other systems:

- extremely accurate 3-D positioning,
- worldwide positioning with a common grid,
- passive, all-weather operation,
- 24-hour availability,
- position updates to 20/times per second,
- real-time and continuous operation, and
- survivability in a hostile environment
- free to the civil community

GPS was designed as a possible replacement for other positioning systems -- Loran-C, Omega, VOR/DME, TACAN, and Transit. Loran is a radio-based system based on signals from ground stations. The Transit system (also called SatNav) is based on Doppler frequency measurements using satellites in a very low orbit. These other systems have disadvantages as compared to the GPS, including positional accuracy, frequency of position updates, geographic coverage, and temporal availability.

Positioning Methodology

Position determination with GPS uses the range measurements from four satellites to the GPS receiver. Each satellite broadcasts a signal carrying its own location and time of transmission. The range is determined by computing the elapsed time from the signal transmission to the signal reception. In two-dimensional space only three range measurements are required to fix an unknown position. However, in three-dimensional space, four range measurements are required. For positioning on the surface of the earth, only three points are theoretically required as only two possible locations will be found; one of them being not possible on the ellipsoid. However, four measurements are still used to compensate for the timing error introduced by the crystal clock in the receivers.

The major factors influencing the spatial error due to the geometric configuration of satellites, satellite messages, and environmental factors. The accuracy of the estimate of a geographic position from range measurements depends on the geometric configuration of the satellites in relation to the GPS receiver. This geometric configuration is referred to as Position Dilution of Precision (PDOP). Low PDOP values (e.g. less than 4 for 2-D and 6 for 3-D) represent the best configuration. Good receivers will track multiple satellites and select the four satellites that result in the lowest PDOP. Some receivers can use all satellites in view (i.e. more than four). The best configuration for triangulating a position is with a wide range in angles between the four satellites.

Each GPS satellite broadcasts an L1 and L2 signal that each carries the navigation message (i.e. satellite position and time). Both the L1 and L2 signal also carry the precise code (P-code) while only the L1 signal carries the coarse acquisition (C/A) code. The C/A code is 1023 bits in length and the unique sequence is repeated every millisecond. The P code sequence is 6.2 trillion bits long and repeated once each week. The important satellite clock bias and ephemeris data are repeated every 30 seconds.

Environmental factors influencing the positional accuracy include the impacts of the atmospheric path (ionosphere and water vapor), geometry of satellite configuration, and processing of the signals. The differential atmospheric density introduced by the ionosphere and troposphere causes the propagated satellite signal to slow, thus, resulting in a slightly greater time lapse. These effects of the ionosphere are not constant but vary geographically. Some receivers use generalized models of the geographic variation in the ionosphere to adjust for this error. Other "dual-frequency" receivers can estimate the actual error by comparing the signal propagated on both the L1 and L2 frequencies.

Some receivers are very accurate at interpreting the satellite sent time signal by tracking both the pseudo-random code (as in most receivers) with the carrier frequency. These receivers can typically position to centimeter accuracy. Processing the carrier range typically requires several minutes of observation. In general, the less expensive receivers only operate in code phase. Receivers capable of processing the carrier phase are considerably more expensive.

Differential Correction

Differential GPS (DGPS) greatly improves the position estimate by using a reference receiver at a known position (usually a monumented position from surveying methods) to determine the cumulative errors in the standard GPS signals. The DGPS approach measures the differential error by determining either 1) the overall error in position or 2) the individual satellite range errors. The error(s) is then transmitted to other GPS receivers in near real-time or used to post-process other GPS data collected at the same time. Typically, the individual satellite range errors are used as offsets for the range measurements received by the GPS receiver. Not surprisingly, the utility of differential measurements becomes less reliable as the distance between the monumented position and the roving GPS receiver increases. This is true because the satellite ranges between each position is somewhat different and because both receivers should be receiving signals from the same satellites.

It is interesting to note that the computation of ranging errors and transmission/reception of the errors by another GPS receiver requires a finite amount of time. Thus, by the time a GPS receiver picks up the range errors at Time1, the roving GPS would be making positional estimates at time Time1+n. This latency can be up to 5 seconds. In an attempt to compensate, the system that computes the differential error tracks the temporal variation in errors. Before the differential corrections are broadcast, a projected error rate for each satellite is made based on the temporal variation in errors. (The RTCM methodology follows this approach is to measure range corrections and range rate corrections for each satellite used in the position estimate.)

GPS Positional Accuracy

The Standard Position Service (SPS) was designed for a horizontal accuracy of 100m (2 drms). Thus, 95% of the observations will be within 100m of their true location with 99.99% of the observations within 300m of their true location. The vertical accuracies are 140m (2 drms). Precise Positioning Service (PPS), primarily available only to military users, provides 21m horizontal accuracy (2 drms).

Each of the system, configuration, and environmental error sources accumulates to the total error in the derived location. An estimate of the relative magnitude of each individual source is shown in Table 1. Selective Availability, when activated, introduces the largest error in the location. The positional accuracy from GPS derived measurements depends on a number of geometric and environmental factors as well as the capabilities of an individual receiver. Furthermore, as with all statistical distributions, by taking repeated measurements at the same location, the positional estimate may be improved. Some users claim unbelievably accurate results while others claim rather poor positional estimates. Empirical estimates from a variety of sources have been summarized in Table 2. This project uses GPS to obtain the position of a moving vehicle. Because the vehicle is moving, the position cannot be estimated by repeated fixes at the same location. To our knowledge, there has been little empirical work evaluating the positional accuracy from a moving vehicle.

Table 1: Error Budget Table Using Block I Satellites

Error Source	**Error**
Satellite Clock Error	2 feet
Ephemeris Error	2 feet
Receiver Error	4 feet
Atmospheric / Ionospheric	12 feet
Worst Case S/A	25 feet
TOTAL RMS	15-30 feet
	(depending on S/A)

The above RMS must be multiplied by the PDOP value which usually ranges from 1 to 6.

Total RMS (good receiver)	60-100 feet
Total RMS (S/A)	350 feet

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* Taken from Trimble product literature.

Table 2: Estimated Errors in GPS SPS Derived Positions

Method	Accuracy(RMSE)
Single Fix (2-D)	25m
Single Fix (3-D)	30m
Averaged[1] (2-D)	15m
Averaged (3-D)	20m
Averaged (X-Y-Z)	25m
Averaged Differential (2-D)	5m[2]
Averaged Differential (3-D)	10m
Averaged Differential (X-Y-Z)	15m
Dual Frequency	1m
Carrier Phase	<1m

[1] Averages are with 25 points.
3-D means that you do not have an estimate for the altitude.
[2] Some vendors quote 1m for differential accuracy. The accuracy can vary greatly depending on the quality of the receiver.

Hardware Characteristics

GPS receivers come in several hardware forms. Common forms are "hand-held" while survey-type receivers are more cumbersome. Many companies now offer the basic GPS technology on a small waferboard to be put into aftermarket packages, such as vehicle navigation systems. Each of these GPS forms typically provides different fundamental components C power, software, input data, and output capabilities. As mentioned earlier, the receivers vary by how many satellites are simultaneously tracked. For some applications, the storage capacity (i.e., number of points) is of considerable importance. Additionally, GPS receivers have predefined protocols for the input/output data streams.

The common hand-held GPS receiver typically has a serial port for RTCM SC-104 computable differential correction input. The same serial port could be used as a means to output collected positions. If only one port is provided, then real-time differential corrections cannot be simultaneously made and output. Most hand-held GPS units and all other survey and motherboard PGS-based units have an input port for an external GPS antenna. The GPS antennae "built-into" hand-held units are usually adequate for many applications. However, for operation inside a moving vehicle and for added reception capabilities, an external antenna is desirable.

For operational use, the protocols for input (differential signals) and for output (derived GPS measurements) are a major consideration. GPS receivers that have differential input capabilities normally accept the RTCM SC-104 signal protocol. There is a greater variety in the output formats produced by the GPS receivers. Many of the receivers can output proprietary formats that may only be read by using proprietary software links (e.g. DDLs, linkable object code) or links embedded in other applications (e.g. plug-and-play tracking software). Some older GPS receivers, in particular, only produce output coordinates only in a proprietary form.

