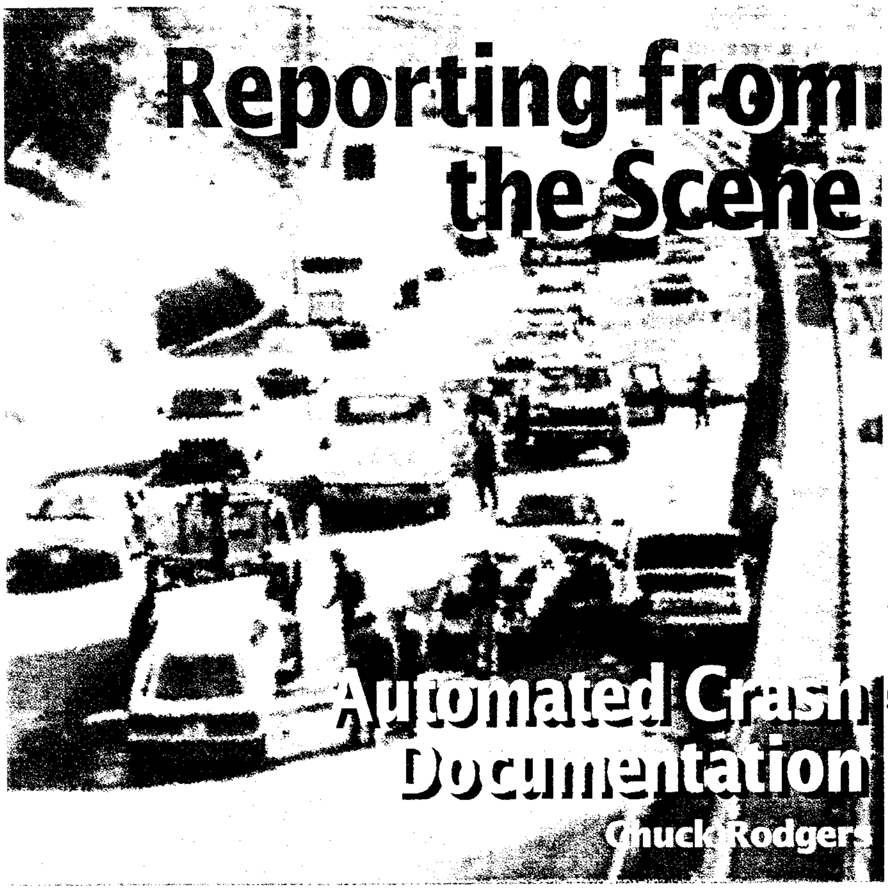
Reporting from the Scene

Automated Crash Documentation

Chuck Rodgers



Oregon Department of Transportation

The Automated Documentation of Crash Scenes using GPS (AutoDOCS-GPS) provides police officers with a faster, more accurate way to record and analyze vehicle positioning after a crash. This can help increase road and vehicle safety.

Chuck Rodgers, *chief technical officer of OPTIMUS Corporation, received his BSEE and MSEE from the Georgia Institute of Technology. He has worked with military and civil GPS for fifteen years, and has received four patents for applications of GPS carrier-phase technology. He is currently developing a GPS-based pedestrian alert system for the Federal Highway Administration, and was a technical contributor to the Volpe NTSC and Department of Transportation's study of the Vulnerabilities of the Transportation Infrastructure Relying on GPS.*

Driving an automobile is one of the most dangerous activities in which people routinely engage. The National Highway Traffic Safety Administration (NHTSA) is the agency in the federal government charged with minimizing that danger throughout the United States. One method they use is to analyze crash scenes to determine the factors that contribute to their occurrence. The knowledge gained can then help promote safer roadways and vehicles.

NHTSA has teams of crash researchers across the country who document crash scenes after the local authorities have completed their investigation. The goal of the documentation is to accurately capture the physical aspects of the scene, as the position and orientation of vehicles relative to each other and roadway features are important to determining the crash dynamics and cause.

In addition, at the state and local level crash investigators analyze crash scenes to determine civil and criminal liability, and increasingly seek to use the data to improve the design of the roadways they oversee. Both local investigators and NHTSA use similar procedures to capture the scene.

The investigator first examines the scene to determine elements important to crash depiction. The most common means of measuring a scene are still manual: tape and wheel measures to a resolution of one inch. Measurements are handwritten and object positions are calculated manually. The scene is sketched roughly to scale, with added keys to scale and measurements. Most often this is the final form of the data.

In this form, it is impossible to correlate the thousands of crash scenes on which NHTSA has documentation. In addition, when states use crash data from local jurisdictions in their roadway analysis, standardized crash reports are important to efficiently correlate data from scores of crashes at a particular intersection.

Recently computer drawing programs have aided crash documentation but the investigator must still scale and orient the objects manually, as well as label the measurements manually. Other modern tools include laser range finder systems for scene measurement but these systems are expensive, fragile, require high maintenance, are not all-weather, and require line of sight between the measurement points. Since the laser systems only provide measurement point coordinates, a drawing program has to be purchased in addition to the measurement equipment.

