Development and Implementation of an Automated Facility Inventory System

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Infrastructure assets are a vital investment in the well-being of a society. If they are not managed properly, the inevitable degradation of these assets could become a source of liability and a significant financial burden to a public agency. Therefore, infrastructure facility management requires reliable and accurate information. Monitoring infrastructure facilities requires extensive data collection efforts. Because present data collection methods are costly and time-consuming, automated methods of data collection are needed to meet evolving management needs. Roadware Corporation has introduced a subsystem for its Automatic Road Analyzer that addresses the need for automated data collection of roadside furniture. Surveyor™ is a new technology used to make measurement from images recorded on videotape. With computer-scaled video and measurement data, an operator at an engineering workstation can measure the size and location of objects quickly and accurately. This information is flexible because the data output is fully compatible with Geographic Information Systems and Computer Automated Design systems. Sign management is one of the primary function of this technology, but there are several applications. Surveyor addresses those issues that make data collection and postprocessing efforts difficult and labor intensive. Implementing an automated data collection system ensures a more comprehensive data base, allowing for more accurate prediction and performance models. Automated data collection provides accurate data in a timely and cost-effective manner.

Infrastructure assets are a vital investment in the present and future well-being of a society. If these assets are not managed properly, their inevitable degradation could become a liability and a significant financial burden to a public agency. To manage infrastructure facilities successfully, reliable and accurate information is required. This need for data has been recognized by many government bodies and is currently used for the Highway Performance Monitoring System (HPMS), which is regulated by the FHWA.

Of the types of data required for infrastructure management, the most critical for developing a comprehensive system are inventory and location of facilities. For facilities to be managed effectively, (*a*) they must be inventoried and classified according to type, (*b*) their condition must be recorded, (*c*) their locations must be registered. An accurate record of location is necessary to (*a*) reduce the possibility of confusing similar facilities that are in close proximity, (*b*) allow for quick and accurate identification while in the field, and (*c*) create unique facility locations for data base management systems, including Geographic Information Systems (GIS).

Transportation agencies that are required to collect the infrastructure inventory and location information generally consist of state departments of transportation, county roads and public works departments, and city engineering departments. With such a wide variety of data users, applications for infrastructure data have expanded and include GIS, facility management data bases, and inventory surveys.

Maintaining and monitoring infrastructure facilities require extensive data collection efforts, which can be costly and labor intensive. To effectively manage the network, managing agencies require the timely delivery of this data. This need will only become more urgent as traffic demands increase, budgets shrink and time constraints on management grow. Current data collection methods for conducting a facility inventory and recording its location are costly and time-consuming. Aerial and remote sensing are expensive data collection methods, and the resulting data do not provide the detailed feature information many transportation agencies require. For example, using aerial methods to identify mile markers, culverts, fire hydrants, and signs is often inaccurate and inefficient. A portion of the costs associated with remote sensing may be attributed to the high capital and operational cost of the required equipment and personnel. Aerial data collection methods are therefore limited by unreliable information.

Currently, manual surveys are conducted to obtain the detailed information required for various management purposes. Data are collected using a variety of methods, from pen-based computers to paper and pencil. Although the data obtained during manual surveys are very specific and detailed, there are several drawbacks to manually collected data:

- Because the entire process is done manually, there is a long turnaround time for the completion of the survey. This includes all survey tasks: from data collection and verification to data input and implementation. If the researcher does not use automated data collection techniques, the effort required does not allow for the timely completion of a survey project.
- Production rates are susceptible to environmental factors, because it is difficult to conduct a field survey during adverse weather conditions.
- Personnel safety is a concern while the field crew is collecting data on-site. The presence of crew members on the road and in traffic poses the danger of serious accidents.
- Much of the data collection effort is associated with the set-up and dismantling of the necessary traffic control devices.
- Incorrect and inaccurate information may be reported as a result of the previously mentioned conditions. Data discrepancies can also be attributed to inconsistencies in the data collection methods and to fatigue.
- There is no permanent or visual record with which to compare the data readings unless the field crew go out into the field again and resurvey the infrastructure facility. Even if photographs are taken in the field, the quality of the resulting photos is not immediately known due to processing delays.

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These deficiencies in performing inventory and location surveys using manual procedures show that a more automated approach is needed.