Differential Correction Service

There are several private companies and one Federal Agency that offer differential correction service. Each of these companies provides receivers as well as the subscription service. Of particular interest to the user is the geographic coverage, quality of the derived estimates of the range errors, and cost of the service.

U.S. Coast Guard

The U.S. Coast Guard is building a DGPS service that will broadcast the necessary pseudorange corrections over marine radiobeacons. This agency makes use of two Ashtech Z-12, dual frequency, 12-channel receivers per site (for redundancy reasons). Estimates of error differences associated with the NAD83 coordinate system are made. The corrections are broadcast over the Radio Technical Commission Maritime (RTCM) Special Committee 104 Version 2.0 format (i.e., the RTCM-104 acronym). The corrections may be received free of charge to all users. However, the GPS receiver must be linked to a receiver capable of receiving the broadcast at 4800 baud. The Coast Guard network of receivers covers the coastal US and the major inland navigable waterways (e.g. Mississippi and Great Lakes).

The Coast Guard's differential GPS (DGPS) program has been fully funded by Congress and is due for completion in 1996 with over 120 radiobeacon stations covering the U.S. coastal waters and the Great Lakes. Depending on the specific radiostation, the same signals can be received inland at distances up to 100-150 miles.

The Federal Aviation Administration (FAA) and U.S. Coast Guard (USCG) have recently (March 15, 1994 for USCG) approved use of GPS for navigation purposes. Aircraft operators can employ GPS under FAA guidelines to provide primary navigation as along as another navigation system is on board and operating. Differential geo-positioning service may eventually replace the microwave landing system (MLS) currently used by the FAA for approaches to airports.

Differential Corrections Incorporated

Differential Corrections Incorporated (DCI) broadcasts corrections over a FM subcarrier (actually the same as Accqpoint). The output from their receiver is RTCM 104. Subscription to the DCI service is approximately $600 annually plus the data receive. There is no activation fee for their service. Each receiver is $375 - a portable receiver (about the size of a belt pager) and a vehicle receiver (a car antennae). The rate of differential broadcasts is about once every 2 seconds.

For applications that do not need the higher accuracies, DCI offers "truncated data" at a reduced subscription cost: 10m - $75year, 5m - $250year, 1m - $600year. However, to fully accommodate the high precision data for the increased accuracy, a high quality GPS receiver is required (e.g., Pathfinder Pro-XL about $9-12,000).

In the summer of 1995, 90 DCI broadcast stations were operational. Around 350 stations will be required for full coverage in the United States. DCI hopes to have this coverage in about 18 months (i.e., the spring of 1997).

OmniStar

The OmniStar differential correction service system uses data from 12 base stations in the U.S. and transmits the differential data through a satellite to most of North America. At each of the 12 base stations is a Trimble 4000 receiver. (Each Trimble 4000 receiver is about $15,000). The range errors for each satellite are computed. Also, the range error rates are derived. These data are then transmitted over leased lines to the network control center. The error data are then transmitted to the SATCOM3 (S3) satellite at 87 degrees west longitude. (The company owns the $8 million 72MHz transponder.) The satellite then rebroadcasts the data from all 12 stations on the 4GHz C-band to most of North America. A new set of data is broadcast every 2.5 seconds. The differential error measurements are actually about four seconds old by the time they make it to the receiver.

The hardware includes a low-noise amplifier and down converter with a 1" high omnidirectional antennae. The OmniStar antennae will work with moving vehicles and aircraft and is not affected by velocity. Using data from all 12 base stations, the range errors and range error rates are then used in an inverse distance weighted solution to estimate what the range errors and rates would be at another location.

The ionosphere/tropopause effects are also derived for each base station location and these effects are estimated for the location in question. The OmniStar correction method requires the user supply an approximate location for the GPS receiver (i.e. an estimate within 50 - 100 mile of the true location). One way of estimating the location is to initialize the system with a value and then feed the output signal from the GPS back into the OmniStar correctional system as an estimate of the geographic position. The RTCM 104 method of estimating the single differential error at the given location is then computed. A single differential value is output regardless of geography. The real-time accuracy for the OmniStar differential derived positions is claimed to be about 30cm horizontal and 70cm vertical (RMS) if a good receiver is used (e.g. Trimble 4000).

The geographic coverage for the differential satellite broadcasts is most of North America. The satellite is only 3 degrees above the horizon at Anchorage; thus, the data cannot be reliably received. For the Oak Ridge Reservation (ORR), the satellite is approximately 50 degrees above the horizon.

The hardware cost for the OmniStar system is $4,000 and the annual service is $3,000 per year. The OmniStar system is appreciably more expensive than either DCI and Accqpoint. The company has been broadcasting since 1987 (formerly called Starfix).

Accqpoint

Accqpoint is a second company offering broadcast differential corrections. Accqpoint offers a Wide Area DGPS service comprising two satellites and 450 FM stations for North America. The Accqpoint receivers generate RTCM 104 compatible corrections at 9600 baud. The costs for the system and service are a one-time connection fee of $100, a receiver (about $350), and an annual service fee of $600. Discounts for volumes over 25 reduce the service fee to $500year and an $80 activation fee. Any GPS receiver will work with the FM differential receivers as long as the GPS receiver allows RTCM 104 compatable input.

For land use, the signal strength is only good to about 30 miles. The signal is basically line-of-sight dependent. The age of the differential error is between 10 and 12 seconds.
The three receiver types provided by Accqpoint are a data pager and a radio card. The data pager is a self powered unit (1.5 volt AA cell) that connects directly to the GPS unit via a DB9 or similar connector. The data pager has an internal antenna. The unit will decode RTCM-104 transmissions, transferring them to the GPS unit in real time. The Delta 200 unit (12-21 VDC 3 watts) allows for an external antennae (about 12"). The radio card is for EOM applications. This unit is suitable for embedding in dedicated GPS systems and is available for OEM applications. The unit incorporates several control features offering the EOM several service and fee structuring possibilities. As with all our receiver units this is a frequency agile unit, tuning automatically to the nearest transmission and re-tuning when a stronger (closer) signal is present. Accqpoint buys data from the OmniStar base stations and rebroadcast from local FM stations. Accqpoint uses their own algorithms for estimating rates and corrections in errors. The Accqpoint service is focussed on the market interested in accuracies no higher than 1m. Unlike the 12 station data broadcasts by OmniStar, Accqpoint only rebroadcasts one differential correction data locally.

Inmarsat

Inmarsat has negotiated with three companies to offer transmission of wide area integrity messages, differential corrections, and ranging signals for both the Russian Global Navigation Satellite System (GLONASS) and GPS satellites. The first Inmarsat satellite was scheduled for launch in 1995 but may not be launched until 1996.

Qualcomm Automatic Satellite Position Reporting (QASPR) Positioning Methodology

The Qualcomm Automatic Satellite Position Reporting (QASPR) system replaced the use of LORAN-C for positioning of mobile vehicles in their OmniTRACS reporting and receiving service. This system became operational in 1990. Qualcomm claims that approximately 120,000 units have been placed on rails, tugs, fishing fleets (Northeast), state police, and emergency service vehicles. The Qualcomm positioning system triangulates using two geosynchronous satellites (22,600 miles altitude and a 24 degree separation) B the K-1 and GSTAR-1 GE satellites. These two satellites behave as a "data" satellite (GSTAR-1) and a "ranger" satellite (K-1). Every 15 seconds a synchronized timing signal is sent from the "ranger" satellite. Each time the vehicle is polled (at least once per hour), the data satellite sends out a range signal that is matched with a range signal from the "ranger satellite." The round-trip delay time between the two signals is computed at the San Diego based operations center. Two range positions are not sufficient for determining a precise location. In fact, there are a number of positions that are for the intersection of two spherical shaped ranging signals. However, the correct position must be on the surface of the earth. A modified model of the earth's surface is used to derive the range from a third location (i.e., the center of the earth). The ellipsoidal model of the earth is modified using a digital elevation model to improve the estimate of the vehicle's distance from the center of the earth.

Similar to the GPS, the Qualcomm positioning system requires "line-of-sight." The ranging signal cannot penetrate most materials. Thus, obstructions like terrain and tree cover can block the ranging signal.

