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Surveyor
Mobile Highway Inventory and Measurement System

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Surveyor is a mobile highway data collection system designed to collect measurement data about objects, features, structures, and landmarks located along highways and roadways for highway planning, management, and maintenance. It creates classified inventories annotated with object dimensions, object position relative to the road, and global position reference. The mobile data collection part of the system consists of a high-speed multifunction vehicle with minimum complement of a right-of-way video system with a precisely calibrated high-resolution video camera, a distance-measuring instrument for spatial positioning, a gyroscopic geometrics system, and an ultrasonic grade system for precise measurement of vehicle attitude. Data acquisition is facilitated by multiple on-board computers, and the right-of-way video uses a time code for synchronization to the geometric and position databases. The interactive (postprocessing) part of the system uses a workstation to retrieve and buffer the video for the user to identify targets by using point and click with a mouse, to classify them, and to request position or size measurements. The software can make measurements on multiple images by using triangulation or on single images by using the idealized plane of the highway as a reference.

The inventorying of roadside and overhead facilities along the nation's highways is becoming an important issue for infrastructure management by public works administrators. With increasing demands to regulate ever-growing traffic densities together with shrinking budgets, traditional methods of highway inventorying are simply too inefficient.

Highway facilities—for example, signs—may be subject to regulations or specification in terms of their size, positioning, or visibility. Consequently, verification that a single sign is appropriately situated may require manual measurements of the sign's position with respect to a mileage reference marker and the object indicated by the sign. The offset from the edge of the highway and the height of the sign above the pavement may also be important. Measurement of these parameters is a time-consuming and costly manual exercise. Furthermore, it may be necessary from time to time to verify that the sign has not deteriorated to the point at which its visibility is compromised or to verify that it has not been vandalized or damaged from snowplowing. From the viewpoint of protection from future litigation, a pictorial record of compliance may be prudent. All this effort is costly in terms of person-hours and dollars, requiring not only the time to make these measurements but also the time required to travel to and between sites. In addition, there is risk to worker safety when the worker is working and the worker's vehicle is parked on the shoulders of busy highways. After all of that, the data gleaned from this intensive investigation (of a single sign) need to be entered into some type of database management system.

To adequately address the need for inventory and measurements, a radically new solution is required, a solution that is divorced from manual field measurements and that is, for the most part, automated.

AUTOMATED ROAD FACILITY INVENTORY SYSTEM

The solution to efficient inventorying of highway facilities lies in modern technology. Surveyor (Roadware Corporation) is a mobile right-of-way inventory and measurement system that can visually capture and accurately locate roadside features while it is moving at highway speeds (*1*). It consists of a two-part system: a fully automated mobile data collection vehicle (Figure 1) and a postprocessing workstation (Figure 2), in which an operator scrolls through the video images, selects objects of interest with the click of a mouse, and classifies them.

The advantages of this technology over manual measurements are numerous:

1. Inventorying and measurement are extremely fast, with little delay between identification of a feature and incorporation of the feature into a database. For manual measurements, the turnaround time is typically much longer, and significant effort and disruption because of traffic control and diversion may be involved. In addition, there will be less delay from adverse weather conditions.
2. Because of the speed of the measurements, these tend to be cost-effective, even when one considers the capital costs involved with obtaining the equipment.
3. The data collected will be more objective, more accurate, and more uniformly reported. Manual measurements are typically obtained by different crews, which involves various degrees of subjectivity in measurements and reports. Depending on the competence of the crew, the weather conditions, and the degree of fatigue among the members of the crew, there may tend to be more errors in manual measurements.
4. A permanent record is established with this technology. Measurements can be recalculated at any time by reanalyzing the video without returning to the field.

