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Surveyor[®] :

MOBILE HIGHWAY INVENTORY AND MEASUREMENT SYSTEM

Norbert H. Maerz, University of Missouri-Rolla, 1006 Kingshighway, Rolla MO, 65409-0660, USA. Tel: (573) 341-6714, Fax: (573) 341-4368, e-mail: norbert@umr.edu.

Steve McKenna, Roadware Corporation, 147 East River Road, Paris, Ontario, N3L-3T6, Canada. Tel: (519) 442-2264, Fax: (519) 442-3680, e-mail: smckenna@roadware.com.

ABSTRACT

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, managing, 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 compliment 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 time code to synchronize to the geometric and position databases.

The interactive (post processing) part of the system uses a workstation to retrieve and buffer the video for the user to identify targets, 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 using triangulation, or on single images using the idealized plane of the highway as a reference.

KEYWORDS

Mobile data collection, Highway measurements, Instrumented vehicle, Highway inventory management, Infrastructure management.

1. INTRODUCTION

1.1 Highway Inventories

The inventorying of roadside and overhead facilities along the nations 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, using signs as an example, may be subject to regulations or specification, in terms of their size, positioning, or visibility. Consequently, to verify 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. To measure these parameters is a time consuming and costly manual

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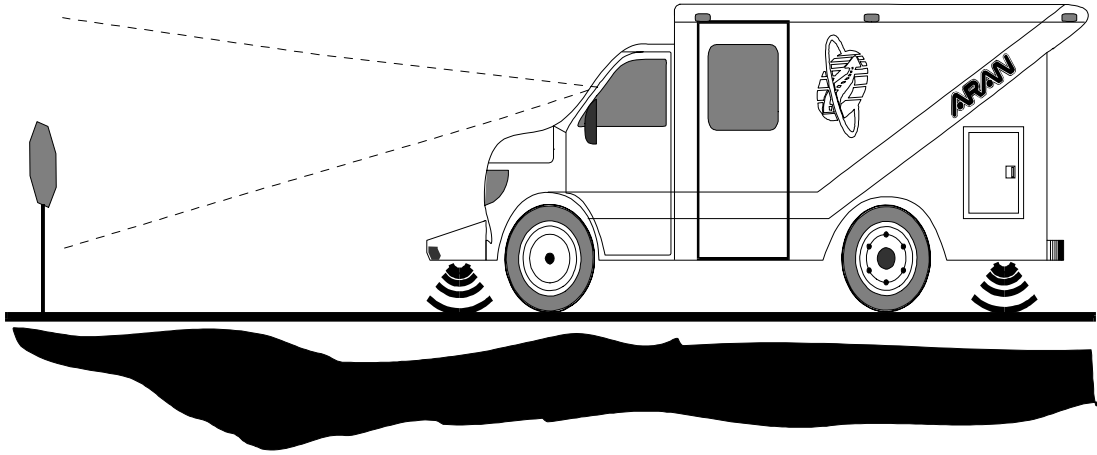


Figure 1. Schematic of a data acquisition vehicle showing the right of way video and the grade sensors.