The geographic coverage of the positioning system is the contiguous 48 United States. The positioning service also extends several hundred miles out from the coast, enabling near-shore ocean vessels to be tracked.

Qualcomm's service automatically polls once every hour. The user may poll the vehicle more than this hourly interval. When either Qualcomm polls the vehicle or the vehicle operator is ready to transmit message, signals from both the ranger and data satellites are collected. This information is sent back to Qualcomm in San Diego and related to the estimated elevation (range of vehicle from Earth's center) and a geographic position determined. The accuracy of this positioning system is approximately 800-1000'. The entire polling and transmittal process takes about a minute.

Hardware

The 11-lb. antennae used in the reception/transmission of messages contains an electric motor that directs the antennae towards the data satellite at all times. The signal is broadcast over the KU band. Power requirements are 30 watts/12 volts for transmit (Note: other documentation suggest that 60 watts are required), less for reception.

Service Costs

The costs for the dual positioning/communication system is an initial $1500 installation (for setting up the communication channels), $25month service fee and an $8hour (or 13 cents per minute) long-distance telephone toll. The hardware charges for the receiver/transmitter and keyboard are approximately $4,000. One position fix per hour is included in the service charge. For additional positioning fixes, there is a $.05 charge per fix. If a position fix is obtained through a one-minute phone call, the position will cost 13 cents. If multiple vehicles are tracked by the service, essentially all the vehicle positions may be retrieved in the same long-distance call.

Although the QASPR does not use GPS for deriving positions, a GPS may augment their basic service. GPS information can be incorporated into the header for the message string. Basically, the position data simply replaces the QASPRS derived position information in the header.

Considerations for Tracking Moving Vehicles

The use of carrier phase tracking typically requires several minutes of correcting to "lock on " to the signal. This impediment results in an impracticality for moving vehicles. Differential corrections are used for the same sets of satellites observed by those by the base receiver and those by the moving receiver. For the same satellites to be in view, the receivers must be in close proximity. The further the receivers are apart, the more different the geometric configuration of satellites. Another important consideration is that the GPS position estimates are for the antennae, not the receiver. The GPS positions use the WGS-84 ellipsoid. The vertical positions using this ellipsoid can be greater than 100m different than those based on mean sea level (MSL). When a GPS receiver is initially turned on it takes at least 30 seconds (more often greater) to acquire the first position fix.

An advantage of using the differential correction data from a system like OmniStar is that the uncorrected GPS data from a remote vehicle can be corrected at the command center because all of the differential errors from 12 dispersed base stations are broadcast. Thus, a remote vehicle in California could be differentially corrected at ORNL. The remote vehicle would not need the differential receiver and hardware.

The QASPR system cannot be used on aircraft because the transmitter is not aerodynamic and a Doppler shift problem will occur for message transmission at speeds over 150mph.

The unique capabilities of Qualcomm's service is the two-way message passing through an existing satellite-based telecommunication's infrastructure. The transfer of location and other limited messages and or sensor data may be performed with this commercial system. For each poll on the vehicle, a 1900 character message string (plus the position and timestamp in the header) is transferred.

The QASPR system from Qualcomm is extremely attractive for tracking vehicles as the infrastructure for transmitting the position is in place. Also, some limited messages may be passed with the position and timestamp. Unfortunately, the data rate for transmitting these data is relatively slow about 150bps (see Section 4). These data rates are not sufficient for the transmission of video imagery or video stills.

Section 3: AUDIO/VIDEO CAPTURE

The collection of audio and video data from a remote vehicle involves determining the desired data quality, data sampling rates, and hardware/software costs for data collection. These data collection factors must be tempered with the limitations of the wireless transmission technology used. The transmission rates will be further discussed in the next section, but for now, we simply indicate the rates are limited to a few thousand bytes per second.

Capture Hardware Video

Video imagery is best described as a temporal series of still images collected over some interval of time. The characteristics of each still image include image size, monochrome or color, and monochrome or color resolution. The fundamental characteristic of the temporal series of images is the frame rate, or number of images captured per unit of time. A discussion of digital video imagery is somewhat different than the original medium of video that is analog. For the purpose of this project, video data will be described with digital characteristics.

Analog video data (NTSC standard) has a vertical resolution of 525 lines (some of which do not contain picture information) and a monochrome horizontal resolution of 450 lines. Each frame is composed of 2 fields: the first and second field shaving odd and even horizontal lines, respectively. Color information is encoded as color difference components (red - gray and blue - gray). Color resolution is much lower; e.g., red has a resolution of about 55 horizontal lines. Thus, using an analog-to-digital conversion at a higher resolution than the inherent resolution in analog data is redundant. Common analog-to-digital conversions of each video frame are 640 rows by 480 columns and 320 rows by 240 columns. A digital version of a frame at the lower resolution contains 1/4 the number of pixels (i.e. picture elements) as a frame recorded at the higher resolution.

Video data is recorded in either grayscale or color. The differences between each rendition not only affects the appearance of the image but also the size of the digital image. Each pixel in a black/white video frame may contain one of 256 different gray tones while a pixel in a color frame may be one of 16.8 million possible colors. The color depth determines the number of possible gray tones (in B/W imagery) or colors. Eight-bit color depth is used to represent 256 possible tones or colors per pixel, 16-bit for 32 thousand colors and 24-bit for 16.8 million colors.

A digital video image containing 320 columns by 240 rows at 24-bit color depth requires 230,400 bytes of storage (Table 3). At the typical 30 frames per second video acquisition rate this would result in 6.9 MBytes per second, or 55 Mbits per second (Mbps) if all data were transmitted. These data magnitudes will be a severe restriction on the amount of video data that may be transmitted. Such limitations will also encourage judicious selection of a color depth representation and frame rate.

Audio

The fundamental characteristics of sound representation include the number of channels (i.e. either mono or stereo), pitch, and loudness. A mono sound stream may be digitally represented by a sine wave. Pitch is depicted by the frequency of the wave and loudness by the wave height. Two time-sequenced mono sound streams represent stereo sound.

A digital sound file stores samples of this waveform at a specified sample rate and quanitization. Typical sampling rates range from 8 to 44 kHz, where a higher rate produce higher quality sound representation. An 8 kHz rate produces 8,000 digitized samples per second. Each sample is then recorded as an 8-bit or 16-bit encoding scheme, where 16-bits results in a better quality representation. In stereo sound, the sample for the two channels are interleaved, resulting in a single file containing two audio channels.

The five common compression schemes used for sound files are CCITT A-Law, CCITT m-Law, Adaptive Differential Pulse Code Modulation (ADPCM), MACE, and MPEG. The CCITT compressions use special analog-to-digital and digital-to-analog converters having step-sizes that decrease logarithmically with signal level to compress the dynamic range into 8 bits. ADPCM encodes only the difference is signal levels on adjacent time samples. The compression ratio for the A-Law and m-Law is approximately 2:1 while the compression ratio for ADPCM is about 4:1. MACE and MPEG use multiple band-pass filters to optimize noise masking by selectively encoding each filter's signal into a variable number of bits (Shlien, 1994). MPEG can compress two channels of 44 kHz sampled 16-bit sound to 128 kbits/sec without obvious artifacts (compression ratio of 11:1) (Fogg, 1995). MACE allows compression ratios up to 6:1. Hence, MACE can encode 8-bit audio into only 1.3 bits (30 kbits/sec for a 22 kHz sampling rate). Such low data rates do have audible artifacts, but speech is intelligible.

Table 3: Raw Video Image Size

Spatial Resolution	Color Depth	Frame(s) per second	File Size (thousand of bytes)
320c x 240r	8-bit B/W	1s	76.8
	16-bit Color	1s	153.6
	24-bit Color	1s	230.4
640c x 480r	8-bit B/W	1s	307.2
	16-bit Color	1s	614.4
	24-bit Color	1s	921.6
320c x 240r	8-bit B/W	30s	2,304.0
	16-bit Color	30s	4,608.0
	24-bit Color	30s	6,912.0
640c x 480r	8-bit B/W	30s	9,216.0
	16-bit Color	30s	18,432.0
	24-bit Color	30s	27,648.0

Time Stamping

It is desirable to time-stamp an audio or video transmission so that the time an event occurred can be determined. It is then possible to correlate the video with vehicle position. There are several ways to encode time stamping. It can be encoded as part of the NTSC analog video, by the video compressor, or by separate data.