AUTOMATED MOBILE DATA COLLECTION SYSTEM

Principles

The heart of the Surveyor mobile data collection system is the continuous video imaging that takes place while the vehicle is moving at normal traffic speeds (Figures 3 and 4). The video image is tied to computer data files that continuously track the orientation and position in space of the cameras at all times. The

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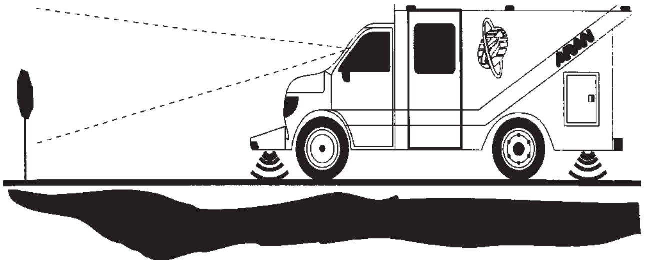


FIGURE 1 Schematic of data acquisition vehicle showing right-of-way video and grade sensors.

video camera pan, tilt, and zoom are locked down in an orientation and zoom that are appropriate to the application, and the camera is calibrated to that position. The calibration data are retained and are later used to define the orientation of the camera with respect to the direction of travel of the vehicle and to define the scale of the image.

Hardware

The hardware for the mobile data collection system consists of an integrated system of video, hardware sensors, and two data acquisition computers (Figures 5 and 6).

Video

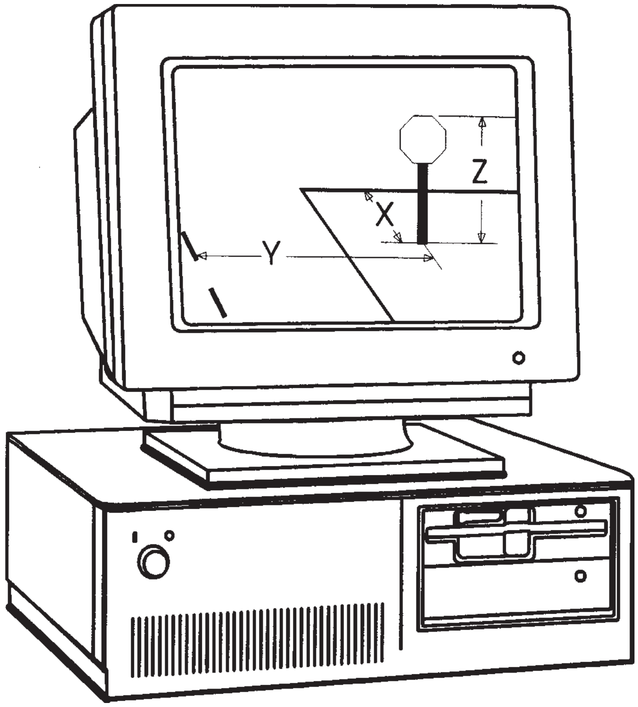


FIGURE 2 Schematic of workstation used to analyze video images.

FIGURE 3 Cab-mounted video camera in data collection vehicle.

The system uses any Phase Alteration Line or National Television Committee color right-of-way video camera capable of super video output. The images are stored on super-VHS video recorder with Society of Motion Picture and Television Engineers time code capabilities. Images are indexed by frame numbers, which are stored on the videotape and synchronized to the position orientation data of the vehicle at all times. The video recorder is controlled by a data acquisition computer called the smart video controller (SVC), which, in addition to starting, stopping, and rewinding the videotape, adds the time code to the videotape and overlays a video header onto the video images (Figure 7).

Geometrics: Chainage

Chainage is a measure distance along the prescribed route. This distance is measured with a distance-measuring instrument (DMI), which uses an optical shaft encoder on the drive axle to count wheel rotations at 1,800 pulses per revolution. The DMI is calibrated by

FIGURE 4 Roof-mounted video for panoramic view.