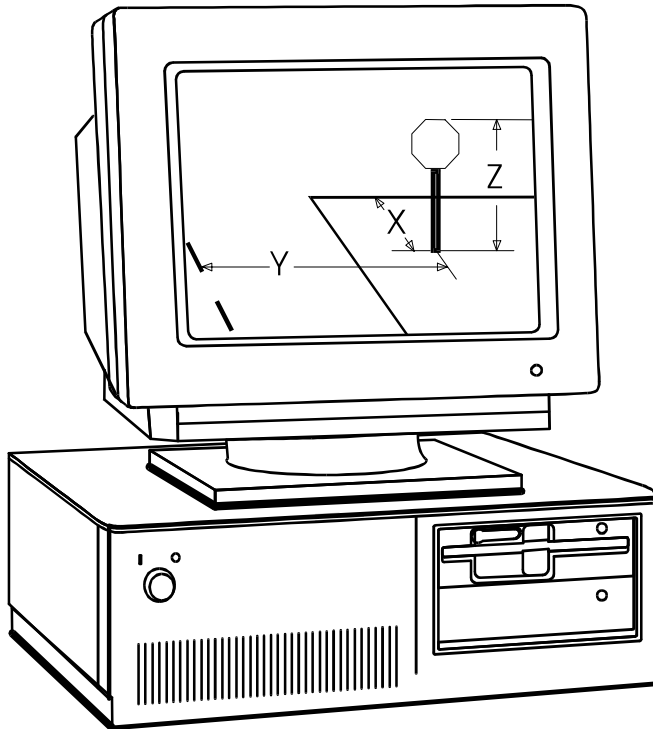


Figure 2. Schematic of a workstation to analyze the video images.

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exercise. Furthermore, it may be necessary from time to time to verify that the sign has not deteriorated to the point where its visibility is compromised, or become vandalized, or damaged from snow plowing. From the viewpoint of protection from future litigation, a pictorial record of compliance may be prudent. All this effort is costly in terms of man-hours and dollars, requiring not only the time to make these measurements, but also the time involved to travel to and between sites. In addition there is risk to worker safety when working and parking vehicles on the shoulders of busy highways. And, after all of that, the data gleaned from this intensive investigation (of a single sign) needs to be entered in some type of database management system.

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

1.2 Automated Road Facility Inventory System

The solution to efficient inventorying of highway facilities lies in modern technology. Surveyor is a mobile right of way inventory/measurement system that can visually capture and accurately locate roadside features, while moving at highway speeds (1). It consists of a two part system: A fully automated mobile data collection vehicle (Figure 1), and a post processing workstation (Figure 2), where 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 identifying a feature and incorporating it into a database. For manual measurements, the turnaround time is typically much longer, and there may be significant effort and disruption involved with traffic control and diversion. 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 considering the capital costs involved with obtaining the equipment.
3. Data collected will be more objective, more accurate, and uniformly reported. Manual measurements are typically conducted by various different crews, with varying degrees of subjectivity in measurements and reports. Depending on the competence of the crew, the weather conditions, and the degree of fatigue among the crew, there may tend to be more errors in manual measurements.
4. A permanent record is established with this technology. Measurements can be repeated at any time, by re-analyzing the video without returning to the field.

2. AUTOMATED MOBILE DATA COLLECTION SYSTEM

2.1 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, 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 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 is retained, and 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.

2.2 Hardware

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

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Figure 3. Cab mounted video camera in the data collection vehicle.



Figure 4. Roof mounted video for panoramic view.