SMPTE Time Code

The Society of Motion Picture Engineers (SMPTE) has two standards for time encoding on analog video. These are designed for synchronizing and locating scenes during videotape editing. This is normally an elapsed time rather than absolute time and is encoded once or twice a second.

The older standard encodes time by a series of variable width pulses recorded on a spare audio track or a special address track. The time-code is an 80-bit word for each frame. The first 58-bits are used for encoding time in hours, minutes, seconds, and frames. Each of the four time units are encoded as binary-coded-decimal (BCD) and 4 bits separate each decimal digit. Note that the tens-of-hours digit is only encoded as 2-bits since the maximum value is only 2 (Swetland, 1978).

The newer technique encodes time directly on the video signal during the vertical interval between frames or fields. The time is encoded as a 25-bit binary word (Racelo, 1984). Also, there are options of correcting for the NTSC frame-rate not being exactly 30 fps. One option is to occasionally decrease the interval between times stamps by a frame (about 1 out every 1000 frames), while the second option is to hold the interval constant and allow a -0.1% clock error to accumulate (about -4 seconds per hour) (Swetland, 1978).

Compressor Time Code

When the video signal is compressed, the SMPTE time code may be lost. Fortunately, most of the standard compression schemes support encoding of time data either directly (MPEG) or as part of the computer's video compression support (e.g. QuickTime). QuickTime encodes time to arbitrary accuracy (normally 0.01 sec.) (Apple Computer, 1993a). It does this by default to synchronize sound with video. MPEG allows a time code with the SMPTE vertical interval format to be placed in a header just before the picture header (Fogg, 1995).

Separate Time Code

Sending the time of occurrence as separate data is the simplest approach. Even with the preceding time codes, at least one separate time data may be needed. Since the compressor and SMPTE time-codes are elapsed times, and start time must be sent so that absolute times of individual frames can be calculated. Since the compressor and SMPTE time-codes are typically elapsed times, start time must be sent so that absolute times of individual frames can be calculated. Separate time codes are especially appropriate for slow frame rates.

Time Calibration

Regardless of which approach is taken for time stamping, a means of calibrating the times is needed. For extremely low frame rates, simply setting the remote computer's clock manually is adequate. Were greater precision is needed, a host clock can be used to periodically send the correct time to the remote computer to automatically recalibrate the clock. This host clock could be the host workstation. In applications where GIS satellites are used to locate the vehicle, time-calibration can be obtained from the GIS satellites.

Moderately priced equipment is available to encode time received from a GIS satellite onto the video signal. This would be useful when video is recorded onto a video cassette recorder (VCR) for later playback at the host computer location or for later transmission. The VCR could store 30 fps video, and selected scenes could be transmitted over low-bandwidth channels at low frame-rates over a longer period of time. Then, the selected scene could be played back at 30 fps at the host computer. For example, a 4 second scene at 30 fps would take 5 minutes to transmit over a channel having a maximum frame rate 0.4 fps.

Video Compression Methods Lossy Vs Lossless

The fundamental characteristic of an image compression algorithm (whether still or video) is the objective of either compressing the original image without information loss or with an allowable amount of information loss. The former objective would require using a lossless image compression scheme while the latter objective could make use of a lossy scheme. A lossless scheme results in an image that retains the "fundamental" spatial/spectral information of the original scene while discarding some of the information. Not surprisingly, a lossless scheme usually results in a compressed file size that is not as efficient as a scheme that allows some loss of information. Most lossy schemes allow variability in how much of the information is fundamental to the interpretation of the scene. Thus, a compression scheme may "lose" a lot of the original information (with a corresponding significantly smaller file size) or only a little information.

For several decades, a number of lossless image compression methods have been developed and used for compressing still imagery, such as remotely sensed images of the earth's surface or raster-based GIS files. Familiar compression methods are run-length encoding, quadtree encoding, and wavelet transformations. The characteristic image in the remote sensing and GIS applications is typically much larger (i.e. thousands of rows and columns) than the standard video images of a few hundred rows and columns. Further, unlike video imagery, the imagery in remote sensing and GIS applications rarely involved multiple observations of the same or similar scene over small increments of time.

The objective of compressing video imagery is more recent than that of remotely sensed imagery. Thus, the selection of compression methods is continuing to expand. There are a number of variants even for a single compression method (e.g. JPEG). Some compression schemes may be either lossy or lossless. For example, the Joint Photographic Experts Group (JPEG) compression scheme may be either a lossless or lossy scheme.

A key indicator of the efficiency of the compression algorithm is the compression ratio C a ratio of the compressed file size to the original file size. A compression ratio of 20:1 indicates that the compressed file is only 1/20th the size of the original file. Thus, a compression ratio of 100:1 is considerably more efficient than a compression ratio of only 5:1.

Another important indicator of compression schemes is the speed of compression/decompression. For real-time applications of acquiring and displaying video imagery, the compression scheme must quickly compress the imagery for storage or transmittal and decompress the imagery for display. Recently, very efficient hardware compression/decompression schemes have become available.

The compression ratio and speed of compression/decompression are inextricably linked. Suppose a compression scheme with a high compression ratio requires a longer time to compress an image than another compression scheme that produces larger files. The savings in transmission costs of larger files may offset this cost in compression times.

Finally, the nature of the imagery will ultimately affect the speed and compression efficiency of the compression scheme. Images of fairly homogenous scenes may be compressed to very small file sizes. With video imagery, scenes that rapidly change over time cannot be compressed with the efficiency that video imagery of more stable scenes. Even by varying the frame rate of a video sequence, the compression ratios may decrease. To obtain a more uniform data rate, a frame buffer can be used. The more frames a buffer can hold, the more uniform the data rate. However, a frame buffer will delay transmission of video frames (Pancha and Zarki, 1994).

Joint Photographic Experts Group (JPEG)

The Joint Photographic Experts Group (JPEG) image compression scheme was one of the first and most common schemes for compressing video imagery. The resolution of the color difference components are cut in half since the eye determines images detail mostly from the grayscale component. This allows a color image data reduction of 2:1 before spectral compression is done. JPEG compresses each frame of an image by encoding the gray value or color of "blocks" of the image with similar spectral characteristics. Thus, JPEG compresses imagery by analyzing only the spatial dimensions (adjacent rows and columns) within a single image or frame (Lei and Ouhyoung, 1994). Thus, JPEG is an intraframe compression method. JPEG compression may result in compression ratios of up to 100:1.

Moving Pictures Expert Group (MPEG)

The Moving Pictures Expert Group (MPEG) compression scheme analyzes the redundant information within a frame (as does the JPEG scheme) and the redundant information between successive frames. Similar to JPEG, MPEG also uses intraframe compression but also employs interframe compression. In simple form, MPEG stores all the information in an initial frame but only records the information that changes in successive frames. Thus, compared to JPEG compression, MPEG compression can result in a further reduction in compressed file sizes (Fogg, 1995).

Video

The Video compressor is a proprietary compression scheme developed by Apple Computer for use in compressing QuickTime movies. It can use both interframe compression and intraframe compression and makes greater use of the reduced color resolution in NTSC video than JPEG and MPEG. With intraframe compression, compression ratios from 5:1 to 8:1 can be obtained on color video with reasonably good quality. Compression ratios range from 5:1 to 25:1 can be achieved with both interframe compression and intraframe compression (Apple Computer, 1993b).

Cinepack

The Cinepack compressor is a proprietary compression scheme developed by Radius and Adobe for use in compressing QuickTime movies.

Animation

Apple Computer for use in compressing QuickTime movies developed the Animation compression scheme. It uses run-length encoding and is lossless at high quality settings. It is best used for computer graphics. Compression ratio is highly sensitive to picture content and is greatly reduced by picture noise.

Empirical Comparisons

Three factors are important when considering which compression scheme is best: speed of compression and decompression, compression ratio, and image quality. Of these considerations, a high compression ratio is mandatory for real-time motion video.

The original video of space shuttle docking was captured as 320x240 pixels with 16-bit color depth. The movie was saved to disk before compression to avoid problems with compression time. Note that "YUC" has no compression while "None" is the theoretical rate for no compression. Except were noted, the quality setting was medium. No compression would result in a data rate of 5.5 Mb/s.