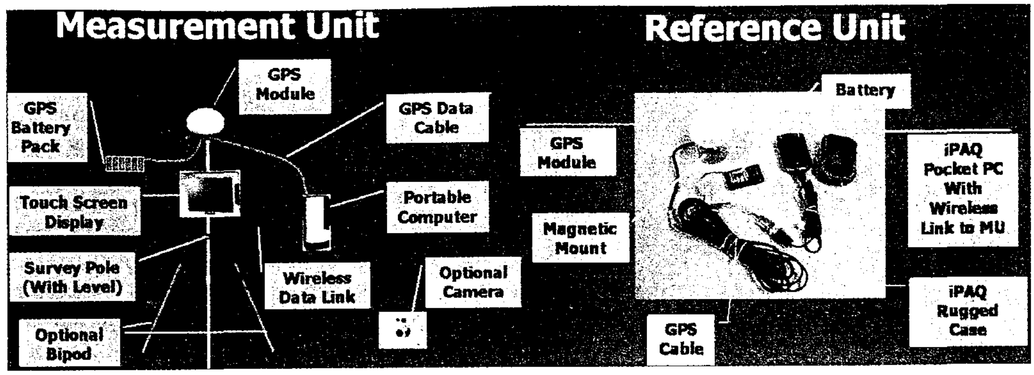
To determine a crash scene's absolute location in latitude and longitude, the investigator has to add a GPS receiver to a laser system. Only large jurisdictions can afford the training, equipment, and maintenance costs of such systems, and they are only used for major crashes.

NHTSA contracted with Optimus Corporation under the Small Business Innovative Research (SBIR) program to develop AutoDOCS, a GPS based system that would provide more accurate scene measurements than manual methods and produce data in a form that can be readily stored, transmitted, and analyzed. Optimus demonstrated proof-of-concept through a trial that compared GPS scene measurement to measurements made by expert crash investigators from a major northern Virginia county. We used a Least-Mean-Squares (LMS) algorithm to determine the kinematic positions of scene points to within a few centimeters accuracy. By comparing the time required for the measurement of each scene, we also determined that AutoDOCS will be three to five times faster than conventional scene documentation methods.

AutoDOCS Features

AutoDOCS was designed to provide features desirable to NHTSA and to local crash investigators. Its major features include:

- Better than two centimeters RMS base measurement accuracy
- Lower cost than alternative measurement and documentation systems
- Procedure guidance and automatic data recording
- Standardized electronic data for efficient analysis, transmission and storage
- Automated computer-aided design (CAD) drawing and text report
- Rapid single investigator operation
- Ability to incorporate supplemental manual or laser measurements



AutoDOCS measurement unit (left) and reference unit (right)

Our testing has demonstrated a base accuracy (no user-induced errors) of less than a centimeter on typical crash scenes. This is much better than the current one-inch (2.54-cm) resolution of manual measurements. In addition, three- dimensional scene measurement data is available.

As AutoDOCS automatically records and processes the data, it will have better integrity than manually recorded data and calculated results. AutoDOCS also prompts the user to take sufficient measurements to define each object to further enhance scene documentation integrity. The user prompts and simple graphical user interface (GUI) should reduce training costs, and single person operation further reduces personnel costs.

AutoDOCS supports the entire set of NHTSA's Minimum Model Uniform Crash Criteria (MMUCC) but allows the user to select only those fields for which they desire to collect data. These preferences can be saved as a template so the user is only queried about those data elements. The user also can create a format template for the text report so that the data are ordered as desired. Another type of template provides the ability to save measurements and drawings of the roadway and environment at crash "hotspots" such as a busy intersection so it does not have to be measured each time.

Upon completion of the scene measurements, AutoDOCS processes the data and automatically generate a scene drawing and text report from the measurements and data entered. Objects in the scene drawing are oriented and scaled to proper size without user intervention. In electronic format, the user will be able to click on objects that have digital pictures associated with them to see the photos. The user has the capability to modify the drawing or report.

System Architecture

As a kinematic differential GPS (KDGPS), AutoDOCS requires a Reference Unit (RU) and a Measurement Unit (MU). A kinematic system relies on measuring the change in the GPS signals' carrier phase to millimeter level as the user walks about the scene. Double differencing algorithms remove errors common to the RU and MU.

The RU is designed to be left at a fixed point near the scene such as at the investigator's car. It collects reference GPS data used to remove measurement errors common to both units. The photo above (right) shows the components of the RU (to scale); the same type of GPS receiver as the MU, and a PocketPC with ruggidized case. It can be powered from the vehicle power supply or its own battery.

Measurement Unit. The MU hosts the AutoDOCS software, and is used to enter scene data and perform the scene measurements. The scene measurements are processed in the MU, and the drawing and report are created within it. All scene data and products are stored there. The MU also interfaces to optional accessories such as a digital camera. The photo above shows the MU and an optional computer, camera, and optional bipod legs (not to scale). AutoDOCS was designed as an add-on to an existing portable computer but the optional computer shown is easier to use in the field than a laptop; the processor portion is worn on the belt or on the shoulder and the 1-pound, all-weather, truly daylight readable, wireless (802.11b) touchscreen is mounted on the survey pole.

The AutoDOCS software in the MU has four main modules; survey, processing, CAD, and report.

Survey Module. This includes the graphical user interface (GUI), receiver setup and control, and data collection. This entire module has been designed and developed by Optimus with the goal of minimizing the complexity and workload for the user. Most GPS functionality is hidden from the user who is not expected to be a GPS expert.

Processing Software. This consists of our KDGPS, extended Kalman Filter, and supporting algorithms.

