
A Video Tracking Photogrammetry Technique to Survey Roadways for Accident Reconstruction

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Reprinted From: **Accident Reconstruction 2004**
(SP-1873)

ISBN 0 7680 1427-1



SAE *International*[™]

**2004 SAE World Congress
Detroit, Michigan
March 8-11, 2004**

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ISBN 0-7680-1319-4
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Printed in USA

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ABSTRACT

When reconstructing vehicle accidents, it is often important to record the accident scene roadway geometry. Survey techniques such as the plane surveying method¹ and the coordinate and triangulation method², have been the most widely used recording methods and are generally accepted in the industry. This paper proposes to introduce video tracking photogrammetry as a new tool in gathering accident scene and roadway data. The video tracking photogrammetry technique makes it possible to use accident scene video to record the accident scene geometry by incorporating photogrammetry principles. This paper will also report on the accuracy of the video tracking photogrammetry technique and discuss its strengths and limitations.

BACKGROUND

Photogrammetry is the science of obtaining accurate measurements from photographs. Photogrammetry technology has been used in accident reconstruction to determine crush profiles of vehicles, to determine the location of objects at an accident site, and for analysis of tire marks' length and radius^{3,4}. In the past, photogrammetry technology has relied on still images for use in obtaining three-dimensional data. However, photogrammetry technology has grown to incorporate video images. Digital video's capacity to incorporate single images at 30 frames per second, combined with automatic tracking of features that change between each frame, has made video a powerful tool for obtaining three-dimensional data from a two-dimensional source. This paper describes a video tracking photogrammetry technique for obtaining surveys for accident reconstruction.

Accident reconstruction engineers often use scene surveys to analyze an accident. But obtaining surveys can be costly, time consuming, and dangerous. This paper explores technology that is currently available for

producing three-dimension survey data from a single camera video source. The analysis reported in this paper compares the 3 dimensional survey data derived from Video Photogrammetry Tracking to an actual survey of the same site, in this case a flat stretch of highway in Colorado, a hilly section of highway in Missouri, and a residential neighborhood intersection in Colorado. The software that is utilized for the photogrammetry process is used in the Hollywood industry to mirror the movements of a camera in the computer, with the movements of a camera in real life. While this software is not specifically designed to produce surveys, it does use a Photogrammetry process that will, with time and development, result in the accurate recording of three-dimensional data from a single video source. This paper will show that, in combination with other software packages, the photogrammetry analysis in Boujou⁵ can be used to create a simple survey, accurate enough for many applications in accident reconstruction. Imagine being able to simply videotape a crushed vehicle, for instance, and the video tracking application will generate 3D geometry automatically. This process would be immensely helpful in obtaining crush measurements, graphics and animations, and saving time and money. Siggraph 2003 presented several papers on the development of video photogrammetry and its ability to generate 3D data simply from video. This paper analyzes a direct use of this technology, i.e. surveys, to determine how close the technology is today. From the results, the technology works with a small range of error. The technology is continually progressing, and with improvements in digital imaging and photogrammetry software, the accuracy will continue to improve.

INTRODUCTION

Whenever possible, an accident reconstructionist will visit the site of an accident to document physical evidence, take measurements, photographs and video. In addition, a survey of the site showing the roadway, lane lines and other key markers on the site can be extremely useful. Surveys of accident sites can be done

with a variety of methods including tracing an aerial photograph, measuring off a baseline, or hiring a professional survey company to document the scene with laser equipment. Each of these methods has varying accuracy. An aerial may be an old photograph or too low of a resolution to see important features. Measuring off a baseline or with a measuring wheel can also produce inaccurate results. Professional surveys are highly accurate but can be costly, time consuming and dangerous. This paper will explore a method to compliment these survey methods that relies almost solely on video footage. While it is not as accurate as a professional survey with laser equipment, it provides a level of ease and flexibility that may make it a useful tool for getting survey data and will provide accuracy

comparable to other survey methods (i.e. aerial photographs and measuring wheels). Video tracking photogrammetry enables an accident reconstructionist to obtain the data for a survey from the safety of their vehicle in the length of time it takes to drive the desired stretch of roadway. The video footage is processed using video tracking software such as Boujou 2.0. The end product of the software analysis is a three-dimensional point cloud. The point cloud can be imported to a cad program, scaled and traced to create a final 3D survey CAD drawing. See figures 1a-1d. If specific objects in the video are critical to the survey, these objects can be specially marked and then located in the 3D point cloud.