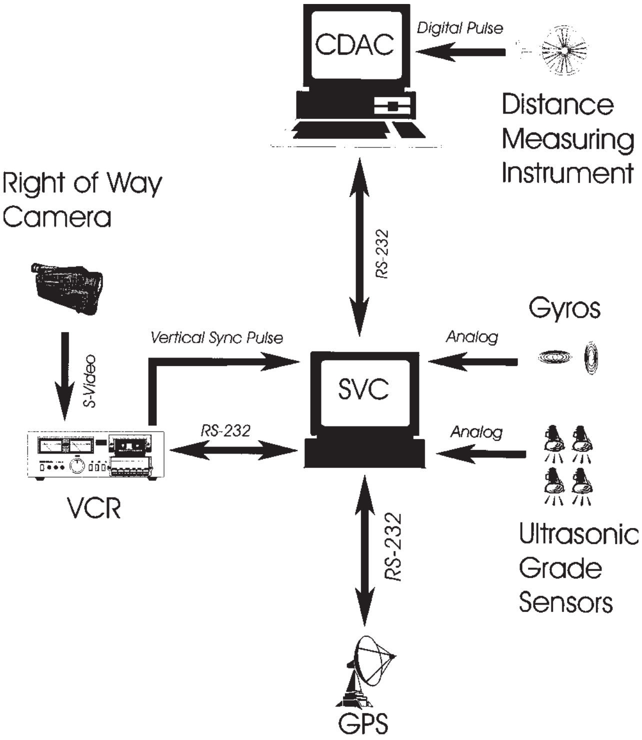


FIGURE 5 Schematic of information flow between CDAC, SVC computer, VTR, and various sensors.

driving the vehicle over a measured distance of at least 1 km and is considered to be accurate within 0.02 percent. The chainage is tracked by the central data acquisition computer (CDAC), which is also responsible for compiling and recording all the data produced by the various other onboard computers.

Geometrics: Gyroscope-Based Roll, Pitch, and Heading

Vehicle attitude is measured with conventional gyroscopes. One gyroscope is used to measure pitch and roll, and a second is used to measure the heading. This system can be used for inertial navigation over short distances. Measurements are taken to coincide with every second video frame, or at $\frac{1}{15}$-s intervals. These measurements are collected by SVC and are sent to CDAC.

FIGURE 6 Cutaway of data acquisition vehicle showing video camera, computers, video recorders, and camera.

Geometrics: Grade Sensors

Grade sensors are used to determine the pitch and roll of the vehicle with respect to the plane of the road pavement. These sensors consist of four ultrasonic sensors, located at the four corners of the vehicle, that measure the distance between the vehicle chassis and the road pavement surface at $\frac{1}{15}$-s intervals. These are also collected by SVC and are sent to CDAC.

Geometrics: Global Positioning System

An optional Global Positioning System (GPS) is used for retrieval of more accurate position information. A standard or differentially corrected GPS can be used with a maximum resolution of up to about 1 m. GPS data come to SVC from a dedicated GPS processor.

Software

Operating System

The SVC data acquisition software is based on the QNX (Software Systems Limited) operating system. QNX is a Unix-like operating system and is considered a real-time operating system because of its advanced interrupt handling and task prioritization capabilities. This makes it ideal for the complex data-handling requirements of the Surveyor system.

The software on SVC is coded in C language and has no user interface but is controlled by and reports to CDAC.