CAD Component. This component uses a commercial-off-the-shelf (COTS) CAD package. Predefined drawing objects are available or various user-defined shapes can be used to capture any object's dimensions. We developed algorithms to automatically position, scale, and orient the drawing objects based on the scene measurements.

Report Module. This also is based on a COTS word-processing product, chosen for its ubiquity and because it, as well as the CAD tool, can be automated using Visual Basic programming.

The AutoDOCS-GPS software combines eight custom-developed software components written in several different software languages. Five of the eight custom developed software components are for the MU and the other three are used in the RU. The MU components are:

- AutoDOCS.VSD (drawing file)
- Kalman Filter.EXE (DOS Executable)
- TranferDecode.OCX (ActiveX Object)
- GPSComm.OCX (ActiveX Object)
- GPSConversion.DLL (Dynamic Link Library)

The RU components are:

- ReferenceUnit.exe (Windows executable)
- DataRecord.ocx (ActiveX Object)
- FileXfer.ocx (ActiveX Object)

The two principal elements are the AutoDOCS.VSD and Kalman Filter.EXE.

The double-difference, carrier-phase, kinematic Kalman filter was developed, tested with simulated data, then with field

$$X_K = \begin{bmatrix} \Delta X \\ \Delta \dot{X} \\ \Delta Y \\ \Delta \dot{Y} \\ \Delta Z \\ \Delta \dot{Z} \end{bmatrix}$$

EQUATION 1 where ΔX, ΔY, ΔZ = 3-dimensional ECEF vector-reference antenna to measurement antenna (meters)

$\Delta \dot{X}$ = rate of change (velocity) of the X-axis component of the vector between antennas (meters/second)

$\Delta \dot{Y}$ = rate of change (velocity) of the Y-axis component

$\Delta \dot{Z}$ = rate of change (velocity) of the Z-axis component

data in a Matlab environment. Then the algorithms were converted to executable code using the Matlab compiler for integration with the rest of the software in the MU.

The filter has six states, and the state vector is **Equation 1**. The initialization procedure requires that RU and MU antennas be brought together for 10 seconds to force the unknown integer carrier cycle ambiguities to zero. This enhances solution integrity and speeds operation by eliminating any search for the initial integer count.

As the investigator moves away from the RU, the MU continually measures the change in carrier phase due to his or her motion. Other common sources of phase change (satellite orbit errors, atmosphere, and so on) cancel when the MU and RU data are double-differenced in the Kalman filter, which calculates an accurate vector between the RU and MU for each second of the survey.

The focal point of the entire AutoDOCS software is AutoDOCS.VSD, a highly customized CAD application. AutoDOCS make extensive use of many of the built-in features of the CAD package but adds significant functionality through the use of SmartShape programming and the CAD package's Visual Basic for Applications (VBA) scripting language.

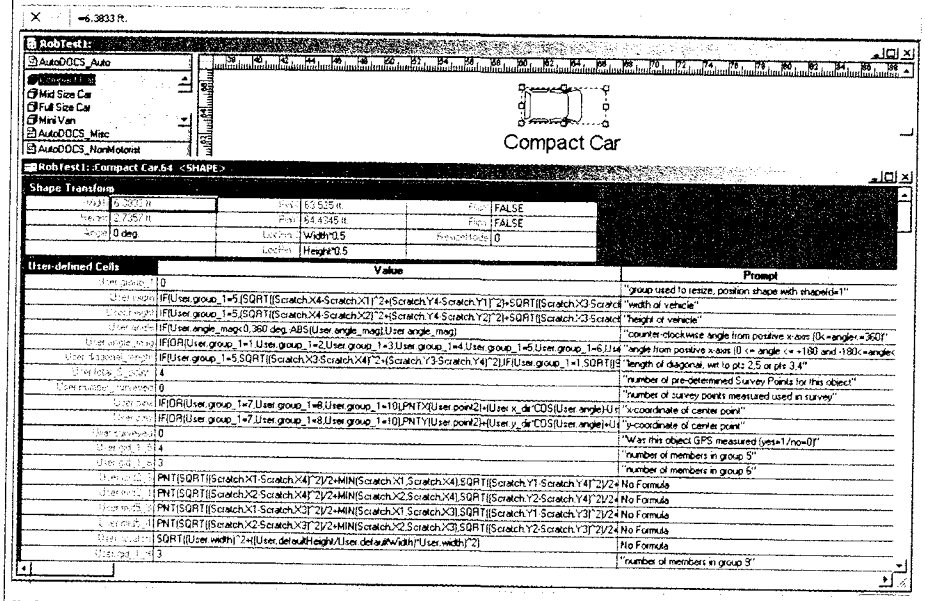


FIGURE 1 User-defined shapesheet section for calculating compact car size and orientation