AUTOMATED RIGHT-OF-WAY DATA COLLECTION

Automated methods of data collection that meet present and future management requirements are clearly needed. These methods use a host vehicle traveling at highway speed while recording the appropriate infrastructure data. The data acquisition vehicle collects all the required data in a single pass of the facility. The vehicle uses video and other sensors (e.g. lasers, ultrasonic sensors, etc.) to capture data automatically, allowing for subsystem processing at an office workstation. The collected data can then be related to a referencing system such as mile marker or Global Position System (GPS).

With automated methods of collecting road data, departments can reap the following benefits:

- An increase in daily production rates during favorable weather conditions;
- Storage of the information for postprocessing;
- Collection of more data items on a per diem basis;
- Reduced expenses;
- Reduced susceptibility to weather because the data collection effort requires significantly less time in the field;
- Information that is processed at an engineering workstation, in an office environment;
- Field data collection that is completed in the vehicle, eliminating the need for crew members to work near the traffic flow;
- Equipment and capital costs that are significantly less than those associated with remote sensing;
- Time requirements that are lower than for a manual survey;
- Accuracy and data detail that are not compromised;
- Quality control procedures that are easier to implement, and discrepancies that can be easily rectified; and
- A visual record of the facility that department members can view at any time.

Automated data collection that provides the user with accurate and consistently reliable data, along with flexibility, will save the department time and money without compromising quality.

INTRODUCTION TO SURVEYOR

Roadware Corporation has developed a new automated facility inventory and location system for right-of-way (ROW) measurements called Surveyor. The Automatic Road Analyzer (ARAN) is a high-speed, mobile data acquisition platform that carries the Surveyor subsystems. The ARAN collects and stores the road data in one pass while traveling at highway speeds.

Surveyor is a patented technology used to make measurements from images recorded on videotape or other video recording media. Associated software uses location information from the distance measuring instrument (DMI), Geometrics System, and GPS to accurately determine the location and attitude (three-dimensional orientation) of the vehicle. This information, along with multiple-frame video images, can be used at an office workstation to establish with accuracy the location of signs, guide rails, bridges, culverts, and other roadway features that can be seen in the ROW video. With ROW video and measurement data, an operator at an engineering workstation can measure the size and location of objects quickly and accurately. To make linear measurements of an object, the video image is digitized at the workstation and the operator uses the computer mouse to select an object on the screen. The computer automatically calculates and reports the object's x and y coordinates and the location (Figure 1). Height, width, and other measurements can also be made. Data output is fully compatible with GIS and Computer Automated Design (CAD) systems.

The vehicle data collection subsystems required for video measurements include the following:

- DMI—An optical shaft encoder, driven by a speedometer cable from the rear wheel, produces a stream of 1,800 pulses per wheel revolution. These pulses are sent to a central data acquisition computer for use by other subsystems. The DMI readings are accurate to within 0.02 percent of the total distance traveled by the vehicle.
- ROW Video—A full color charge coupled device video camera is mounted between the driver and the passenger, and points forward out the vehicle's front window to record a continuous video log of the road ROW. The ROW camera has a horizontal resolution of 720 television lines and a shutter speed of 1/2,000th of a second. The video subsystem is controlled by a 486-based Smart Video Controller (SVC). The SVC controls the video recording functions of the Super VHS (S-VHS) videotape recorder (VTR). Identification and measurement information is overlaid onto the video images for later reference. The ROW the data capture for postprocessing is illustrated in Figure 2.

The ROW perspective video is collected using a high resolution video camera to record Super-Video in S-VHS format. Each video frame is automatically computer-encoded using Society of Motion