Compression 1 achieved a compression ratio of nearly 4:1. The default settings on Compression 2 (resulted and a disappointing data rate of 3.4 Mb/s. This result was obtained with intraframe compression only and with each frame repeated six times to obtain an output frame rate of 24 fps. A data rate of 1.1 Mp/s was obtained with and output frame rate of 8 fps. When interframe compression was used and output frame rate dropped to 4 fps, data rates dropped as low as 333 kb/s (i.e., compression ratio greater than 16:1). Using just the past and present frames (PI) for interframe compression increased the data rate about 30% over using both past, present, and future frames (BPI).

Compression 3 compression resulted in a data rate of 853 kb/s. Compression 4 compression produced a data rates of 1381 and 662 kb/s for medium and low quality (LOW Q) settings, respectively. Compression 5 compression yielded data rates comparable to or better than Compression 2, i.e., 391 kb/s and 223 kb/s in medium and low quality settings, respectively. The latter was the highest compression obtained in this test (i.e., compression ratio greater than 24:1). However, the low quality image was noticeably degraded.

All of the compression schemes can be accomplished with software, but some of these are too slow to compress and decompress video in real-time. There are accelerated hardware solutions for Compression 3, Compression 5, and Compression 2. While low-cost hardware decoders for Compression 2 are available, fast hardware Compression 2 compressors tend to be expensive.

The ratio of the number of frames and the compression time gives the sustained compression frame rate. Compression 4 and Compression 1 were the fastest compressors at 1 fps. Compression 3 was the second fastest compressor at 0.5 fps. Compression 5 compressed at 0.25 fps at all quality settings. For 4 fps, Compression 2 compressed at 0.25 and 0.17 fps for PI and BPI compression, respectively.

The proceeding tests were done with slowly changing video at slow frame rates. Tests with video shot from a vehicle moving at 50 mph were conducted with Compression 2 compression at high frame rates and two different picture resolutions. A 320x240-pixel video with 16-bit color depth was captured at a rate of 30 fps. Without compression, the data rate 14.8 Mb/s. The same video was captured at 20 fps and Compression 2 compressed at two output frame settings. Data rates of 947 and 562 kb/s were obtained (i.e., compression ratio greater than 15:1 and 26:1) with the best and 8 fps settings, respectively. Then the video was captured at 30 fps and 160x120 resolution. The data rates were 8.5 Mb/s and 221 kb/s without and with Compression 2 compression at the best frame rate setting, respectively. Thus, a higher compression ratio greater than 38:1 was obtained with the lower resolution image.

Conclusions

As will be discussed in Section Four, a constraint on monitoring a remote vehicle is the transfer rate of digital data over the wireless communications network. Existing infrastructures for wireless communications are fairly low, typically measured in the thousands of bytes per second. Because of this constraint, it is highly desirable to compress the audio and video data before transmission.

Compression 2 compression should normally be superior to Compression 3 compression for video imagery. However, Compression 2 compression typically requires a longer time to analyze the image frames than Compression 3 compression. Furthermore, if only stills (i.e. one image every so many seconds or minutes) from a video sequence will be transmitted from the remote vehicle, the use of Compression 2 compression is not effective. For typical voice recording, the lesser quality sampling rate of 8 kHz and 8-bit digitization of audio is sufficient. If frame rates above 1 fps are desired, then software compression is too slow for this vehicle-tracking project over available communication lines. There are several hardware image compression boards available. While low cost hardware for Compression 2 decoding exists, real-time compressors tend to be expensive. Most low cost boards use Compression 3 compression. Such boards can compress 640x480, 24-bit color video at 30 fps to data rates between 8 and 16 Mb/s. However, prices on hardware compression are rapidly falling.

Section 4: WIRELESS DATA TRANSMISSION

The portion of the system responsible for moving the data between the remote vehicle and the central site is the wireless transmission subsystem. This section identifies the characteristics of the wireless subsystem and presents the alternatives considered to meet the requirements of the overall project. The final paragraph describes the configuration selected for the prototype system.

Transmission Characteristics

There are many transmission characteristics important to wireless data transmission. These characteristics are frequency/bandwidth of channel, analog/digital information, geographical coverage or signal strength, transmission rate of the signal, hardware needed for transmission, and service providers available for wireless transmission. Frequency is important in wireless data transmission because it determines the propagation distance of the transmission. The bandwidth is the information capacity of each channel at a specified frequency.

Analog signals are continuous and can have infinite values of amplitude over time. Therefore, both amplitude and frequency characterize analog signals. There are many existing forms of transmitting audio and video data in analog form ▯ AM, FM, television, and cellular voice. We are specifically interested in the transmission of audio, video, and geographic position data in digital form rather than analog form.

The third transmission characteristic is geographical coverage of a wireless data service. Coverage is the availability of the channel or service to transmit over some geographic area. For example, most digital wireless transmission methods are limited to 50 miles or less and are essentially line-of-sight (e.g. a cell in cellular has a coverage of only a few miles). However, if the service provides automated linkages between cells, the transmission may be sent over much larger areas. By combining a wireless method(s) with landlines, the method may be used for continental or even global applications. During wireless transmissions terrain and weather conditions affect the signal strength. Our transmission alternatives had geographical coverage from line-of-site (2 miles) to global depending on the service provider.

Another important characteristic of wireless data transmission is the transmission rate. The transmission rate of a signal is the speed in which the data transfers across the channel provided. The cost of the transmission service is closely tied to data transmission rate. The greater the transfer rate the more expensive the service. Also there are delay times associated with transmission of data, which need to be evaluated. The delay time for transmission/reception of a satellite hop is 250ms to 500ms whereas the delay time for a cellular transmission is less than 10 seconds.

The fifth characteristic of wireless data transmission is hardware. This is the physical characteristic of the transmission or the equipment needed to make the transmission over the channel. The hardware used must take into account the format of the data being transferred. For example, INMARSAT terminals and antennas are bulky and the equipment is costly to purchase or lease, and operate. Cellular equipment is small and portable but spotty coverage is often a concern due to terrain and weather conditions.

The last wireless transmission characteristic to evaluate is the service provider. The service providers are the companies whose business is to provide a channel or multiple channels for communication access. Depending on the data rate and availability of a service, a service charge is assessed. Cellular and satellite service providers have a monthly fee along with a per minute transmission fee.

Transmission Alternatives

This section is a comparison of transmission alternatives for Wireless Data Transmission. The following tables compare radio frequency (RF), cellular, personal communication system (PCS), Inmarsat, Qualcomm's OmniTRACS, Ardis Wireless Network transmission systems with transmission characteristics (frequency/ bandwidth, analog/digital, geographical coverage, transmission rate, and hardware).

In summary of tables 4 and 5, it is evident that the first method of wireless transmission, radio frequency transmissions, are line-of-site transmissions. Such transmissions are typically restricted to within a few miles. Radio frequency transmission requires two units, a transmitting and a receiving unit.

The second method of transmission, cellular, has spotty coverage in some areas of the nation due to terrain and structural interferences. Cellular also experiences handoff zones when a moving vehicle switches from one cell-site to another. These handoff zones can cause a loss in connection. With cellular service, as you travel through difference sections of the United States you will acquire roaming charges for the use of non-home cellular system. These roaming charges can range from \$2 - \$8 per call.

Company H will not be commercially available until 1996. PCS will be fully digital, less expensive than cellular, and use lower transmission power. It is not clearly defined yet whether this service will be global or national. The "cells" in PCS will be smaller than the existing cellular systems.

The fourth method of wireless transmission, satellite service, covers a wide geographical area but poor weather conditions or large structural obstructions can affect transmissions. Inmarsat Land Mobile Satellite equipment is bulky and expensive to operate. The Land Mobile Inmarsat terminals will not operate from a moving vehicle because the antenna will loose satellite positioning and signal as the vehicle changes location. The Qualcomm OmniTRACS satellite equipment uses such a low transmission rate (i.e., 150 bps) that video and audio files could not be sent via this method. The fifth wireless transmission method, the Company J Network, requires up to a six-second delay for real-time conversation. This service is widely available in the U.S. but requires a modem and service agreement for access. A monthly bill on Company J can cost from \$39-\$299 per month. Mobile personnel for E-mail and Interned access basically use the Company J system.