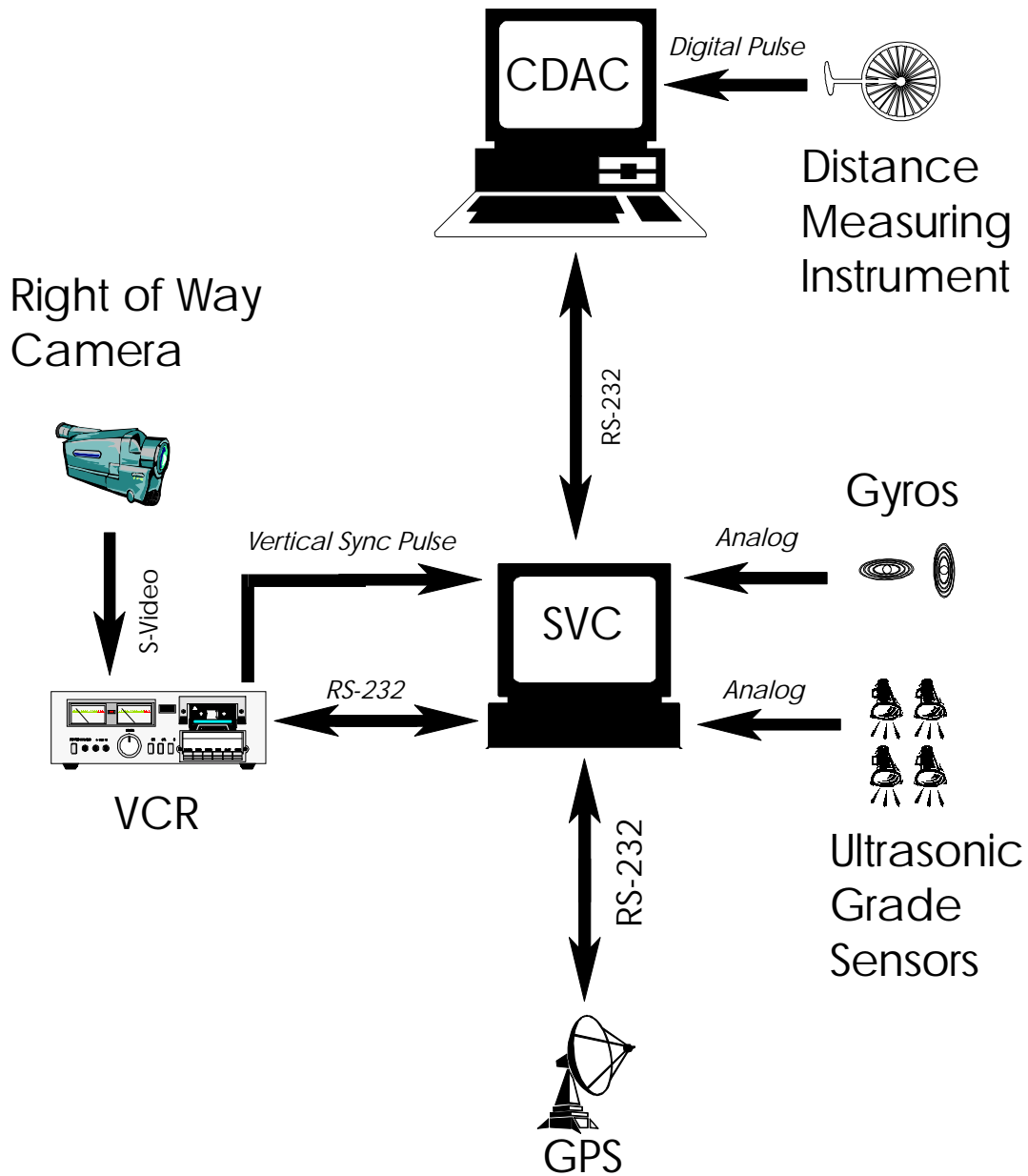


Figure 5. Schematic of information flow between the Central Data Acquisition Computer (CDAC), Smart Video Controller (SVC) computer, video tape recorder (VTR) and the various sensors.

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Video

The system uses any PAL or NTSC color right of way (ROW) video camera capable of S-video output. The images are stored on an S-VHS video recorder with (SMPTE) timecode capabilities. Images are indexed by frame numbers, which are stored on the video tape 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 video tape, adds time code to the video tape, 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 using a distance measuring instrument (DMI), which uses an optical shaft encoder on the drive axle to count wheel rotations at 1800 pulses per revolution. The DMI is calibrated by driving the vehicle over a measured distance of at least 1 km, and is considered to be accurate within 0.02%. 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 on board computers.

Geometrics: Gyro based roll, pitch, and heading

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

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, which measure the distance between the vehicle chassis and the road pavement surface at 1/15th second intervals. These are also collected by the SVC and sent to the CDAC.

Geometrics: Global positioning system (GPS)

An optional GPS system is used for more accurate position information. Standard or differentially corrected GPS can be used with a maximum resolution of up to about 1 meter. GPS data comes to the SVC from a dedicated GPS processor.

2.3 Software

Operating System

The SVC data acquisition software is based on the QNX[®] operating system. QNX, a unix-like operating system, which 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 the SVC is coded in the “c” language and has no user interface, but is controlled by and reports to the CDAC.

VTR Control

At the beginning of the data collections run, the VTR is powered on by a relay using a TTL digital output signal, and the tape is initialized and positioned by programming the VCR on a serial interface. When data collection actually starts, the VTR is started and interrogated for the starting video frame number.

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Figure 6. Cutaway of the data acquisition vehicle showing video cameras, computers, video recorders and camera.