Videotape Recorder Control

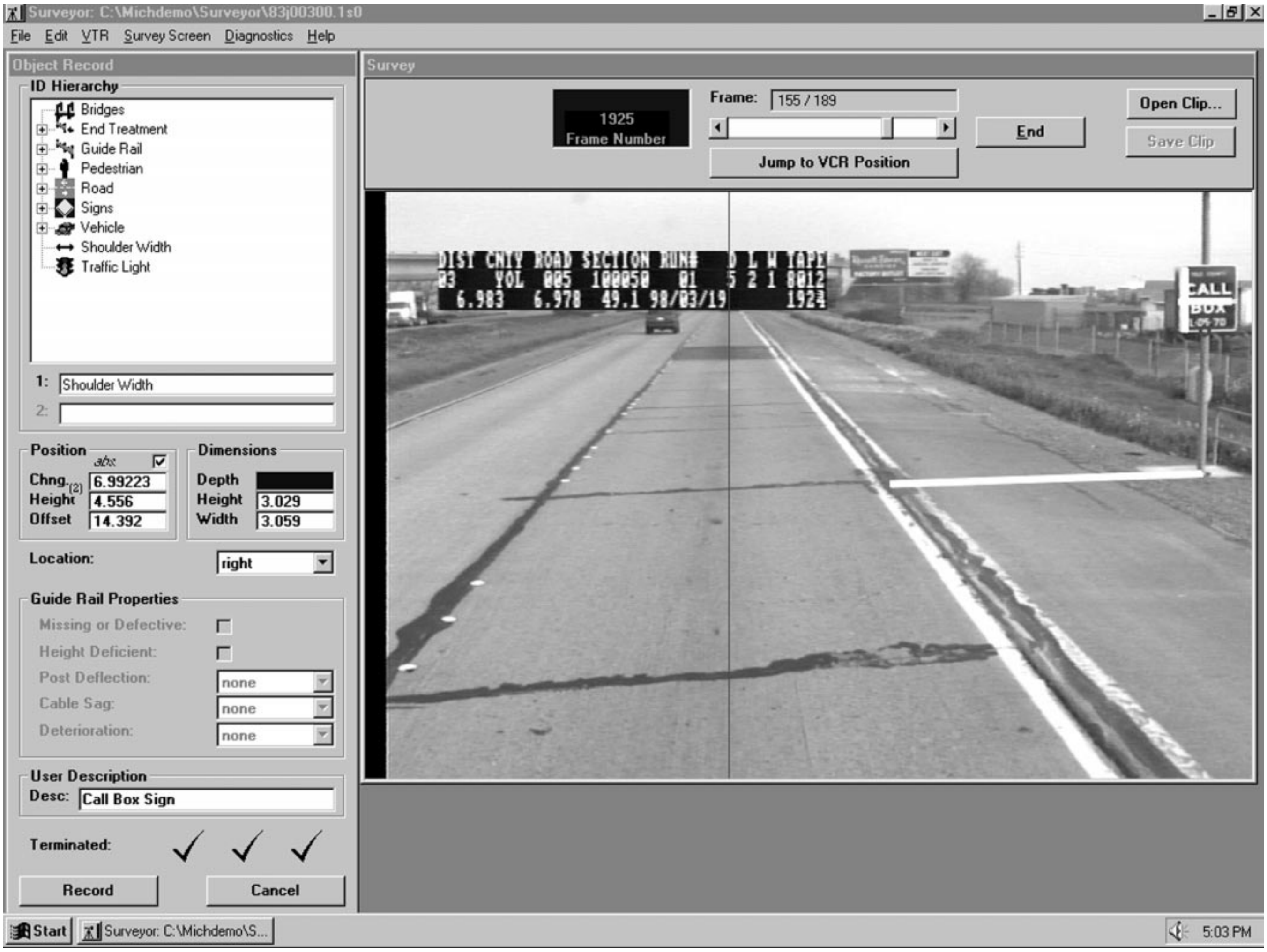
At the beginning of the data collection run, the videotape recorder (VTR) is powered by a relay with a transistor-transistor logic digital output signal, and the tape is initialized and positioned by programming the VTR on a serial interface. When data collection actually starts, the VTR is started and is interrogated for the starting video frame number.

Timing of Data Acquisition

Timing of data acquisition is taken off the vertical blanking pulse from the VTR. The SVC computer sees this as a hardware interrupt and tracks frame numbers by counting interrupts, which occur every $\frac{1}{30}$ s. At every second frame (even frame numbers), a data acquisition sequence is initiated. This is done to reduce the amount of data that need to be recorded. Data for every odd-numbered frame are interpolated between even-numbered frames.