Figure 1a



Figure 1b

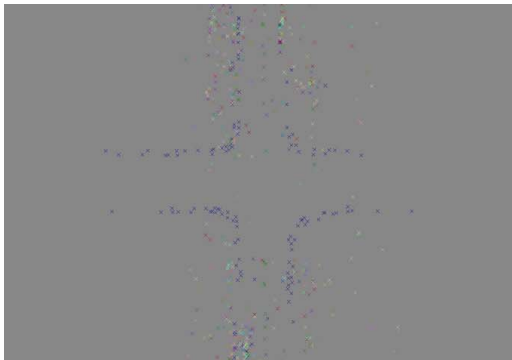


Figure 1c

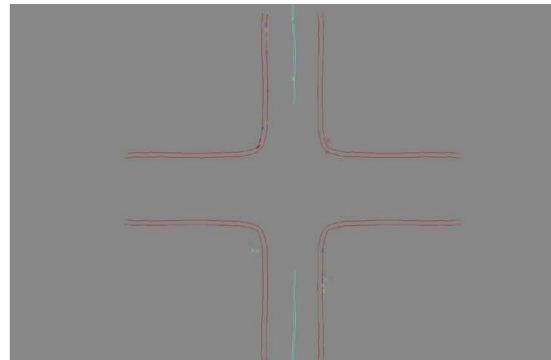


Figure 1d

- Figure 1a- Original Video Footage
- Figure 1b- Point Cloud overlay on Video
- Figure 1c- Point cloud in CAD program (colors represent object groups)
- Figure 1d- Completed 3D survey

While the ease of creating of survey through this method is quick, and inexpensive, the trade-off is in the details and the accuracy. A typical survey will include contours, pitch of the roadway, unbroken edges of roadway, median and other demarcating features. Video tracking photogrammetry provides ample accuracy and the details needed for the majority of accident reconstruction needs. For instance, video tracking photogrammetry can create a survey that outlines the roadway, identifies the lane lines, approximates geometry of signs and other objects, and describes the slope and radius of roadway curvatures (see case studies). The survey produced by video tracking photogrammetry would not be suitable for

more detailed analysis such as fuel flow off of the roadway in an accident, the pitch of the roadway, sections longer than 5 miles, visibility studies, or where the slope of the roadway is severe: 5% grade or higher. As an added benefit, when the video has been properly tracked, the solution for the video can also be used for creating composited animations that can be used in court. Because these animations are shown using actual video footage, the animation is validated and is generally admitted into court. See figures 2a-2c. In the sections that follow, the video tracking photogrammetry technique is described and case studies are presented.



Figure 2a



Figure 2b



Figure 2c

Figure 2a- Original Video Footage

Figure 2b- Computer generated animation on “Green Screen” background

Figure 2c- Final composite image of computer animation on live footage

VIDEO TRACKING PHOTOGRAMMETRY

Several software packages are available on the market that will create three-dimensional camera movement and calibration from video. These software packages make it easier to add computer-generated objects to live camera footage in 3D animation packages by creating a virtual camera that matches the physical one that took the shot. The process the software goes through to get this camera movement requires a three-dimensional point cloud to be generated of objects in the video scene. It is this three-dimensional cloud that is created in the software that can be utilized as a survey method as described in the paper. Figure 4a shows original footage. Figure 4b shows that footage being analyzed by Boujou. The way Boujou analyzes footage is by looking at variations in value of pixel comparisons within a given range. These “features” are followed from frame to frame. When enough features are tracked for a given video footage segment, calculations are done to create a 3D point cloud, and virtual camera trajectories. Figure 4c shows the 3D point cloud that is generated by the Photogrammetry processes of the video tracking. This point cloud can be directly imported into a 3D software

package and scaled from any one known dimension (see Figure 4d).