Timing of Data Acquisition

Timing of data acquisition is taken off the vertical blanking pulse from the video tape recorder (VTR). The SVC computer sees this as a hardware interrupt, and tracks frame numbers by counting interrupts which occur every 1/30 sec. Every 2nd frame (even frame), a data acquisition sequence is initiated. This is in order to reduce the amount of data that needs to be recorded. (Data is interpolated between even frames for every odd frame).

Data Acquisition: Gyroscopes

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

Data Acquisition: Ultrasonic Grade Sensors

On odd 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 frames, the timers are read, and the time for each sensor is converted to a physical distance. This is reported with the accuracy of 1.0 mm, with a range between -128 to +129 mm above the datum.

Data Acquisition: GPS

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

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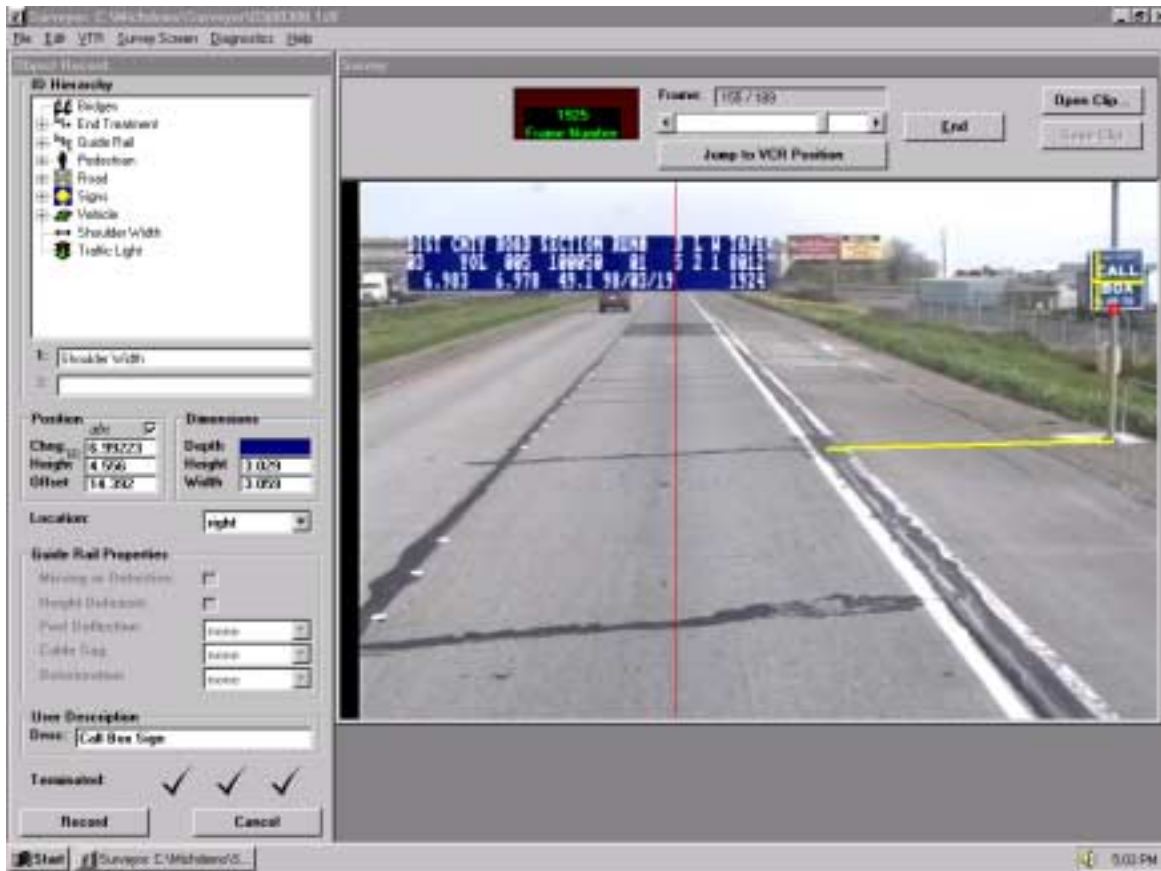


Figure 7. Screen dump of the Surveyor workstation showing the measurement and inventorying of a call box.