Data Acquisition: Gyroscopes

The gyroscopes are continually outputting analog data. At every even-numbered frame, the gyroscope data are read, compressed, and recorded to a file. The heading gyroscope is read in a range of 0 to 360 degrees with a resolution of 1.3 min of arc. The tilt and roll gyroscopes are read in a range of -11.2 to $+11.2$ degrees, with a resolution of 5.2 min of arc.



Surveyor: C:\Michdemo\Surveyor\83j00300.1s0

1925 Frame Number

Frame: 155 / 189

1: Shoulder Width

2:

Position abs ☑

Chng.(2) 6.99223

Height 4.556

Offset 14.392

Dimensions

Depth

Height 3.029

Width 3.059

Location: right

Guide Rail Properties

Missing or Defective: ☐

Height Deficient: ☐

Post Deflection: none

Cable Sag: none

Deterioration: none

User Description

Desc: Call Box Sign

Terminated: ✓ ✓ ✓

```
DIST CNTY ROAD SECTION RUN#    D L W TAPE
03    YOL  005  100050   01    5 2 1 0012
  6.983  6.978  49.1 98/03/19       1924
```

FIGURE 7 Screen dump of Surveyor workstation showing measurement and inventorying of call box.

Data Acquisition: Ultrasonic Grade Sensors

On odd-numbered frames, the grade ultrasonic sensors are fired and the timer registers are set up to count and latch the echo from the sensors. On even-numbered frames, the timers are read, and the time for each sensor is converted to a physical distance. This is reported with an accuracy of 1.0 mm, with a range between 128 mm below and 129 mm above the datum.

Data Acquisition: GPS

GPS data are recorded less frequently than gyroscope or grade data. They are reported every second, or once every 30 frames. Interpolation between stations is done by "inertial navigation" by using gyroscope and DMI data.

Calibration Requirements

The Surveyor system needs to be calibrated to make geometric calculations. Two calibrations are required: a factory calibration and a field calibration.

Factory Calibration

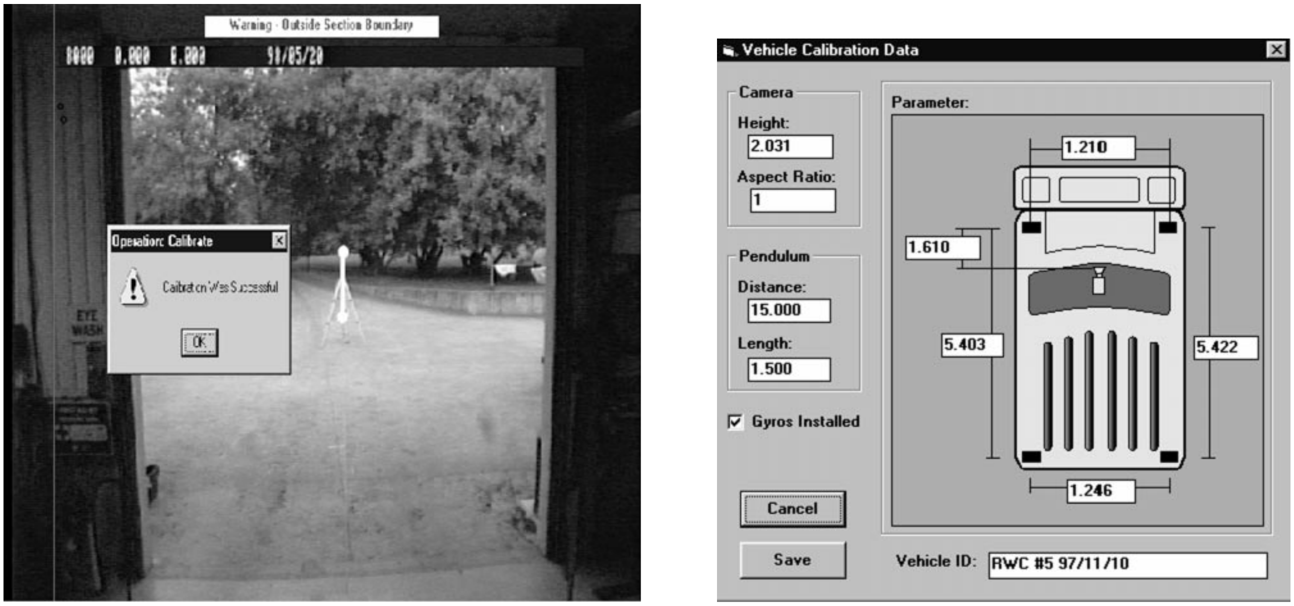
A factory calibration is done only once, during the production phase. It consists of various measurements and the positioning of a sighting hair on the vehicle windshield.