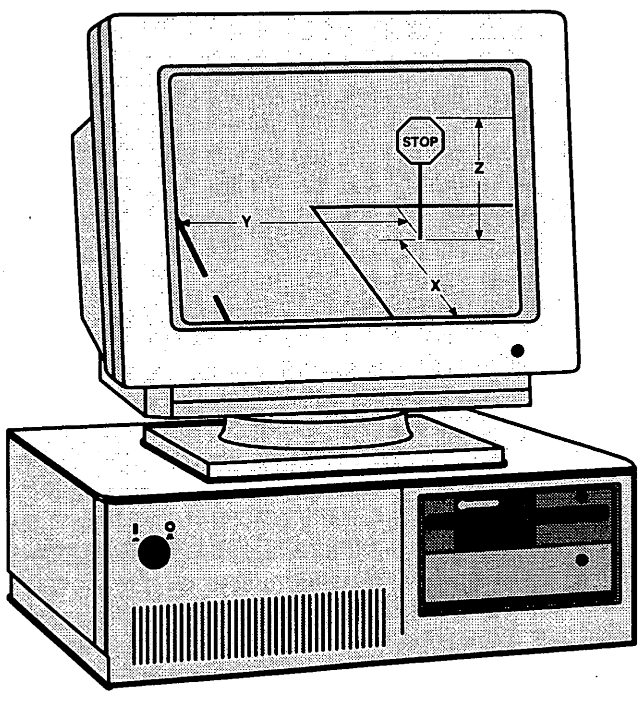

FIGURE 1 ROW video measurements.

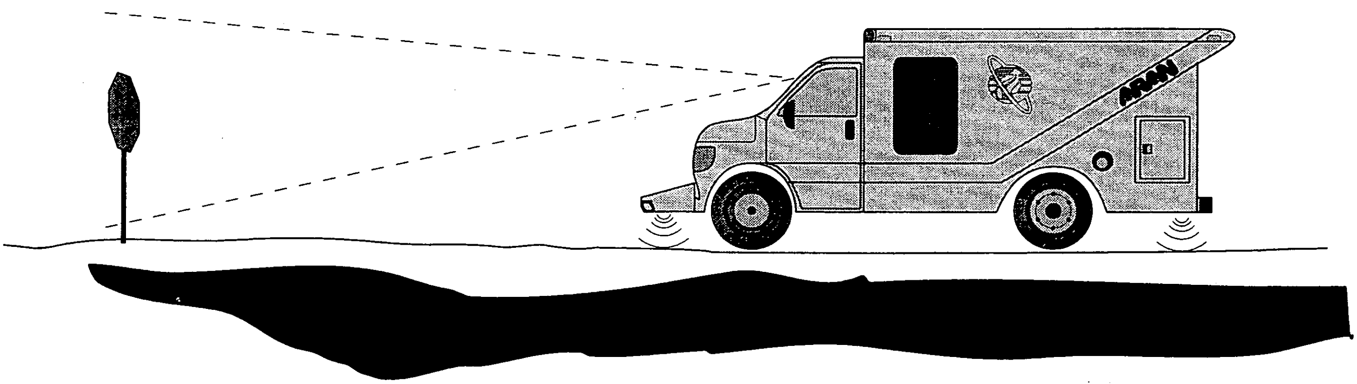

FIGURE 2 ROW data capture.

Picture and Television Engineers (SMPTE) time code and is cross-referenced with distance measurements for rapid access and retrieval during postprocessing. This coding allows the user to review and analyze the video images at a workstation. Associated Search and Find software uses the SMPTE time code, which enables the SVC to position the videotape at any location requested by the user via a keyboard.

- Geometrics System—The geometrics system aboard the data acquisition vehicle uses accelerometers to continuously measure the roll, pitch, and heading of the vehicle. The gyroscope readings provide information on the orientation of the vehicle and the camera with respect to the vehicle's start position.
- Ultrasonic Sensors—These four ultrasonic sensors on the vehicle's chassis measure the vertical displacement of the chassis to the road surface 15 times per second. The distances measured with these sensors are accurate to 1 mm (0.04 in.). The ultrasonic sensor data are used to determine the alignment of the vehicle with respect to the ground to determine the orientation of the camera.

The configuration of the data acquisition system for computer-scaled video is illustrated in Figure 3.

To obtain accurate measurements, the ROW camera must be calibrated to the ultrasonic sensors and the geometrics system. This calibration is completed by performing a factory calibration and a field calibration.

The factory calibration records information specific to the installation of the system on the vehicle. The distances between each ultrasonic sensor and the camera are measured and recorded. An alignment mark is placed on the windshield to align the field calibration with the direction of travel of the vehicle. The factory calibration is performed once, after the system is installed.