SCENE SURVEYING

Obtaining video for the video tracking photogrammetry technique typically requires the following equipment (see also figure 3a):

- Sony PD 100 3CCD DV Digital Video Camera
- Sony PCG-GR270P Laptop
- Vehicle with a sunroof
- 100 min High Definition DV tape
- Tape measure
- Still Camera
- Safety Signage and Vests
- Stop Watch

This equipment was used for the case studies that follow. For these cases studies, the above equipment was utilized to obtain high quality video footage and some key measurements needed to complete the survey.



Figure 3a



Figure 3b

Figure 3a- Photo of necessary equipment

Figure 3b- Photo of vehicle and videographer

SETTING UP THE VIDEO TAKE

Before taking video, the reconstructionist should measure a scene dimension that will be easily recognizable in the video and the resulting point cloud. This can be the width of the roadway or the lane, the width of the median or shoulder, or some other identifiable marker; in general, the longer the distance the better. Record the measurement and take a photograph as documentation. In this case, we used the dimension of a lane width as our reference. In order to have an unobstructed video clip, we used a tall SUV vehicle with a sunroof (see Figure 3b). This allowed the camera operator to stand in the middle of the vehicle and take clear, unobstructed video footage. The windshield can also be problematic since glare and reflection are undesirable artifacts that can degrade the accuracy of the video tracking process. The best time to take video footage depends on the sun's angle. It is desirable to be driving with the sun at your back for best visibility. A cloudy day can also be beneficial since this minimizes sharp contrasts between reflections and shadows. However, under any conditions, the DV camera you use should be equipped with controls for exposure and shutter speed. These settings need to be locked so they will not automatically adjust during the video shoot. If the camera is allowed to automatically adjust while it is recording, then "flickering" occurs. Flickering is the rapid change of lighting in the footage from frame to frame as the exposure settings adjust for different light conditions. While De-flickering is possible for digital footage, it reduces the quality of the footage and requires extra steps. Therefore, it is best to make sure the settings are locked and will not change during the course of the video shooting.

TAKING THE VIDEO

One driver and one camera operator are needed to safely obtain the footage. To reduce vibration, the driver should go as slow as possible and avoid bumps, expansion joints, debris, and abrupt changes in steering wherever possible. Begin taking footage several seconds before the area desired and for several seconds after. The digital video file can be cropped later to focus on the area needed. The camera operator needs to anticipate bumps and vehicle movement to minimize vibrations and jerkiness of the camera. The DV camera used in these case studies was equipped



Figure 04a

with a "steady-cam" feature that dramatically improves the smoothness of the footage. Objects that move within the scene should be avoided as much as possible. The Video Tracking process works best with static objects, and objects that move with the camera must be masked out. So for roadway footage, choose the longest opening of traffic before beginning recording.

TIPS

- Keep camera as smooth and steady as possible
- Keep moving objects out of the scene where possible
- Avoid "Flickering" affect by locking the f-stop and shutter settings
- Avoid Glare from light sources
- Record plenty of footage before and after the desired area
- Use Digital Video for highest quality raw footage

PROCESSING THE DATA

After retrieving footage, digitize the file to an .avi⁶ format and crop to the desired length. This length should include several additional seconds before and after the area of interest. The footage should be at the standard 29.97 frames/sec and should contain no fields. For a description of fields in video footage, see compositing manuals (Adobe After Effects and Adobe Premiere) for a detailed description of interlaced and deinterlaced footage that contains fields. Import the footage to Boujou 2.0 and set up the video tracking software to solve for the 3D point cloud (see figure 04d). It is beyond the scope of this paper to explain or demonstrate the settings tools used for performing video tracking, since there are many programs and methods for achieving this. Please refer to the manual for specifics on using this software.

When the solution is completed, preview the results. Mark tracks in the video as needed to obtain specific object locations and reprocess (see figures 4a-4d). When the processing is adequate, export the data to a 3D package. Import the 3D data and at this point scale the 3D point cloud to the measurement taken at the accident site (see figure 4e-4f). With the 3D point cloud scaled and accurate, begin tracing the points to generate a completed 3D survey (see figure 4f).