The measurements are concerned with the relative three-dimensional position of the camera focal point with respect to the grade sensors (for orientation and position with respect to the road surface) and the GPS antenna (for orientation and position with respect to global positioning coordinates). These measurements are recorded manually and are made part of an initialization file for the workstation software.

The second part of the calibration is done by placing a sighting hair on the windshield in the exact position so that the vector between the camera focal point and the sighting hair is parallel to the line of travel of the vehicle. This sighting hair is needed for the field calibration.

Field Calibration

A field calibration must be done once after the factory calibration and each time that the pan, tilt, or zoom of the camera is changed. A free-swinging pendulum target is placed at a fixed distance in front of the stationary vehicle and is positioned in the direction of the line



Operation: Calibrate

Calibration Was Successful

OK

Vehicle Calibration Data

Camera

Height: 2.031

Aspect Ratio: 1

Pendulum

Distance: 15.000

Length: 1.500

☑ Gyros Installed

Cancel

Save

Vehicle ID: RWC #5 97/11/10

FIGURE 8 Image used to calibrate Surveyor camera.

of travel by sighting through the sighting hair with a surveying level. A short calibration videotape is recorded, and later, from the tape, the scale and rotation of the camera are calculated, as is the angle between the median direction of the video camera with respect to the direction of travel (Figure 8).

Simultaneously, four hydraulically interconnected water buckets are placed below the four grade sensors to establish a horizontal datum. At the same time, the pitch and roll gyroscopes are nulled. The data collected by the sensors are automatically stored in a calibration file, which is linked to the calibration videotape.

POSTPROCESSING WORKSTATION

Principles

The Surveyor system allows the user to review the videotape, isolate a particular series of frames, and select objects on one or more images by pointing and clicking with a mouse. The Surveyor system isolates the location of that point in space. Use of subsequent mouse clicks allows the user to define the extent of the selected object, and on that basis, the Surveyor system quantifies the dimensions of the object. Each object is classified by a user-defined identification number and is stored in a database along with position and dimensions.

Hardware

The Surveyor workstation consists of a personal computer, multiple monitors, and VTRs (Figure 9). The computer uses an Optibase video capture card with JPEG hardware compression capability and incorporates live video overlay on the computer screen.

Software

The Surveyor workstation software (Roadware Corporation) is based on the Windows (Microsoft) operating system. The user interface and VTR control are coded in Visual Basic (Microsoft), whereas the geometric engines and data retrieval are coded as a dynamic link library under Visual C++ (Microsoft).

User Interface

The Surveyor screen has four distinct areas (Figure 9):

1. A menu bar that functions the same as that in any other Windows application.
2. The video area where the image is displayed and where all measurements are taken.
3. A VTR control bar that resembles the front panel of a VTR and that allows the viewer to review the tape and select a section of interest. This bar is subsequently replaced by a frame selector

FIGURE 9 Surveyor workstation.

(slider), which is used to access individual frames that have been digitized and stored in a memory buffer.