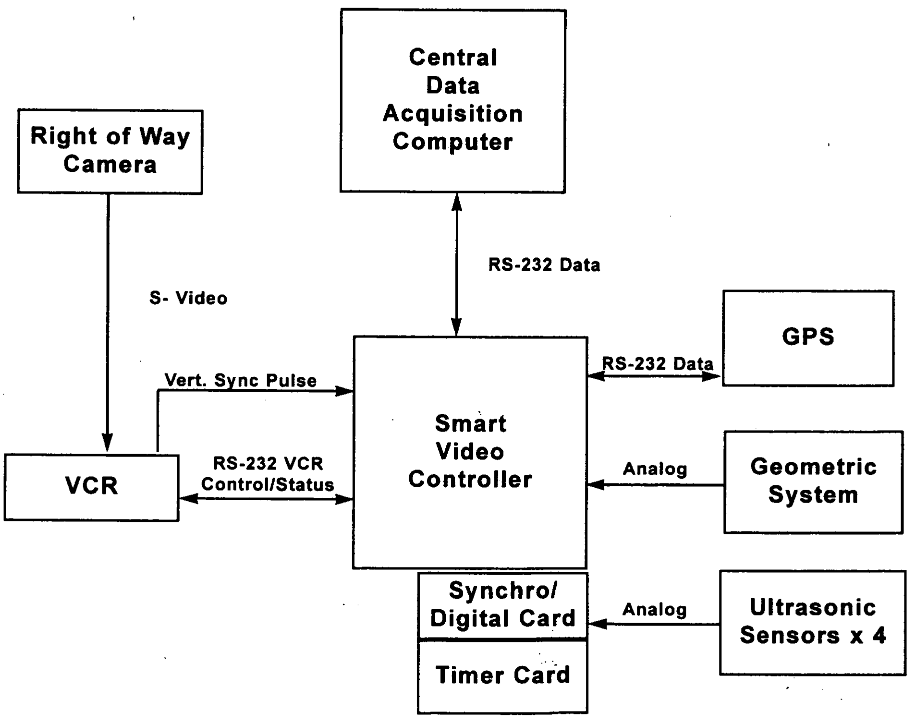

FIGURE 3 Surveyor data acquisition system.

The field calibration is used to calibrate the camera position, focal length, and ultrasonic sensor measurements. A water datum, pendulum, and surveyor's level are used to calibrate all components to a horizontal datum and the direction of travel. The pendulum is placed a known distance from the front of the vehicle. Video of the pendulum is collected while the vehicle is stationary so that a third calibration can be completed at the engineering workstation.

During data collection, geometric and ultrasonic data collected at intervals timed precisely with the shutter of the video camera are collected and stored. This information provides the exact orientation of the vehicle at the time of each video image. As mentioned earlier, all collected data is referenced to the information recorded by the DMI on the data acquisition vehicle.

VIDEO POSTPROCESSING

After the data collection effort is completed, the ROW video is processed at the workstation to record and store all linear measurements. The associated software package is used in the Microsoft Windows environment and allows the operator to select roadway features interactively from the digitized video. The workstation configuration is given in Figure 4.

A software calibration must be performed each time a truck calibration (factory or field) is completed to record the final measurements of the camera position, so the operator may process the video images. The software calibration has two components, a main calibration and a gyroscope calibration. The main calibration uses the videotape of the pendulum taken during the field calibration of the camera, the gyroscope calibration involves updating the calibration files with new gyroscope readings recorded during the field calibration process. When the calibration has been completed, the operator may begin processing the video.

The computer screen consists of four areas: the video area, the menu bar, the VTR control bar, and the object record. The video area is where the digitized VTR image is displayed. All measurements are made from the frame image displayed here.

The menu bar displays functions that are the same as in any other Windows application.

The VTR control bar has two areas, one with five buttons for standard operations, and another with two buttons for shuttle control of the VTR. The counter box displays chainage, frame number, or time. The search button brings up a selection box with detailed search criteria. Figure 5 illustrates the VTR controls.

The object record is where the measured values related to a single object in a single frame are displayed (Figure 6). It also contains an identification hierarchy at the top and an area for user description near the bottom. The position and dimension areas refer to the object being measured on screen. The user description area allows comments to be added and is user-definable.

A computer file is generated corresponding to each videotape. This file is required for postprocessing because it contains ultrasonic sensor and geometric data for each video image.

When the appropriate files are loaded, the user advances the tape. As the tape plays, the video images are digitized and stored in a circular buffer. After the buffer is full, the newest digitized images replace the oldest ones. When the operator has captured the video frames containing an object of interest, the Survey function is selected. The operator then scrolls through the digitized frames that are in the buffer using a scroll bar, and selects the frame that best represents the object. Measurements of the object can now be taken and stored.