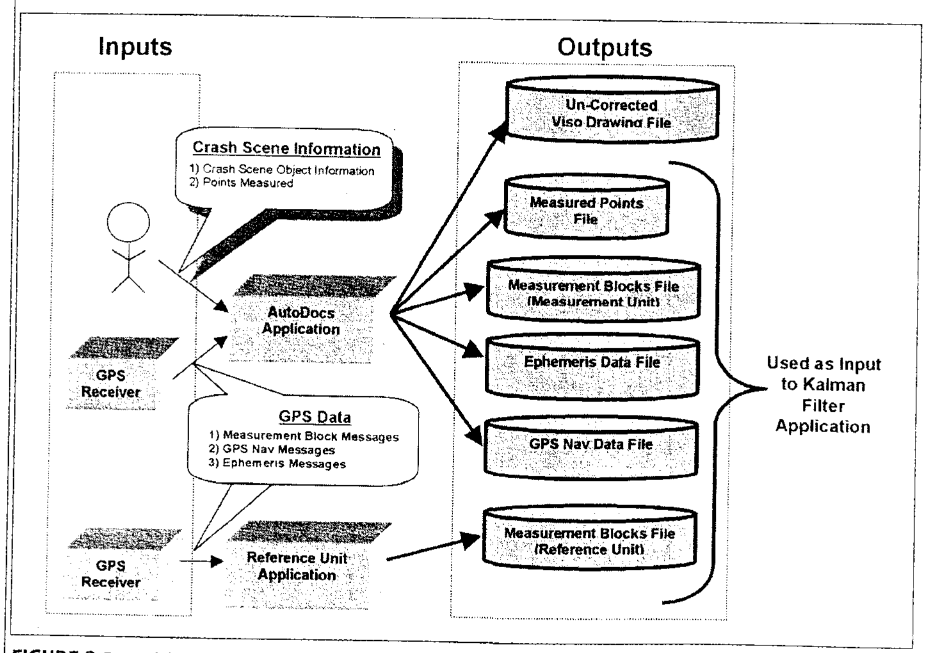


FIGURE 2 Data blocks exchanged in crash scene survey

Each custom SmartShapes required extensive development and a solid basis in geometry to derive novel equations that converted measured point positions to such things as line lengths and angles, defining the size and orientation of each type of crash object. The problem was greatly complicated by allowing for cases where an investigator takes too few points to completely define an elements size or orientation, and where more than the minimum points to define the object are collected. In the former case, assumptions must be made about such things as the ratio of the object's length to width. In the latter case, it is unlikely that the points perfectly define the shape so there is some mismatch in lengths and angles that must be resolved to properly specify the element.

Each SmartShape has a default, or basic, set of ShapeSheet elements supplied as a default. We added many new data items to all the SmartShapes using the sheet sections UserDefined and CustomProperties. **Figure 1** shows portions of the ShapeSheet for a Compact Car SmartShape.

The fields in the UserDefined section are mostly used for manipulation of the size and position of the shape with respect to GPS measured points on the shape. The fields in the CustomProperties section are used for holding MMUCC data elements associated with each SmartShape.

Data Flow

Three basic steps produce an accurate crash scene drawing with AutoDOCS:

- Survey crash scene objects using GPS
- Process GPS data with Kalman filter
- Update crash scene drawing with accurate GPS positions from Kalman filter.

Figure 2 shows the data blocks exchanged in the first step. Except for the uncorrected drawing file, the data files are produced by the MU and RU GPS receivers.