4. An object record area that allows the selection of type of object and recording of the appropriate measurements.

To make a measurement the user is required to

1. Use the VTR control buttons to advance the tape to the appropriate section;
2. Use the frame slider to select an image of interest;
3. Use the mouse pointer to click on a reference point on that frame (single-frame mode) or on the same reference point in two different frames (double-frame mode);
4. Move the pointer to cover the measurement required and click again;
5. Assign the measurement to a class of object in the object record area; and
6. Save the data in various file formats, DXF (Autocad), GPS, or ASCII, or a number of database file formats.

Geometric Engine

When the user selects a point (pixel or picture element) on the image, it is sent to the geometric engine. Each pixel on the video frame represents a vector in space. The *x,y* coordinates of the pixel are converted into a "direction vector," initially with respect to the median vector of the video camera. This vector is first rotated with respect to the pan, tilt, and roll of the camera by using the camera calibration information. In the multiple-frame mode, the vector is then rotated to adjust for the pitch and roll of the vehicle with respect to the horizontal using the gyroscope data. In single-frame mode the vector is rotated to adjust for the pitch and roll of the vehicle with respect to the plane of the road surface by using the grade sensors.

Geometric Engine Single-Frame Mode

Single-frame mode involves intersection of the direction vector with the idealized plane of the road, resulting in the calculation of an offset from the camera *x,y,z* coordinates. By using the geometrics database, the precise position of the camera is calculated for that video frame. The offset is then added to that position.

Second and subsequent points can be used to measure any lengths contained in the plane that is perpendicular to the line of travel and that contains the initial point. In this case, the direction vector is intersected with that vertical plane instead of the plane of the road.

Inaccuracies in the single-frame mode method arise from the fact that the initial point selected by the user must be in the plane of the road. This is typically difficult when one is selecting objects in the ditch. Geometrically, it is not possible to reject any point for this reason, as any selected point below the horizon has a unique solution.

Geometric Engine Multiple-Frame Mode

In the multiple-frame mode, two or more direction vectors intersect at the object being measured. They originate from different points in space and time. Since the origins of all the vectors can be determined by the geometrics, identification of the coordinates of the object is trivial. In the case of two vectors, only the point of intersection needs to be calculated. In the case of three or more vectors, a least-squares algorithm is used to determine the point of intersection.

In the multiple-frame mode there is a singularity if both direction vectors are parallel to the direction of travel of the vehicle. In this case no measurement is possible. Similarly, when both direction vectors are nearly parallel to the direction of travel, large errors are possible.

SURVEYOR APPLICATIONS

Application Areas

Sign Management

With Surveyor, the user is able to quickly establish an initial sign management database. Surveyor can be used to capture most of the key items in a sign management database:

1. Location (linear reference),
2. Offset,
3. *x,y,z* location,
4. Sign face dimensions (height, width),
5. Sign type,
6. Number of support posts,
7. Type of support post,
8. Direction of sign face,
9. Visual condition assessment, and
10. Legend.

After a period of time, the surveying process can be repeated and the results can be compared. As a result, missing signs can be identified and replaced.

Geographic Information Systems

When used in conjunction with the GPS data stream, Surveyor can be used to geographically code the roadway centerline, edge, and shoulder along with the location and type of various roadside appurtenances (such as guide rails or signs) with greater accuracy than that generally obtained from paper maps.

Guide Rail Inventory

With this type of application, the user can easily catalog guide rail locations and offsets, along with a variety of attributes:

1. A guide rail start or end event can be entered.
2. Guide rail position (left, middle, or right side) can be entered.
3. End treatments can also be entered through the icon menu. These are user configurable and might include, for example, buried, bridge connection, breakaway cable terminal, end anchor, impact attenuator, and sloped concrete end treatments.
4. The spacing between posts can be measured by using the depth measurement feature.