Figure 04b



Figure 04c

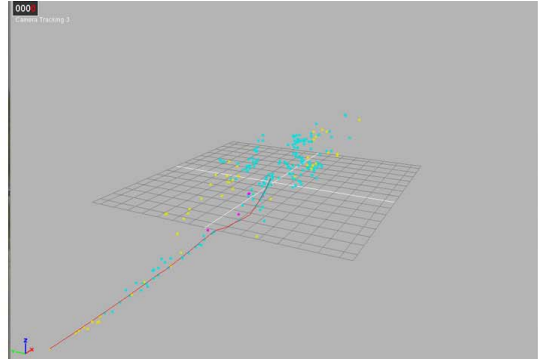


Figure 04d

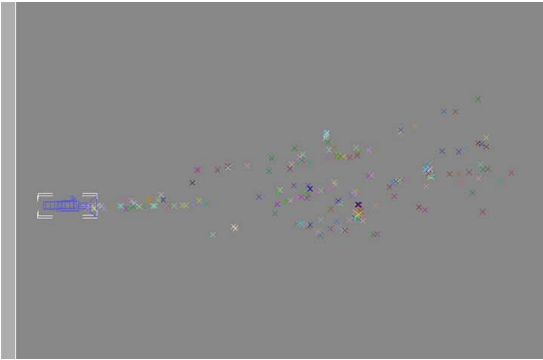


Figure 04e



Figure 04f

- Figure 04a – Original Video Footage
- Figure 04b – Video with tracked pixel comparison overlay
- Figure 04c – Video with 3D point cloud overlay
- Figure 04d – 3D point cloud and camera path
- Figure 04e – Imported 3D point Cloud
- Figure 04f – Cad Survey drawn from 3D point cloud

CASE STUDIES

FLAT HIGHWAY

Since surveys can be created from several sources, three case studies are discussed that all utilize a different method. This first case study uses an aerial as the main source for created a scaled diagram of an

accident site, see Figure 5a. In this case, a survey was done by the local police, but it was not drawn to scale and did not contain enough data to perform an accurate reconstruction.



Figure 5a

Figure 5a - Aerial of Site

Since our goal was to both reconstruct the accident and create an animation of the accident, video needed to be taken at the site. For this reason, it was efficient for us to also create a survey using video tracking

photogrammetry. The 3D point cloud is compared to the aerial photograph in figures 6f through 6g.