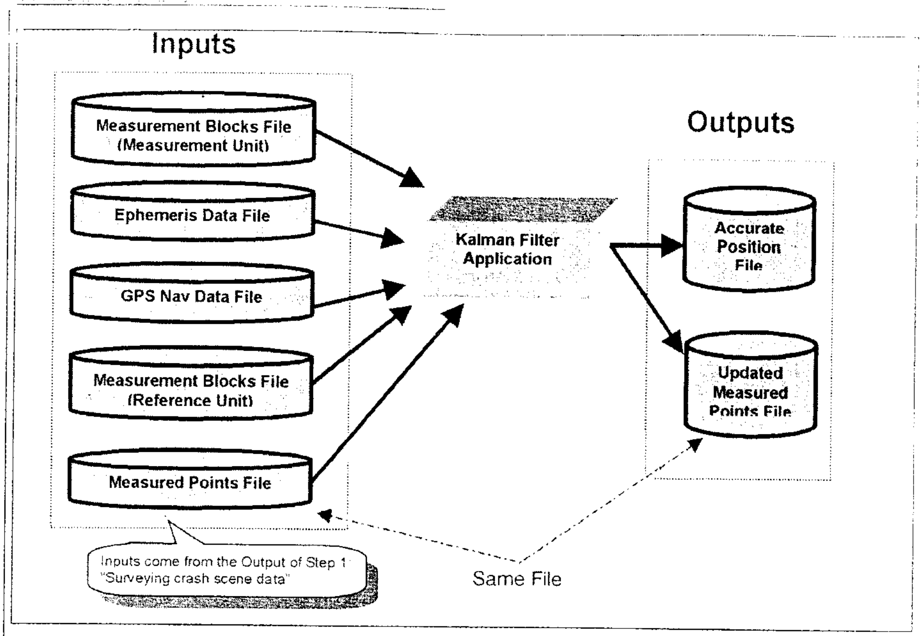


FIGURE 3 Datapaths through Kalman filter and product files

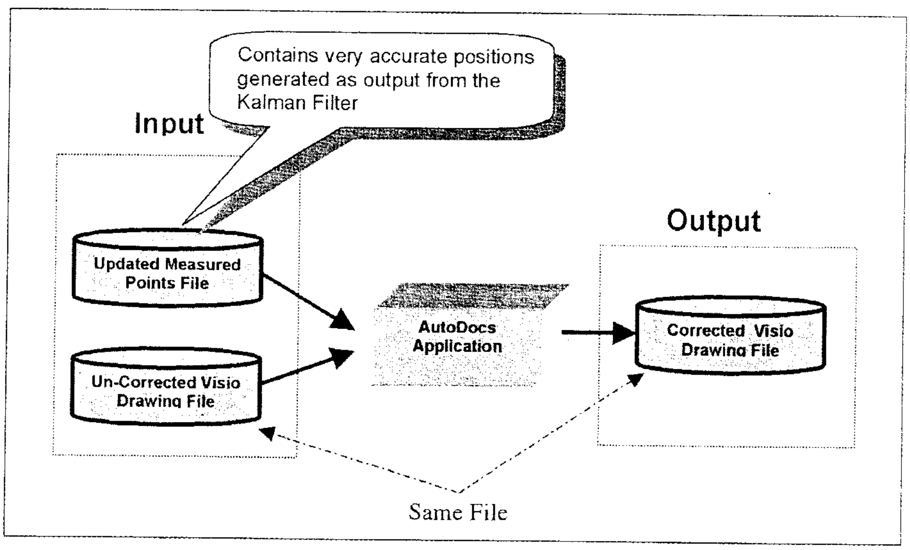


FIGURE 4 Process for recalculating files for CAD drawing

Note that all satellite information comes from the MU receiver and it is in Earth Centered Earth Fixed Coordinates (ECEF).

Figure 3 shows the data paths through the Kalman filter and its product files. The scene point files are in a local East, North, and Up (ENU) coordinate frame centered at the RU. **Figure 4** shows the process of recalculating the scene points using the Kalman filter ENU points and the custom VBA program.

AutoDOCS Operation

AutoDOCS operation was designed for simplicity by putting as many of the scene documentation tasks as possible into the system leaving the investigator free to concentrate on selecting the elements that best capture the scene. The investigator starts the process by examining the scene to determine which elements should be measured, and which scene data should be recorded. They then select the option on the AutoDOCS software that starts a new scene measurement. (The investigator also can return to a previous scene to add more measurements.) AutoDOCS prompts for basic scene information such as a name for the scene (**Figure 5**). Other than a scene name, used to segregate data files, the investigator can choose not to record any other information; it can be added later if desired.

For fields with limited responses, we placed dropdown boxes to speed data entry.

Next, the investigator selects scene elements to be measured by dragging and dropping them from the element menu on the left (**Figure 6**). The elements can be placed at any orientation and position. For each scene element selected, the investigator can enter information in the data fields they selected in their template for each type