2.4 Calibration Requirements

The Surveyor system needs to be calibrated in order 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 manually recorded and made part of an initialization file for the workstation software.

The second part of the calibration is done to place 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 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 positioned in the direction of the line of travel by sighting through the sighting hair with a surveying level. A short calibration video tape is recorded, and later from the tape, the scale and

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rotation of the camera is calculated, as well as the angle between the median direction of the video camera with respect to the direction of travel (Fig. 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 gyros are nulled. Data collected by the sensors are automatically stored in a calibration file, which is linked to the calibration videotape.

3. POST-PROCESSING WORKSTATION

3.1 Principles

The Surveyor system allows the user to review the video tape, 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. Using subsequent mouse clicks allows the user to define the extent of his selected object, and on that basis, the Surveyor system quantifies the dimensions of the object. Each object is classified by a user defined ID, and stored in a database along with position and dimensions.

3.2 Hardware

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

3.3 Software

The Surveyor workstation software[®] is based on the Windows[®] operating system. The user interface and VCR control are coded in Visual Basic[®], while the geometric engines and data retrieval are coded as a dynamic link library under Visual C++[®].

User Interface

The Surveyor screen has four distinct areas (Figure 4):

1. A menu bar that functions the same as in any other Windows Application
2. The video area where the image is displayed, and all measurements are taken.
3. A video tape recorder (VTR) control bar that resembles the appearance of the front panel of a VTR, and allows the viewer to review the tape, and select a section of interest. This bar is subsequently replaced by a frame selector (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.
6. Save the data in various file formats, DXF (autocad), GPS, ASCII, or a number of database file formats.

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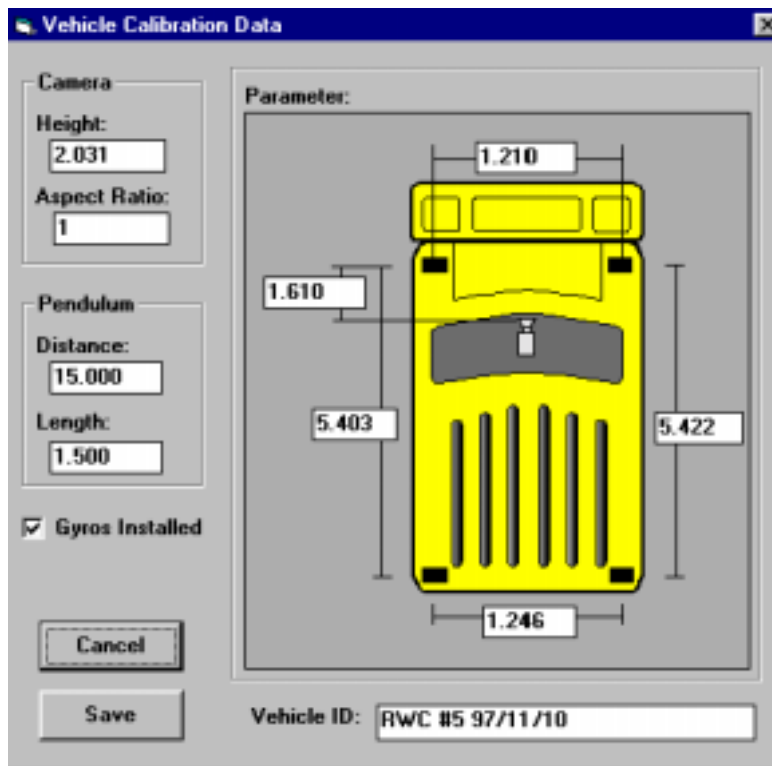


Figure 8. Calibration image used to calibrate the Surveyor camera.

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Figure 9. Surveyor workstation.

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, using the camera calibration information. In 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 gyro data. In single frame mode the vector is rotated to adjust for pitch and roll of the vehicle with respect to the plane of the road surface using the grade sensors.