The software determines the distance between the object and the camera by recognizing each pixel as a specific distance from the camera, after the video is calibrated. The software is able to accurately determine the linear measurements of the object using an

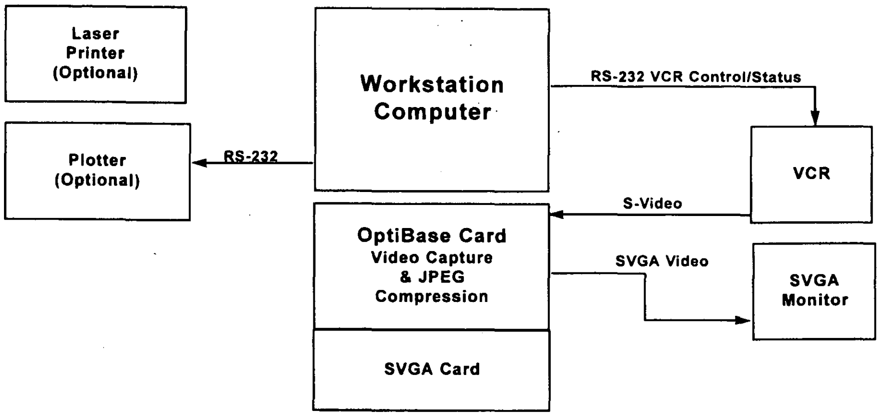

FIGURE 4 Postprocessing workstation configuration.

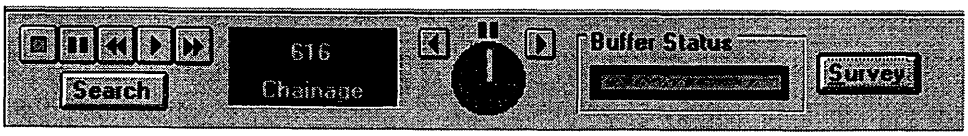

FIGURE 5 VTR control bar.

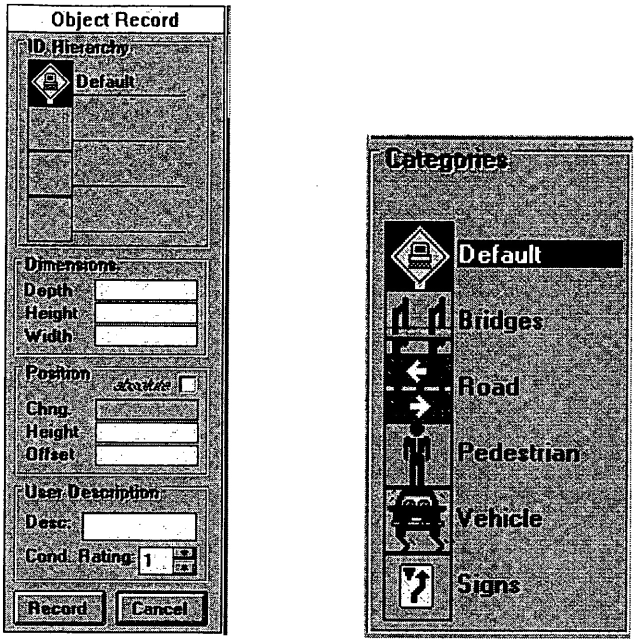

FIGURE 6 Object record and identification hierarchy.

aspect ratio and a radians-per-pixel value. The radians-per-pixel value is calculated from the vertical size of the static pendulum that was recorded during the field calibration procedure. An aspect ratio is used because the vertical size of the pendulum may differ from the horizontal size of the pendulum on the video screen. The aspect ratio is represented as the ratio of the pendulum's horizontal size to its vertical size. The Cartesian coordinates of the road plan and the object are then calculated. The Cartesian coordinates are adjusted for the roll and pitch of the vehicle, as determined from the ultrasonic sensors on the chassis.

All other linear measurements are made assuming the object lies in a vertical plane perpendicular to the direction of travel. Location is measured in relative chainage or geographic (absolute) coordinates. Linear measurements are reported in imperial or metric units. Surveyor is able to make measurements from the video image using one of two methods, single frame and multi-frame.