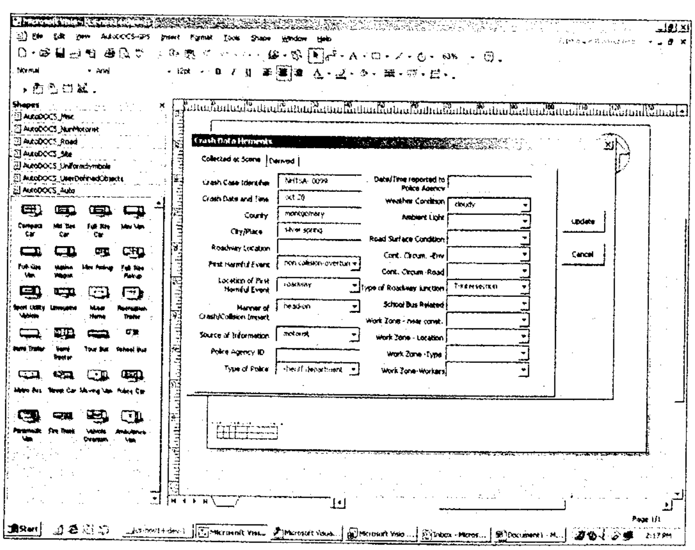


FIGURE 5 Basic scene data prompt

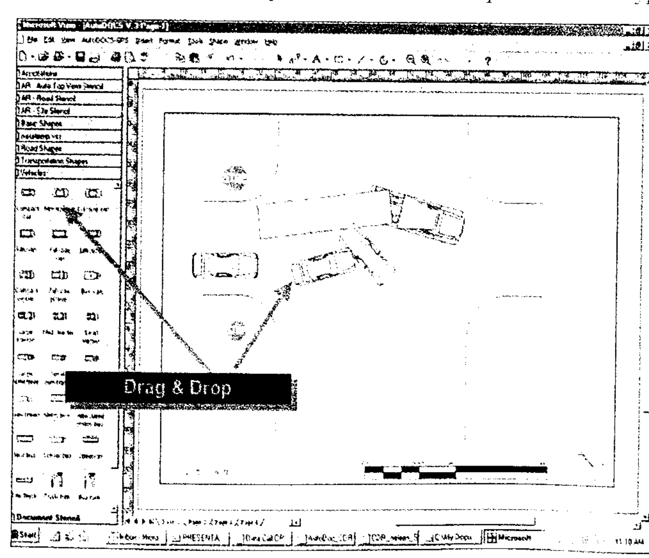


FIGURE 6 Selecting crash scene elements

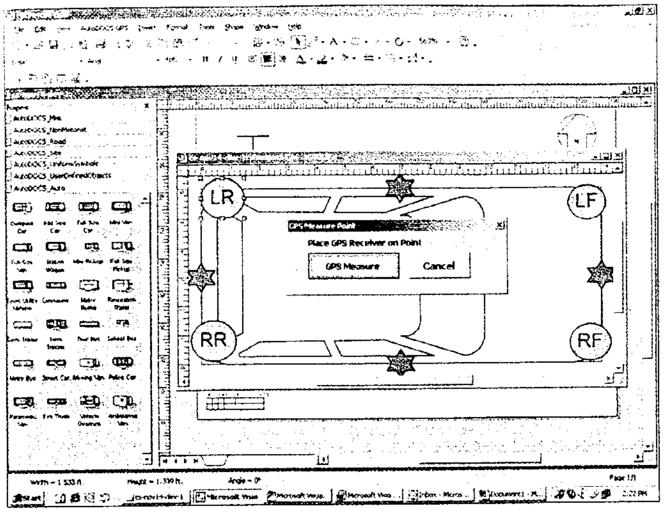


FIGURE 7 Scene element measurement screen

of object immediately, at a later time, or not at all. The user then takes the MU to the RU and starts each recording data. He/she initializes the scene measurement by holding the measurement antenna near the reference antenna and clicking on "synchronize." This helps ensure the carrier cycle ambiguity is resolved accurately.

The user chooses which object they want to measure by touching the object on the screen to display a much larger picture of the object with default measurement points (**Figure 7**). The user can take as many as they desire and even add more. However, if they take less than the minimum number that will produce an accurate scaled drawing, (that is, three points for a rectangular shape such as a car) they are reminded that without more points the object size will only be an approximation. AutoDOCS defaults to GPS measurements but the user can touch the menu to bring up a box to designate it as a manual or laser range finder measurement.

The user places the antenna stake on the point and touches the box to start the measurement. An audible and visual prompt indicates when the measurement period is complete. The default point measurement period is five seconds but it is configurable with the understanding that a shorter period may reduce the measurement accuracy.

The investigator also can measure user-defined crash elements, which are those which don't have a standard shape or don't have a predefined element in the menu. Elements such as an area of glass can be captured by selecting an N-point closed shape, which allows the user to trace around the area with as many points as they desire. The last point is connected to the first point to close the shape.

The measurement process repeats for all scene elements. The user then stops the RU data recording, and touches a button to start wireless transfer of data from the RU. The investigator can either select to process the data, create the drawing and report immediately, or it can be done later. Once the drawing and report have been automatically created, the investigator can use the full functionality of the CAD and word programs to modify or augment the drawing and report. **Figure 8** shows an example of a NHTSA report with drawing. We customize the report to match a jurisdiction's current accident report.