Table 4: Characteristics for Each Wireless Communication Alternative

TRANSMISSION ALTERNATIVES	FREQUENCY	BANDWIDTH	FORM	GEOGRAPHICAL COVERAGE	TRANSMISSION RATE
Airlink products by Cylink (RF)	ISM frequencies, L-band (902-928 Mhz), and S-band (2.400-2.483Ghz)	26 Mhz, L-band 83Mhz, S-band	analog	line of site, 30 miles maximum	64,128,256,384,512 Kbps voice, 19.2,64,128,256 Kbps
Sierra Digital Medium Haul Video Link Microwave Radios (RF)	31.0 - 31.3 Ghz	300 Mhz	analog	2 miles	500 Kbps
Cellular	900 Mhz		analog	national	not defined yet
Company H	2 Ghz for wireless PBX		digital	national	less than 14.4 Kbps
Inmarsat A (Satellite)	L-band 1636.5-1645 Mhz	8.5 Mhz	analog	global	56/64 Kbps
Inmarsat B (Satellite)	L-band 1636.5-1645 Mhz	8.5 Mhz	digital	global	56/64 Kbps
Inmarsat M (Satellite)	L-band 1636.5-1645 Mhz	8.5 Mhz	digital	global	2.4 Kbps
Qualcomm (Satellite)			digital	national	150 bps

Table 5: Hardware Characteristics for Each Wireless Communication Alternative

TRANSMISSION ALTERNATIVES	HARDWARE
Airlink products by Cylink (RF)	transmitter and receiver (4 lbs.) transmitter and receiver (8 lbs.)
Sierra Digital Medium Haul Video Link Microwave Radios (RF)	transmitter/receiver unit and 12" antenna
Cellular	cellular modem, cellular phone, laptop or portable personal computer Pentium
Company H	Available for commercial use in 1996
Inmarsat A (Satellite)	antenna and terminal 53"H x 49" W weight of 200 pounds
Inmarsat B (Satellite)	antenna and terminal 53"H x 49" W weight of 200 pounds
Inmarsat M (Satellite)	antenna and terminal 27"H x 24" W weight of 65-105 pounds
Qualcomm (Satellite)	antenna, keyboard and transmitter/receiver unit

Transmission Design

The constraints of the project restricted us to two types of channels for transmission of audio, video and position data B cellular and satellite. These two different types of transmission and their configurations are discussed further in this section.

It was recommended by the cellular service provider, Cellular One, that a three-watt cellular phone be used with our modem. Cellular One provided ORNL with a map of the Oak Ridge area with signal strengths defined for all major routes. The mountainous terrain in the location of the demo had some affect on the signal strength such that a 600mW flip phone would not generate enough transmitting power. Another difficulty with the flip-phone was the car battery adapter used the same connector interface on the phone as the modem did. This meant that the flip phone would have to run off. These nickel cadmium batteries last for one hour of talk time.

For the satellite transmission we used a Magnavox MX 2400T Plus Inmarsat-A transportable system. This system is comprised of two subsystems, the Electronic Unit and the Antenna Unit. These two units are connected via a single cable. The electronic unit contains the electronic console, printer and keyboard. The Electronic Unit is responsible for all processing, display and user input/output functions. The second subsystem, the Antenna Unit contains a power supply, L-band Electronic Unit and a parabolic dish antenna. The antenna is aimed at the desired satellite and transmits signals to, and receives signals from this satellite. The Antenna Unit receives power, intermediate frequency transmission information, and reference oscillator signals from the Electronics Unit via the interface cable.

The first subsystem, the Electronic Unit is composed of three units the electronic console, the keyboard, and printer. The Electronic Console has 10 subassemblies:

1) 120/240 detect panel-

2) Power supply- +5V, +12V, -12V

3) Main Processor board- Z80 processor

4) Receive/ Transmit board-contains all IF circuits

5) Planar Interface board- real time clock for time tagging

6) Interface board-acts as motherboard

7) Interface Adapter board-Interconnects Interface board, Planar Interface and R/T board

8) Planar display- electroluminscent display panel

9) Oven controlled crystal oscillator- provides sinusoidal signal @ 5 Mhz, the timing for all transmitted signals are derived from this oscillator.

10) Telephone- provides options such as, hands free speaker phone, automatic on-hook to off-hook, s

The second unit in the Electronic Unit is the keyboard. The keyboard connects to the Electronics Console via a permanently attached coiled interface. The third unit in the Electronic Unit is the printer. This printer is a □receive only□ dot matrix printer to be used during a telex call to print the received telex data, and also used to record the status of the MX 2400T PLUS.

The second subassembly of the MX 2400T PLUS is the Antenna Unit which consists of a L-Band Unit and an antenna dish with feedhorn. The L-band unit contains a power supply, a RF Processor, a duplexer, and a high power amplifier. This L-band unit interfaces to the antenna via a built-in coax connector and dismounting fitting. The duplexer part of the L-band Unit is a passive device containing two bandpass filters, one in the transmit signal path and one in the receive signal path. The RF processor in the L-band unit is comprised of four major functional areas, low noise amplifier, triplexer, frequency multiplier, and up and down converters. The High Power Amplifier (HPA) in the L-Band Unit amplifies the signals to be transmitted from the RF processor and then routes the signal to the duplexer. The antenna Dish of the Antenna Unit provides 20 dB of gain, which results in an effective isotropic radiated power (EIRP) of 4 Kw. The feedhorn accepts the reflected RF power from the antenna dish and feeds it to the L-band Unit.

Once the cellular transmission channel was determined we needed a modem for the data transmission. For the transmission we needed a fast cellular ready modem. We chose the Simple Technologies Communicator PCMCIA Type II card with data rates of CCITT V.34 (28.8Kbps). The data compression specifications were MNP-5 (with 2:1 ratio) and CCITT V.42bis (with 4:1). This modem has two types of error correction, one is CCITT V.42 and the other is MNP-4. The cellular portion of the modem uses MNP10-EC for error correction and data compression. The Simple Technology's 28.8 Communicator was described as the perfect way to stay in touch when on the road. The modem is also designed for hot swapping, which means while your computer is powered up you can plug this PC Card in without restarting your laptop. The modem's S-registers store important configuration information about the modem. Some S-registers provide status information only and cannot be written to, therefore they are read-only registers. The modem setting for all S-registers that could be written to were configured for the default settings, except for s37 and s10. S-register S10 controls the carrier loss disconnect time. This set the length of time that the modem waits to hang up the line after it detects a loss of carrier. S-register S10 is set for 244 which corresponds to 24.4 seconds before hanging up the line after the loss of carrier is detected. S-Register S37 controls the line speed and this register is set for 8, which corresponds to 4800 bps line speed.

Once the modem was chosen we needed the software to enable the modem to transmit the data. Three communication software packages were used for the data transmission these were Winsock, Trumpet, and FTP. Winsock was used for establishing the TCPIP protocol, Trumpet was used for the slip connection and login, and FTP was used for the file transfers.

Section 5: USER INTERFACE

The user interface for the command center displays relevant information to an operator and allows the operator to ask questions about the history and current state of all vehicles. The interface includes visuals (still and motion imagery), audibles, and allows interactive dialogue with the data. Real-time data transmitted from the vehicle(s) are automatically added to the appropriate databases.

Displayable objects in the GVCS include geographical views, tables, graphs, and images. The user requests information to be displayed and the appropriate object form is either created or an existing object is modified to depict the desired information.

Displayable Objects

Views

A view in the system is a cartographic map that may depict static information (e.g., aerial photography or transportation routes) or dynamic information (e.g. the moving vehicle). The initial display in the GVCS includes an overview window, zoom window, and button bars. The overview window displays the entire domain or "world" available to the user and his vehicle fleet.

For this project, the world is the coterminous United States. The zoom window displays a rectangular portion of the world and at some magnification. This "visible" portion of the world depicted by the zoom windows is depicted on the overview window by a rectangular box.

Tables

All of the attribute information in the databases are stored and may be displayed in tabular form. The tabular display is similar to a "spreadsheet" type of display. As discussed below, queries may be conducted on the tables and subsequently the cartographic views will depict the selected information.