Geometric Engine Single Frame Mode

Single frame mode involves intersecting the direction vector with the idealized plane of the road, resulting in the calculation of an offset from the camera x, y, z coordinates. 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 contains the initial point. In this case, the direction vector is intersected with that vertical plane rather than the plane of the road.

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Inaccuracies in the single frame 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 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 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 origin of all the vectors can be determined by the geometrics, identifying 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 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 near parallel to the direction of travel, large errors are possible.

4. SURVEYOR APPLICATIONS

4.1 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. XYZ 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
10. Legend

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

Geographic Information Systems (GIS)

When used in conjunction with the GPS data stream, Surveyor can be used to geocode the roadway centerline, edge and shoulder along with the location and type of various roadside appurtenances (such as guide rails or signs) more accurately than what is 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. Guide rail start or end event.
2. Guide rail position (left, middle or right side).
3. End treatments can also be entered through the icon menu. These are user configurable and might include: buried, bridge connection, breakaway cable terminal, end anchor, impact attenuator, sloped concrete end, etc.

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4. The spacing between posts can be measured using the *depth* measurement feature.

Bridge Inventory

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

HPMS Data Collection

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

Visual Historical Record

Many agencies perform 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 linear referencing system by means of a land mark 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 be readily observed from the computer screen, then it should be easy to locate in the field. This data can also be used in a GIS.

4.2 Surveyor Implementations

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

1. Rhode Island – Surveyor was employed as part of a comprehensive sign inventory covering some 1,800 centerline miles and 60,000 signs. Data items included: signpost location and offset, sign height, face width and height, MUTCD classification, direction of sign face.
2. Pennsylvania – Surveyor is being used to create a guiderail inventory on approximately 50,000 miles of roadway. Guiderail position, offset, condition and end treatment are recorded. In addition, shoulder width (Fig. 10) and type along with traffic light location and type are being recorded.
3. Arkansas – Bridge width, lane width and shoulder width are a few of the data items that Arkansas collects with the Surveyor system.
4. Massachusetts – The state uses the system to measure lane width and determine sign locations.
5. Siproma – Siproma (a data collection company based in Italy) uses the system to geocode signs and other roadside appurtenances.

5. SUMMARY

Surveyor is a promising new technology for transportation agencies to complete a thorough inventory of roadside structure, features and landmarks, in a fraction of the time it would take to do in any other way. It is a technology that is not only fast, but 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