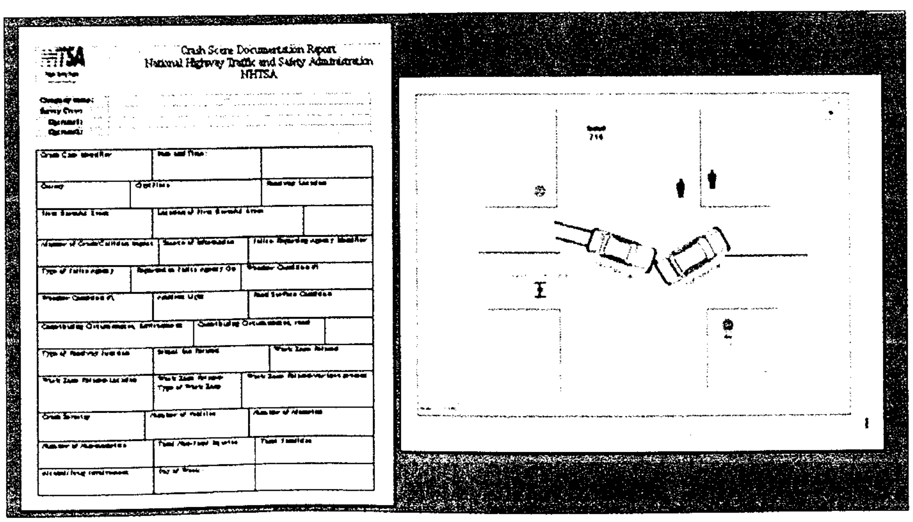


FIGURE 8 Sample crash report shown in preview screen

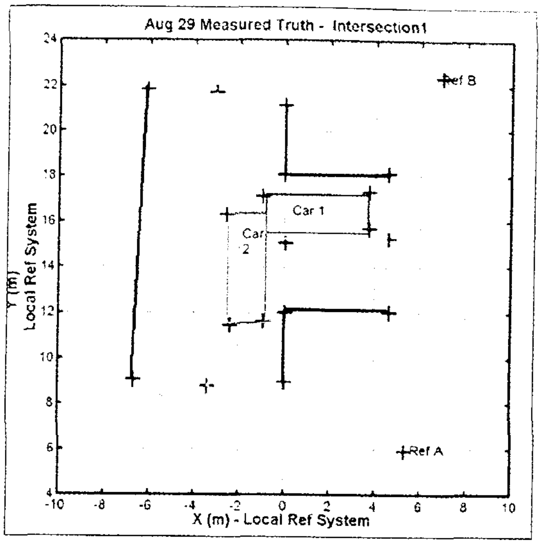


FIGURE 9A Sample accuracy test truth

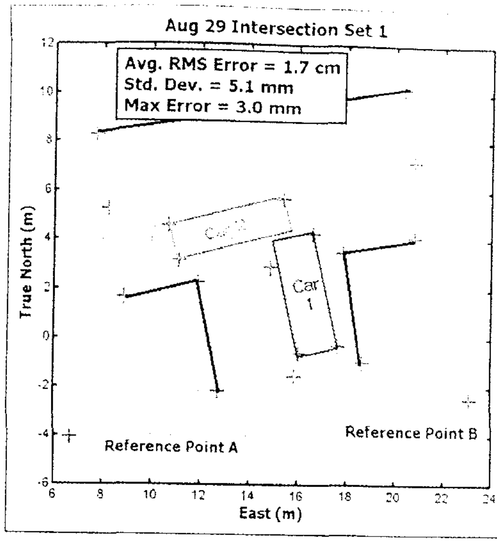


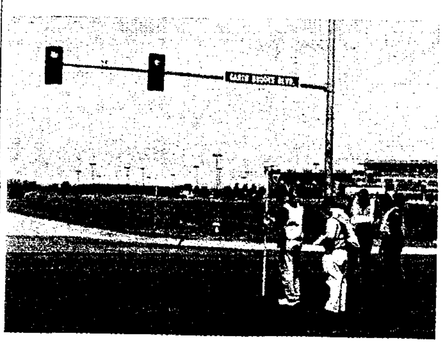
FIGURE 9B AutoDOCS measurement results

As mentioned previously, AutoDOCS supports other methods of taking measurements besides GPS including manual measurements (tape or wheel) and laser range finder. These types of measurements may be useful if part of the crash scene is in an area that cannot receive GPS signals such as a tunnel. Supplemental measurements are usually taken relative to GPS determined points but the accuracy of supplemental measurements depends on the method used to measure them.

AutoDOCS also supports the use of a digital camera to document the scene. The investigator can take pictures of objects and either assign them to the objects on the drawing or survey a "camera point". A camera point is a predefined drawing element surveyed as a single point that indicates the precise position from which a photo was taken.

System Test Results

We performed extensive testing of AutoDOCS. Optimus conducted the alpha testing, while Dunlap, experts in traffic safety and human factors, conducted the beta testing with NHTSA's crash investigation instructors in Oklahoma City and with local police crash investigators in Norwalk Connecticut. The alpha tests focused on confirming functionality and tuning the Kalman filter for accuracy.



Oklahoma City beta test observed by Yukon police officers

The goal of AutoDOCS is to produce a set of points that accurately reproduce the scene dimensions (distances) relative to all other points in the scene. To test the GPS measurement accuracy, Optimus outlined crash scenarios onto an asphalt surface, and carefully measured the scene points manually. **Figure 9** gives a representative example of two cars that collided at an intersection. Fortunately, this was a GPS accuracy test, not a construction survey test; we would have failed the latter as evidenced by our not quite vertical "roadway" in Figure 9. At this point in testing, we were only concerned with the relative accuracy of the scene element points so the CAD drawing elements are not shown.

The left plot in Figure 9 shows the points calculated from the manual measurements made from reference points A and B. The right plot shows shows the plot of the AutoDOCS calculated points and the resulting error statistics from the first set of data. The average position error was 1.7 centimeters with a standard deviation of 5.1 millimeters. The maximum error was 3.0 centimeters. There were 20 scene points and the GPS survey took 700 seconds or a little over 11 minutes.

The accuracy is facilitated by the short separation between the RU and MU required to measure a typical crash scene, the high integrity integer cycle resolution, and the continuous tracking of a set of satellites throughout the measurement. AutoDOCS consistently delivers better than 2-centimeter relative average accuracy between scene points during the duration of a typical crash scene (less than 30 minutes). Note that the AutoDOCS plot is referenced to true north while the truth plot is based on a convenient local coordinate system. In testing with police investigators, we found that the reference direction to north indicated in their hand drawings was off by tens of degrees.

The beta testing by the NHTSA and local police investigators, which focused less on accuracy and more on use of the system was very helpful in honing AutoDOCS' operational performance. For example, the Oklahoma City tests with NHTSA investigators showed that the process required to initialize the MU and RU for GPS measurements was confusing even with the GUI prompts without a background in GPS. Several of the scenes they measured could not be processed for reasons such as forgetting to start the RU data recording before beginning the measurement. In response, we have virtually eliminated the potential for this by replacing the original RU with a PDA with a wireless link and developing real-time checks between the RU and MU that virtually eliminate process errors.

The photo shows one of the beta tests in Oklahoma City. This particular site is in nearby Yukon at the site of an actual fatal accident that occurred a couple of days prior to this picture. The NHTSA investigator holding the survey pole is taking a scene measurement while a Dunlap employee takes notes on his performance and comments. The two Yukon police officers on the right were not part of the test but upon hearing what we were testing they were so interested that they accompanied the testers to the site to observe and try out AutoDOCS. At the end of the test, they volunteered to be a part of any additional testing we needed. They suggested that AutoDOCS provide the capability to store measurement templates of the sites of repeated collisions such as the intersection pictured.

The Yukon officers' interest was typical of the professionals that used the system. Both NHTSA and the local police investigators were enthusiastic about the potential of the system.

The Norwalk police officers, the current traffic homicide investigator and a former traffic investigator, each used the system to document a simulated scene consisting of a pedestrian fatality on a narrow road that resulted in a body in the roadway as well as a stray shoe from the victim. After the impact with the pedestrian, the striking pickup truck veered to the right and hit a parked pickup causing severe deformation to the bed of the parked vehicle. After only about an hour of instruction on AutoDOCS, they produced the drawing shown in **Figure 10**. The red star in the back of the truck bed measures how far inward the truck was crushed.