The single frame mode allows the user to make all measurements using a single video image. All measurements made in the single frame mode must be referenced to the plane of the road. For example, a user who wants to measure a sign begins by identifying the object from where it intersects the plane of the road, at its base. When the object does not intersect the plane of the road or the point of intersection is difficult to discern (because of tall grass, ditches, snow banks, etc.), single frame measurements become impractical.

Multi-frame measurements allow the user to measure objects regardless of where they exist in the image. The user must identify the object in two or more images to make measurements. This method is moderately more time-consuming than the single frame method but provides more flexibility. Multi-frame measurements are made using triangulation calculations.

Both measurement techniques allow the user to measure the three-dimensional position of any object as well as its width, height, and depth.

When all data measurements have been made, the object may be classified in the available identification hierarchy. As the user moves down the classification hierarchy, the object description becomes more specific. The hierarchical structure can be customized for each transportation agency. In the example of a sign inventory, a hierarchical classification such as the one displayed in Figure 7 may exist.

Two additional data inputs are available to the user: condition rating of the object on a scale of 0 to 10 and a comments section to note any irregularities or special characteristics of the facility. When all the information is entered, the operator may save the record in one of three types of file formats: a text file (*.txt), a drawing exchange format (*.dxf) file for use by CAD applications, or a Surveyor file.

APPLICATIONS

The flexibility in file format allows the information to be used in many applications. Collecting additional data items while the vehicle travels the network allows the user to import scaled video data into various software packages, which can be used in any of the following applications.

Sign Management

Sign management practices have not been widespread among transportation agencies in the past, but their implementation is now required by the Intermodal Surface Transportation Efficiency Act. Sign management is one of the primary functions of Surveyor technology, but there are several other applications of this data. Information that would typically be associated with a particular sign includes the following:

- Location (relative or absolute);
- Offset;
- Horizontal width of sign face;
- Vertical height of sign face;
- Height of sign above the road surface;
- Manual on Uniform Traffic Control Device type code;
- Legend (hierarchy);
- Condition assessment;
- Number of signs on the post;
- Number of support posts;
- Type of support post;
- Direction of sign face (north, south, etc.);
- Shared sign post;
- Date installed; and
- Maintenance history.

Traffic Control Signs
  Warning Signs
  Guide Signs
  Regulatory Signs
    Right-of-Way Series
    Pedestrian Series
    Speed Series
    Movement Series
    Parking Series
    Miscellaneous Series

FIGURE 7 Sample identification hierarchy.

GIS

GIS technology is the vehicle used to organize data and understand their spatial associations. GPS and scaled video data may be used together to generate plan view drawings. Because the position data can be represented in (*x*-*y*-*z*) format, the information is already in a useful format for input to a GIS as a data overlay. Compatibility with a GIS format is important, because the collection of accurate positioning data for facilities is a difficult and time-consuming data conversion process when using other methods, such as digitizing maps or aerial photographs.

The benefits of linking Surveyor data to a GIS are categorized as follows:

- Data Integration. All GIS data are tied to a common geographic referencing system, (i.e., latitude and longitude coordinates), making all attribute data available (e.g. traffic accident, population, and maintenance records). The combination of data bases provides the user with a more comprehensive picture of the network.
- Data Format and Accessibility. Accessing data base information by pointing and clicking with a mouse is simpler, in most cases, than entering a text query. The results are more easily interpreted because they are visually displayed on the screen, both spatially and by color coding the results.
- Analysis Tool. A comprehensive GIS makes different types of network information available to the last user, allowing the agency to conduct a more thorough analysis of the data.

Facilities Inventory and Condition Assessment

Facilities inventory and condition assessment is possible using the recorded location and the measurements of the features that characterize various highway facilities. The facilities inventory allows the user to locate a facility, determine its condition visually, and attach any special notation that is desired. The condition assessment from video could include noting condition of signs, guardrails, pavement markings, drains, and so forth.

The inventory information can be supplemented using the workstation inventory keyboard. This keyboard can be used to record various types of information relating to pavement condition and facility inventory while the user views the video images at the workstation. Because each video frame is linked to distance and GPS measurements, the information entered at the inventory keyboard is automatically linked to this location data. For example, during inventory of railroad crossings, the operator would press a predefined key when the correct position for the railroad crossing appears on the screen. When the key is pressed, the image number, route number, milepost location, and GPS coordinates would automatically be written to a file for future use. At that point, video measurements of the crossing length and width can be made.