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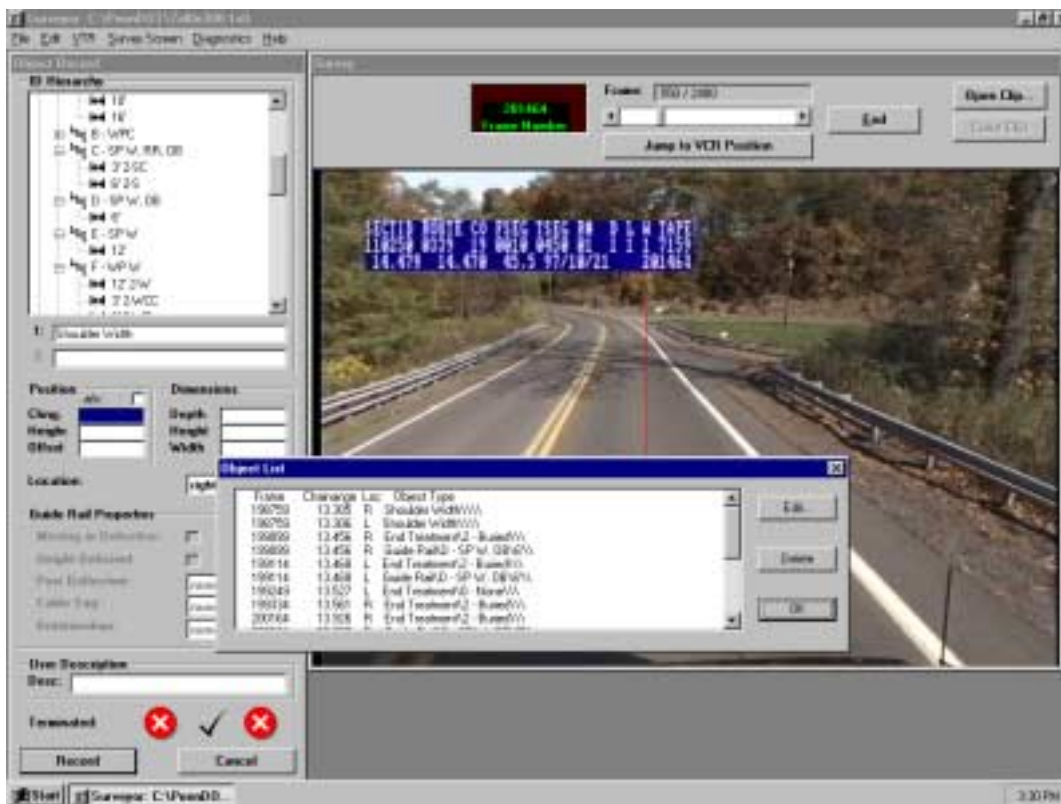
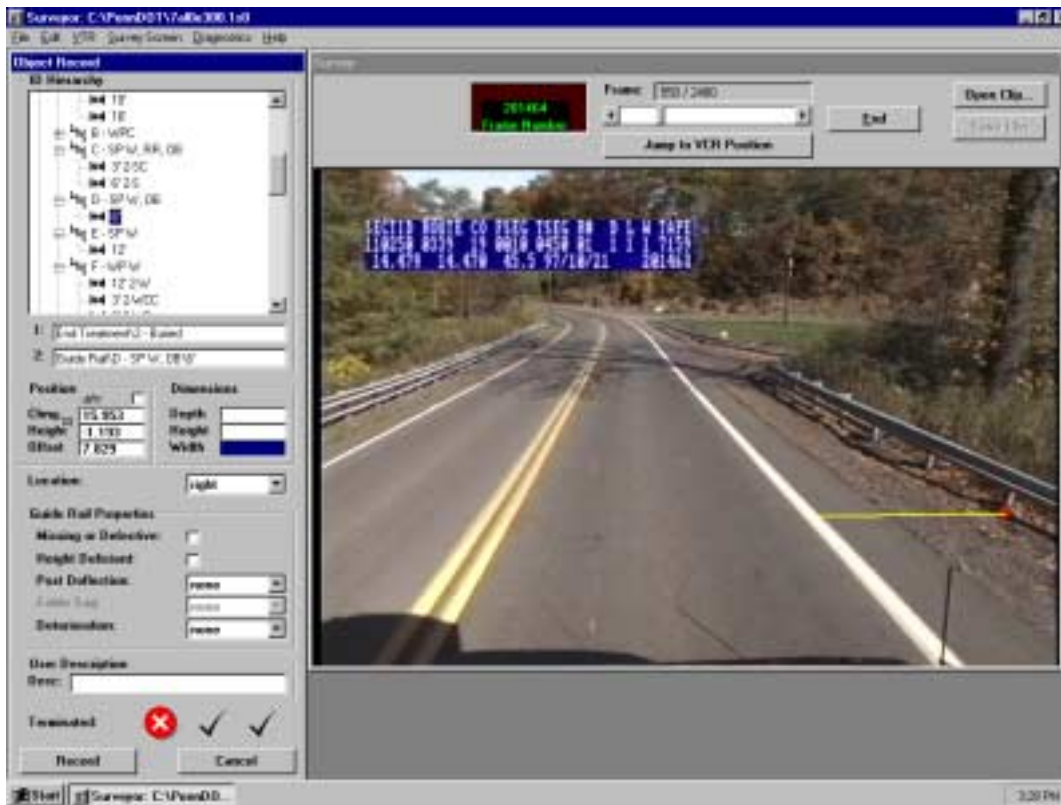


Figure 10. Classifying the shoulder width measurement.

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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.

6. REFERENCES

(1) Mastandrea, A, Swindall, B, and Klassen, G, 1995. Development And Implementation Of An Automated Facility Inventory System. In *Transportation Research Record 1500*, pp. 127-133.

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