Graphs

A graph is used to display a set of information that changes with respect to time. Example data types in the GVCS are data from onboard sensors, such as temperature.

Images

The still video images and weather imagery are displayed in image views. Although transparent to the user, the video clips are displayed using a secondary application (e.g. XV) that is called by the main system.

User Queries

Fundamentally, the kinds of queries that an analyst would be interested in may be characterized as an aspatial, spatial, or temporal query. An example aspatial query might be "What vehicles in the fleet may carry liquid hydrogen?" The result of an aspatial query would be a list of item(s) that match the aspatial characteristics (e.g., vehicles that may carry liquid nitrogen). A spatial query example would be "what vehicles pass through Tennessee?" The spatial query uses geographic location to subset all possible items. Furthermore, the spatial query may use a point, line, or area to define the geographic location constraint in the query.

A combination of aspatial and spatial queries might be "What vehicle shipments that carried liquid hydrogen passed through Tennessee?" Finally, a temporal query constrains the itemized list based on some interval of time. For example, "what vehicles are operating today?" is a temporal query.

Determination of the different types of queries desired will guide the design of the user interface and the database.

Implementation

One of the most complex and substantial investment decisions to make when developing a new GIS related application is which implementation tool(s) to use. The implementation tools may range from an existing GIS to new coding in a programming language, or some combination of these. Creating a system from scratch is not usually desirable and often not necessary.

However, a commitment to some form of existing system should be tempered by the stability of the system, robustness, and long-term vendor support.

For the GVCS, the ArcView 2 GIS interface was selected as the primary system to implement the desired functions and query interface. The primary characteristics for selecting ArcView 2 were:

- cartographic and remotely sensed image display capabilities,
- dynamic update of moving object locations,
- linkage with Arc/Info for expanding functionality,
- graphical User Interface (GUI),
- extendable user defined functionality through Avenue scripts,
- portability to Unix, PC, and Mac platforms, and
- callable user applications through Remote Procedure Calls (RPC).

Section 6: DATABASE DESIGN

Transportation Database

There are a number of sources for transportation related digital cartographic databases. Among these, the most prevalently used sources are Etak maps, National Highway System (NHS) database, Digital Line Graph (DLG) maps, and the U.S. Bureau of Census Topographic Integrated Geographic Encoding and Referencing (TIGER) files. These sources should be evaluated in terms of source materials (e.g. date, scale), generalization performed, categories of information, topology, addressing, geographic continuity, and cost. As with all databases, transportation routes depict the state of highways, railways, etc. at some measured point in time. The transportation paths are dynamic in nature and the database must constantly be updated to reflect new routes and/or modifications to existing routes. For analytical operations such as routing, the complete transportation database must have correct topological connections. The digital maps are notorious for errors in the topology. Most importantly, connectivity of transportation routes between adjacent map sheets must be preserved.

Image Database

Compared to traditional cartographic data, there are two main advantages for using remotely sensed imagery in a vehicle tracking application. First, a cartographic produced, by its definition, is an abstraction of the "cartographer." Selected themes and features are abstracted from other materials (including remotely sensed imagery). Examples of themes might be transportation routes and hydrology. It is only the selected abstractions that are part of the final cartographic database. Remotely sensed imagery, on the other hand, contains all the native information.

Second, because cartographic products require considerable resources to create and maintain, they are often dated. For example, new subdivisions and highway interchanges may not exist on an existing cartographic database. Remotely sensed imagery may be routinely collected and available for analysis on a continual basis for relatively minor resources.

There are four fundamental characteristics of remotely sensed imagery - spatial, spectral, temporal, and radiometric resolutions (Jensen, 1983).

Time Representation

For small geographic areas, representing time (i.e. day, hour, minute, etc.) as local time is desirable and adequate. However, when the application extends over multiple time zones, and/or users in different time zones may query the system, local time is problematic. The use of a single standard time zone, such as Universal Coordinated Time (UTC), provides a solution to the multiple-zone scope. The UTC representation, also known as Greenwich Mean Time (GMT), makes all time relative to a single origin □ the international dateline. For this vehicle-tracking project, all times are represented in UTC. Conversion of UTC time to local time is simple and may be performed "on-the-fly"; thereby, making the storage representation transparent to the user.

Commercial/User-Developed Database Design Options

The nature of geographical data has historically presented a database implementation problem to system designers. While the storage of attributes of geographical features easily lends itself to a relational database management system (RDBMS), spatial characteristics are not well suited for a RDMS. Some geographical features (i.e., lines and areas) are typically variable in the number of points that describe each feature. Storing the topological relationships of geographical features further complicates the problem of storing spatial data.

Finally, while "vector" geographic data explicitly store spatial locations, "raster" data, such as remotely sensed imagery, stores spatial locations implicitly. This difference between the representation of vector and raster geographic data has always been an integration problem and is the source of continual research (Peuquet).

Because of these problems, most GIS applications make use of a hybrid solution. The geographic data are stored in a proprietary spatial database, accessible only by unique proprietary queries. The attribute data may be stored in a commercial RDMS, which may be accessed through a different set of defacto standard queries. For example, the spatial data in Arc/Info is only accessible through Arc queries while the attribute data is accessible through Info or Structured Query Language (SQL).

In the near future, at least two commercial products will allow storage of both the spatial and attribute data together. Access to these data are through the same interface and query language. Although the latter two may be suitable for the spatial data and attribute data for this project, neither database design was available at the time the project was conducted. The advantages of using these database designs may greatly influence future efforts in the design of real-time vehicle monitoring projects; thus, the fundamental merits of each options is briefly discussed.

ESRI's Spatial Database Engine

The major design goal for SDE was speed of access and retrieval over a network. To achieve this, SDE is based on a cooperative processing client/server model. The client and the server share the work, with the client primarily responsible for the spatial operations and the server for data searching and retrieval.

SDE uses an underlying relational database management system (RDBMS) that is invisible to the end user and application developer. This RDBMS stores both the spatial and attribute information under the control of SDE. Hence, all functionality is accessed through the SDE layer.

The functionality of the SDE is integrated with a client application through the SDE Application Programming Interface (API). This API provides an interface to functions that may be either executed on the client workstation or on the SDE server. Integration with other information technology products is under the control of the client, providing the greatest application development flexibility.

Oracle7 MultiDimension

Oracle 7 MultiDimension is an extension of the Oracle relational database management system. MultiDimension offers all the Oracle 7 queries plus a new database structure for efficiently processing spatial data. Like ESRI's SDE, queries may be performed through the same query language on either the spatial or attribute data associated with geographic features.

The spatial data in MultiDimension are organized in a quadtree logical structure. The quadtree structure is a tessellation of two-dimensional Cartesian space where the order of the spatial units is in Morton order (Samet, 1984). Furthermore, the quadtree structure allows for the smallest area unit (a small square) to be aggregated into larger blocks. By using aggregated units and variable size blocks, the number of features per blocks can be approximately balanced. The result of this balancing and spatial ordering is a very efficient spatial query.

Each feature in the Oracle database has a unique Helical Hyperspatial Code (HHCODE), which is essentially an extension of the well-known Morton sequence of 2-dimensions. For example, storing features in X, Y, and Z-space uses an HHCODE of 3 dimensions. Time may also become another dimension, resulting in a 4-D HHCODE. The HHCODE is essentially transparent to the user. Like the unique "id" codes in other relational databases, the codes are there but the user need not be aware of them.

As the quadtree structure and Morton sequence is suitable only for coordinate systems with monotonically increasing axes (e.g., a Cartesian system), the advantages of Oracle's MultiDimension are not possible for spherical coordinate systems, such as latitude-longitude. There are other methods for ordering data based on a spherical system and very efficient sorting algorithms with these methods (Hodgson, 1992). Incorporation of these ordering methods and searching algorithms into this project are beyond the scope of the initial phases of this project.

For an application that requires very fast spatial queries where the geographic coordinates are in a map projection (i.e., Cartesian space), Oracle 7 MultiDimension is a very good database management system. Metropolitan emergency response applications may be a good remote vehicle-tracking candidate for such a database system.

The initial platforms for Oracle 7 MultiDimension will be the Sun Solaris and Data General's VX. Pricing is approximately $3600 per 8-user license.