The inventory keyboard uses backlighted liquid crystal display keys that can display a programmable image for each key. In the example of the railroad crossing, a special symbol representing a railroad crossing could be displayed on the key, making the data-entry function straightforward and accurate.

Keys can be defined for virtually any type of inventory or condition assessment. A key can be programmed to toggle on and off, allowing it to be used to indicate the beginning and ending of span-type facilities, such as guardrails, pavement markings, and passing zones.

Preliminary Survey Measurements

Surveyor can also be used in the planning of new infrastructure accessories or modifications. Surveyor can generate a situation diagram, allowing preliminary surveying measurements to be taken from the video before any field work is required. Potential applications include the layout of new structures and modifications of existing lanes (e.g., road widening). This technology can also be used in planning and engineering studies, with respect to selection and location of traffic control devices.

Landmark Survey

A landmark survey can be performed to obtain an accurate location description of the road network. This can be accomplished using GPS data along with Surveyor measurements to record the location of network landmarks. This information can be used to develop a common location referencing system among various departments, similar to milepost identification markers but more accurate.

Traffic Control Planning

When normal traffic flow is interrupted and traffic control is required, a transportation agency may use the recorded video information to plan the set-up of the site in the office, instead of doing the planning in the field, or from maps or sketches.

Visual Historical Record

Video records can be used in the defense of a tort liability case. Having a visual record of the scene in question may help provide information on whether or not an agency was negligent in a specific situation.

Data Reports

Collected data can be formatted to the users' specifications to provide readily available information for determining relevant statistics and planning analysis.

SUMMARY OF BENEFITS

The versatility of scaled video technology is demonstrated by the preceding illustrations. Surveyor addresses the issues that make data collection and postprocessing of inventory and location data difficult and labor intensive. Implementing an automated data-collection system will ensure total data coverage in a timely manner.

The facility inventory and position reference measurements that can be made from the ROW video provide important information for transportation data bases. Knowledge of the location, characterization, and condition of various highway facilities (when quantified by measurements) provides a foundation of accurate information that can be used to manage the infrastructure. This information will provide transportation agencies with the following benefits:

- Operating costs that are lower than traditional data collection methods;

- Automated data collection that can reduce the time required in the field;
- Increased employee safety without the need for traffic control during data collection;
- Easier budgeting and funding allocation;
- Readily available information linked to all other infrastructure information;
- Anomalies that can be checked easily with video;
- Planning of location and layout of new facilities; and
- Information for political considerations.

SURVEYOR IMPLEMENTATION

The following cases illustrate how Surveyor technology has been implemented by some North American transportation agencies:

Commonwealth of Massachusetts

The Massachusetts Department of Transportation has performed field measurement validation of Surveyor measurements, and has found the offset, width, and height measurements to be accurate within 50 to 100 mm (2 to 4 in.). The Department of Transportation is currently evaluating the use of Surveyor in the collection of highway performance monitoring system (HPMS) data, which would include measurements such as lane widths, median distance, and shoulder width.

City of Surrey, British Columbia

The engineering department of the city of Surrey, British Columbia is using Surveyor measurements to establish a GIS layer for public works facilities. Surveyor will be used to determine centerline offset distances and inventory of fire hydrants, bus stops, curb drains, utility poles, and other infrastructure elements of interest to the public works department. A plan view drawing, with x-y coordinates for the different features, will be generated by Surveyor in CAD format, and will then be merged with other GIS layers.

State of Rhode Island

Surveyor field data has been collected on approximately 2,900 km (1,800 mi) of highway in the state of Rhode Island. The Rhode Island Department of Transportation is considering using this data for a comprehensive sign inventory, which would include measurements of sign offset, height, size, and related data.

CONCLUSION

The advantages of using a more automated data collection method instead of current manual methods have been clearly illustrated. Collecting data from computer-scaled video allows the user to record more data types simultaneously, creating a more comprehensive data base of the road network. This technology was developed to provide access to the complete picture of the network, meeting today's infrastructure management needs. Initial implementation of this video technology has not been widespread, as the product has only recently been made available to transportation agencies. However, the positive results obtained so far promise a broader acceptance and acquisition of this data collection method.

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