Figure 06a



Figure 06b



Figure 06c

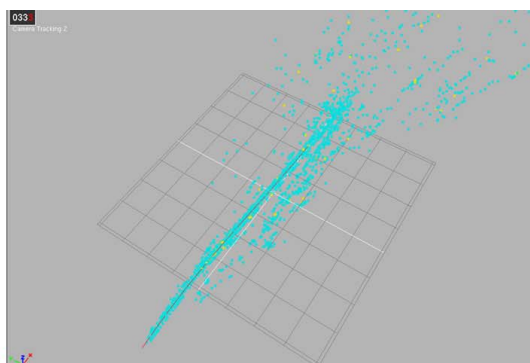


Figure 06d

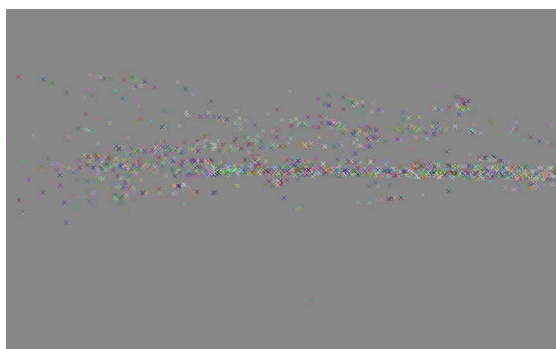


Figure 06e

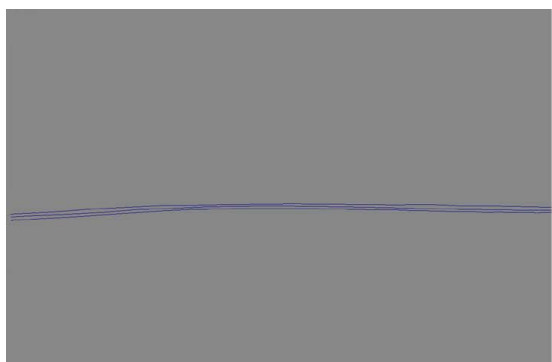


Figure 06f

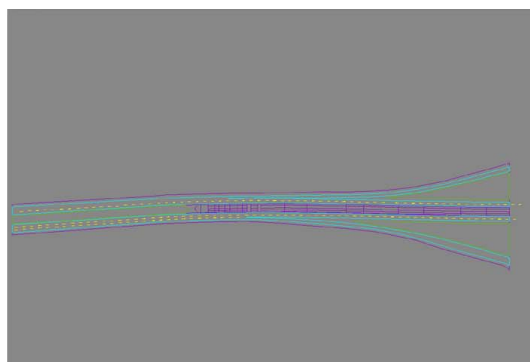


Figure 06g

- Figure 06a – Original Video Footage
- Figure 06b – Video with tracked pixel comparison overlay
- Figure 06c – Video with 3D point cloud overlay
- Figure 06d – 3D point cloud and camera path
- Figure 06f – 3D point cloud imported into CAD program
- Figure 06f – Cad Survey drawn from 3D point cloud
- Figure 06g– Cad Survey done from Aerial Photograph

Because the Aerial is a low resolution, it is difficult to get a good quantitative comparison of both surveys. However, qualitatively, the visual comparison of these two surveys illustrates their similarities.

ROAD SIGNS AND TELEPHONE POLES

This case study also demonstrates the ability for video tracking photogrammetry to estimate geometry of objects in the scene, such as road signage and bridges. The importance of this analysis is to demonstrate that the 3D tracking software is useful not only for flat x and y data of the roadway but can actually determine z coordinate data as well. The road sign tracked in this example was literally converted to a computer generated 3D model (see figure 7e and 7f) that was superimposed on to the photograph. This finding suggests that as the

technology develops, one would be able to obtain 3D data from any object or site such as a crushed vehicle, exemplar vehicle, interior of a building, machinery or an accident site. The example below uses video tracking photogrammetry to estimate geometry and dimensions of a road sign along the highway of the Flat Highway case study. Tracked points were brought into a 3D program and connected to build basic geometry. This geometry was refined to better match the road sign geometrical features, and then textured mapped and prepared to use in a composite animation shot (see images 7a-7f).



Figure 07a



Figure 07b



Figure 07c

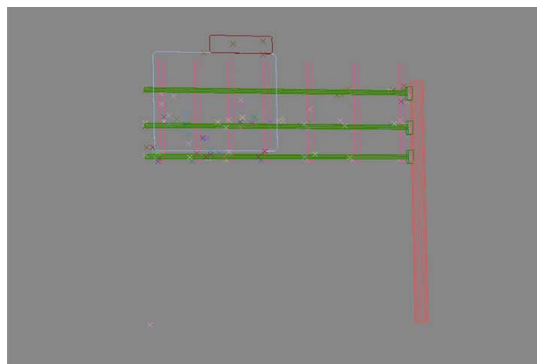


Figure 07d



Figure 07e



Figure 07f

Figure 07a – Original video footage

Figure 07b – Video with tracked pixel comparison of road sign overlay

Figure 07c – Video with 3D point cloud of road sign overlay

Figure 07d – 3D construction of road sign from 3D point Cloud

Figure 07e – Completed computer model of road sign

Figure 07f – Computer model road sign composited on video footage

ROLLING HIGHWAY

In this case study, a highway with changes in elevation was Video Tracked and compared to an actual survey done by a professional survey company. See Figure 8a. The main goal of this comparison was to determine how well the video tracking photogrammetry technique performed at estimating the slope of the roadway as well as the curvature of the roadway. Figures 8a-8d show the tracking process and resulting 3D point cloud. As in the