Section 7: PROTOTYPE STUDY

Prototype Scenario

The prototype system needed to be small and mobile for many applications such as police investigation and hazardous waste vehicle tracking. The components in the prototype system consisted of Trimble antenna and interface software, Pentium Laptop, SNAPPY hardware and software interface, camcorder, 16-bit audio board in PC, Goldwave Audio software and the appropriate interface cables. The one factor, which could change, is the transmission method. The transmission method could be chosen to meet the needs of the application depending on whether the transmission needs to be global, national, or local. Also, this transmission method could be chosen to reflect whether the remote site was stationary or mobile. All the components of the system are small, portable, and had sufficient battery sources.

Desirable Prototype Characteristics

The prototype scenario was to transfer video, audio, and position data from a moving vehicle. For this reason, the equipment used for our scenario needed to be portable and easy to secure. Our equipment required battery power or needed to adapt through the car's cigarette lighter to the car battery. We choose a Pentium laptop, 3-watt cellular phone, SNAPPY video interface, Trimble GPS interface, and video cameras with battery power.

The data transmission method depended on the communication service providers in the Oak Ridge area. Communication services available in ORNL area were INMARSAT, cellular, and Qualcomm's OmniTRACS. INMARSAT was available in the Oak Ridge area but the land mobile systems have antennas, which will not track the satellite from the top of a moving vehicle. The Maritime version operates while the ship is in motion but their antennas are much larger than the land mobile antennas and will not physical fit on top of a vehicle. Secondly, cellular was available in the Oak Ridge Area and Cellular One provided us with a map of the cellular strengths and handoff zones in the area. With this information cellular transmission was the optimal transmission method for our prototype demonstration. Qualcomm was available but did not have the data rate necessary to transmit video or audio data.

Prototype Scenario

The scenario we demonstrated was a law enforcement application. GPS position information, video clips, and audio files would be helpful while an officer is in pursuit of a suspect. The route of the suspect, video footage, and audio files could be captured and transmitted back to headquarters for investigation during the chase. The vehicle would be tracked using the audio files, video pictures, and GPS data collected from the vehicle in pursuit and sent to the control center for geographical mapping. The vehicle could be identified using the license plate photos and an audio clip of the vehicles' make and model. The GPS would be used to track the vehicle's route in the chase and possibly help in estimating his destination.

The audio was collected using a laptop with a 16-bit audio board, and audio software such as

WaveStudio or Goldwave. We choose the Goldwave Software since is was compatible with the SUN u-law audio file format (au). Goldwave allowed the audio files to be exported in the Sun format and no conversion was needed at the command center.

The video was gathered using video cameras formatted for S-VHS, VHS or Hi-8. The video output of the camera should be feed into the SNAPPY "video in" interface and the pictures can be snapped and sent as often as every fifteen seconds. JPEG compression was used within the SNAPPY software.

Position data was gathered using the Trimble PCMCIA GPS card, antenna, and software development kit. Using the software development kit a "C" program was developed to write the GPS position to a file every 1 minute. The file was then transferred using the cellular modem and FTP file transfer. Basically, the current system can transmit audio, video, and position data from a moving vehicle via wireless transmission methods back to the control.

Remote Transmission

The remote transmission consisted of collecting the GPS position data, audio data and video data and transmitting that data back to the control center via wireless data transmission. We chose cellular for the wireless transmission service in the Oak Ridge Area. Two vehicles were used in our demo, a van and an automobile.

There were two GPS system in the van. One was GPS system was the Magellan GPS Systems with Accupoint. The Magellan system used the Accupoint differential error correction to locate the position of the moving vehicle more accurately. This system was used as a backup to the Trimble and used to check the accuracy of the Trimble data collected. The second GPS system used in the van during the demo was the Trimble GPS with direct cellular modem for transmission. This Trimble System came with a PCMCIA card, software, and antenna. The Trimble GPS software could be launched manually or by using the development kit software. Secondly, the GPS Control Panel Software can run concurrently with other third-party applications. This is helpful since the SNAPPY video interface must be running at the same time to collect the video shots. Thirdly, the GPS Control Panel Software initializes on start-up. This initialization consists of downloading a satellite almanac, estimating initial position, and defining the current UTC time. This information collected at initialization significantly reduces the satellite search time. Updated almanacs are broadcast by each satellite and are received and updated by Mobile GPS and the GPS Control Panel as a background task. Also, the GPS Control Panel provides an interface for adjusting the operating parameters of the GPS for improved performance in various environments. Lastly, the GPS Control Panel proves a means for selecting the COM port assigned to the Mobile GPS.

The vehicle under pursuit (the car) was also equipped with a laptop and Trimble GPS System, and Simple Technologies Cellular modem. This GPS session was manually initialized and the data was saved to a data file for a later comparison with the van's Trimble GPS data files for accuracy.

For the collection of audio and video three cameras were used, two cameras in the car and one camera in the van. Of the three cameras used to tape the prototype scenario there was, one

VHS, one S-VHS, and one Hi-8. The S-VHS camera was connected to the SNAPPY collecting the video JPEG files to be transmitted back to the control center. The VHS camera was used as the documentary tape to document the entire scenario and show the connectivity of the equipment involved in the DATA acquisition and transfer. The Hi-8 camera was used as a backup in the case of equipment failure.

During the scenario we collected fourteen video images and transmitted them back to the control center using the SNAPPY interface hardware and software. The SNAPPY hardware used the JPEG technique to compress the files to a reasonable size for transmission. These images were then transmitted via cellular modem back to the control center for evaluation.

Two audio files captured on the camcorder were replayed and captured on the laptop using the" audio in" input of the laptop, and Goldwave Audio Software. The audio clips were approximately 30 seconds long in duration and were exported via Goldwave as a SUN formatted u-law file (.au). These two audio files were then transferred back to the control center using the cellular modem. The SUN u-law formatted audio file could be recognized by the SUN without any changes in formatting.

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Inventions Made or Reported

There were no inventions made or reported in this CRADA.

Commercialization Possibilities

As we have learned since the conclusion of this project, our real-time vehicle tracking software systems was developed at the same time that commercial vendors were developing technologies for the individual consumer. Although limited in terms of the types and form of data display, there are a number of systems now on the market to locate a moving vehicle, such as Guidestar, OnStar, RESCU, and Magellan's Pathmaster. While the commercial marketplace for consumers has implemented similar positioning and transmission (over cellular) capabilities, we are unaware of any commercial product that allows the collection and transmission of an audio/video data stream. We believe it is only a few short years before the commercial marketplace implements inexpensive videocams in automobiles or trucks for monitoring the state of the driver and external environment — particularly during a traffic event. Expansion of our GVCS to become the black-box onboard a vehicle is entirely possible.

The GVCS is a very robust and open-ended system that allows for numerous expansion capabilities. The system could be tailored to tracking any vehicle, land, air, or water, and could also be used to track wildlife. The design of the system allows display of geographic positions, insitu video, and audio. Marketing of the system to other Federal agency applications would require some additional investment.

Plans for Future Collaboration

There are no immediate plans for future collaboration.

Conclusions

Technologies for positioning, capturing video and audio information from a moving vehicle and the real-time construction of a database with geographic display capabilities now exist — although in separate pieces. We have demonstrated that this system could be built, with largely off-the-shelf technologies, through careful planning, design, and connection of the individual components. The decision to build the GVCS at the "command center" based on the ArcView 2.x series GIS software turned out to be extremely useful and in some ways, fortuitous. The evolution of ArcView into the 3.x series has opened numerous additional possibilities through the enhanced capabilities. The GIS marketplace has largely adopted ArcView as the standard for GIS display and query capabilities. This implementation strategies insures the longevity and increases the possibilities of future markets for the GVCS.

The most fragile and inhibiting element in the GVCS was determined to be the wireless data transmission network. During the land-based demonstration we had difficulty in maintaining a strong cell-phone connection for the transmission of large files, such as the video images and audio files. Transmission of smaller files such as the positional information collected by GPS and time of position was relatively trouble-free. We also attempted to collect and transmit data from a helicopter in the final stages of the project. While the collection of data was possible, the transmission of data over cellular network was not possible due to the airframe of the helicopter.

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