Even though it was only the second scene they had attempted, the entire measurement process took only twelve minutes. Their first scene took eighteen minutes to measure. They attributed the rapid improvement to AutoDOCS' ease of use. Similar improvement occurred in Oklahoma City. A complex 36-point scene took NHTSA investigators nearly 50 minutes during the first day of testing. By the third day, a similar scene with the same number of points took 19 minutes to measure.

Based on data from all tests, we estimate that a moderately experienced investigator can expect that it will take about 30 seconds to measure each point in the scene including selecting the object, point, and walking between points. The default measurement period is five seconds at each point. Since the distance between scene points are often the width of a car but almost never greater than several hundred feet, the average movement time is on the order of 15 seconds. That leaves about 10 seconds on average to touch the element on the screen to be measured and then touch the point to be measured on the enlarged drawing element to start the measurement.

The Norwalk officers thought that AutoDOCS would significantly reduce the time it takes to measure a crash scene while simultaneously increasing the quality of the resulting measurements and drawings. This would not only have financial benefits for their department in terms of reduced personnel time but also permit them to reopen streets to traffic sooner thereby lessening the impact of serious crashes on traffic flow. The officers said that on average it took two officers a whole day plus several hours overtime to document a fatal crash. They estimated that AutoDOCS would cut time to document a fatal crash in half. They also particularly liked the ability to be able to return to a crash scene to add details that were overlooked or had to be omitted at the time of the crash.

System Changes

Since the completion of the contract with NHTSA, Optimus has made numerous enhancements in preparation for marketing AutoDOCS commercially. These enhancements include adding a wireless (802.11b) link between the RU and MU that allows the data from the RU to be transferred in seconds to the MU for processing. We also added wireless watchdog functions that constantly check both units to ensure they are in the proper state for that step in the survey process. During beta testing with NHTSA, we found that the new user got confused as to how to initialize the survey as described above and in transferring the data using cables between the MU and RU. They once did not start the RU until after bringing the antennas together to zero the integer ambiguity, and another time they wanted to add a second set of data to a scene just surveyed but forgot to transfer the RU data for the first set before beginning the second set so the first set was recorded over. Now with the wireless cross checks, the user is notified of a missed procedure step or if too few satellites are visible immediately, and he/she cannot proceed with the process until the issue is resolved. These process integrity checks prevent an unnoticed problem from ruining a set of measurement data.

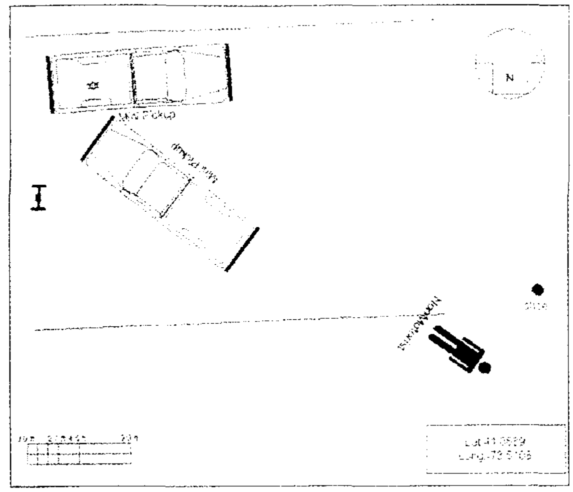


FIGURE 10 AutoDOCS crash drawing produced by *Norwalk police during beta test*

Conclusions

The AutoDOCS research and development is an example of a successful government and small business partnership under the SBIR program, which puts emphasis on developing systems that meet a government need and produce a product for the commercial market. NHTSA provided money to prove the concept, and develop and test prototypes in return for rights to use the product to address their research needs. Optimus invested significant money for a small business in completing the development and testing, and now in marketing and supporting the product.

The benefits of using AutoDOCS also may impact the average citizen. Its accurate, standardized, electronic data may make crash analysis more efficient for NHTSA, local governments, and states which eventually will result in safer roads and vehicles for everyone. In addition, it has been estimated that each mile of traffic backup on a major interstate highway costs our economy around a million dollars in lost time, fuel, and air pollution. If speeding up documentation of serious crashes leads to clearing the roads faster, AutoDOCS will benefit frustrated travelers' mental health, the delivery of all types of goods, and the environment.

Acknowledgements

The author appreciates contributions of Optimus engineers including Darrell Greenlee, Robert Nelsen, and Teddy Assefa. He also thanks Richard Blomberg and Charles Fauchier of Dunlap and Associates, a human factors, traffic, and aeronautical safety firm, for their significant contributions. The entire team thanks Seymour Stern of NHTSA for his support and contributions to understanding the crash documentation process and goals.

Manufacturers

OPTIMUS Corporation (Silver Spring, Maryland) was granted a patent on *AutoDOCS* in December 2002, and delivers its first commercial units to a police department in Delaware in July 2003.

AutoDOCS incorporates two **CMC Electronics** (Saint Laurent, Québec, Canada) *SmartAntenna* GPS receivers (now made by **NovAtel**, Calgary, Alberta, Canada). The optional computer shown on page 35 is a **Panasonic** *Toughbook*.

The system uses **Microsoft** (Bellevue, Washington) *Visio* CAD package and *Word*. All software components use Microsoft programming languages, with the exception of *MatLab* by **MathWorks Inc.** (Natick, Massachusetts). The languages are Microsoft Visual Basic for Applications, Visual Basic, Visual C++, and MatLab by Mathworks Inc.