201459 Frame Number

Frame: 5432 / 7931

```
SECTID ROUTE CO FSEG TSEG R#  D L W TAPE
110250 0339  19 0010 0450 01  1 1 1 7159
 14.476  14.470  45.5 97/10/21     201459
```

1: End Treatment\2 - Buried

2: Guide Rail\D - SP W, OB\6'

Chng.(2) 22.349

Height -1.367

Offset 8.566

abs ☐

Location: right

Missing or Defective: ☐

Height Deficient: ☐

Post Deflection: low

Cable Sag: none

Deterioration: low

Desc:

Terminated: ☒ ✓ ✓

201459 Frame Number

Frame: 5432 / 7931

```
SECTID ROUTE CO FSEG TSEG R#  D L W TAPE
110250 0339  19 0010 0450 01  1 1 1 7159
 14.476  14.470  45.5 97/10/21     201459
```

1: Shoulder Width

2:

Chng.

Height

Offset

abs ☐

Location: righ

Missing or Defective: ☐

Height Deficient: ☐

Post Deflection: non

Cable Sag: non

Deterioration: non

Desc:

Terminated: ☒ ✓ ☒

Object List

199084	13.453	R	End Treatment\2 - Buried\\\
199084	13.453	R	Guide Rail\D - SP W, OB\6'\\
199089	13.463	L	End Treatment\2 - Buried\\\
199089	13.463	L	Guide Rail\D - SP W, OB\6'\\
199254	13.528	L	End Treatment\1 - Fist\\\
199344	13.565	R	End Treatment\2 - Buried\\\
201429	14.472	L	End Treatment\2 - Buried\\\
201429	14.472	L	Guide Rail\C - SP W, RR, OB\6' 2-S\\
201459	14.481	R	End Treatment\2 - Buried\\\
201459	14.481	R	Guide Rail\D - SP W, OB\6'\\

FIGURE 10 **Classification of shoulder width measurement.**

Bridge Inventory

Bridge beginning and end points and width can be recorded with the system.

Highway Performance Monitoring System Data Collection

Surveyor can be used to record a number of data items for the Highway Performance Monitoring System. These include number of lanes, lane width, and shoulder width.

Visual Historical Record

Many agencies prepare video logs to create a visual historic record. These images often prove invaluable during tort liability cases and to help determine whether or not an agency was liable in a specific case.

A visual record provides an agency with a fair-weather view of its pavement and right-of-way. It can also be used to visually monitor pavement or feature deterioration over time.

Landmark Survey

Surveyor can be used to create the baseline for a liner referencing system by means of a landmark survey. Each significant landmark can be located, described, and cataloged from the video screen. A key advantage to this approach is that if the landmark can readily be observed from the computer screen, then it should be easy to locate in the field. These data can also be used in a geographic information system.

Surveyor Implementations

Surveyor is being used for a variety of applications by highway agencies throughout the world. These include the following:

1. In Rhode Island, Surveyor was used as part of a comprehensive sign inventory covering some 2900 centerline km (1,800 centerline mi) and 60,000 signs. Data items included signpost location and offset, sign height, face width and height, Manual on Uniform Traffic Control Devices classification, and direction of sign face.
2. In Pennsylvania, Surveyor is being used to create a guide rail inventory on approximately 80 500 km (50,000 mi) of roadway. Guide rail position, offset, condition, and end treatment are recorded. In addition, shoulder width (Figure 10) and type along with traffic light location and type are being recorded.
3. Arkansas collects bridge width, lane width, and shoulder width, among other data items, with the Surveyor system.
4. Massachusetts uses the system to measure lane width and determine sign locations.
5. Siproma (a data collection company based in Italy) uses the system to geographically code signs and other roadside appurtenances.

SUMMARY

Surveyor is a promising new technology that transportation agencies can use to complete a thorough inventory of roadside structure, features, and landmarks in a fraction of the time that it would take to do in any other way. It is a technology that is not only fast but that is also unobtrusive and safe for the workers. It can provide comprehensive data that can be used directly in databases or geographical information systems. It is being used as a cost-effective solution to the task of inventorying large amounts of infrastructure in times of shrinking budgets and increasing threat from litigation.

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