other case studies, roadway features such as the lane lines and edges of roadway are automatically tracked because of their variation in pixel contrast. Most tracking software packages also allow you to manually place tracking features on objects that you want to be included in the point cloud. For instance, the fence or road sign of the video footage could be manually tracked to be included as a 3D point cloud. Also, more points on the edge of the roadway could be added to get a better definition of the road as represented in the 3D point cloud. The video tracked survey is compared to the professional survey from a top view and a side view in figures 9e-h. The video tracking photogrammetry was able to calculate changes in elevation as shown in the side view comparison. In addition the radius of the Boujou tracked survey is close to the radius of the road curvature as calculated in the survey obtained by a survey crew.

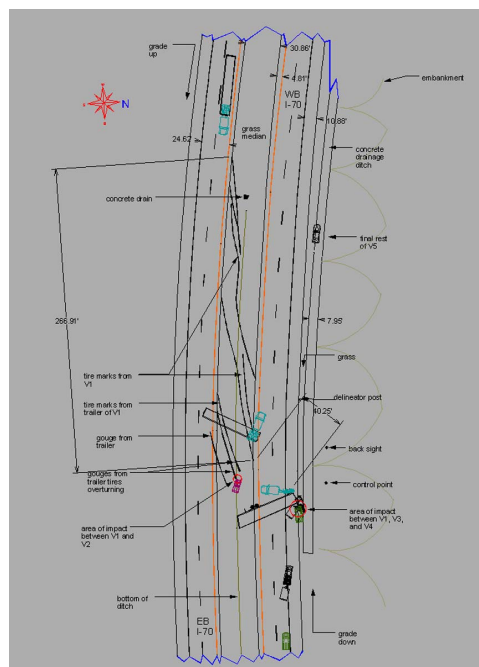


Figure 08a

Figure 08a – Professional Survey of the accident site



Figure 09a



Figure 09b



Figure 09c

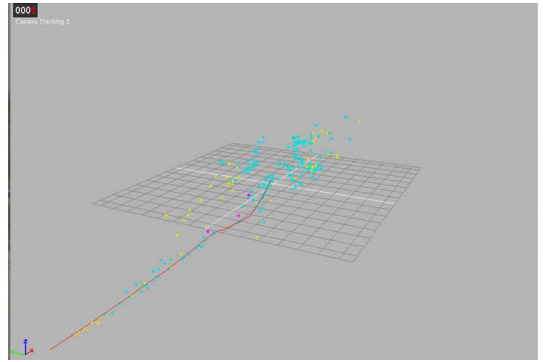


Figure 09d



Figure 09e

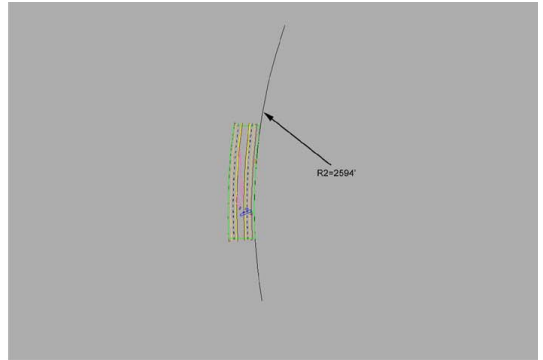


Figure 09f

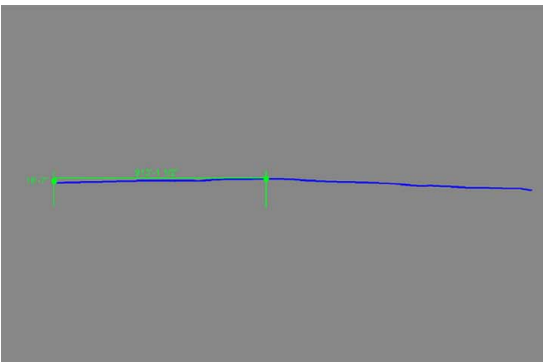


Figure 09g

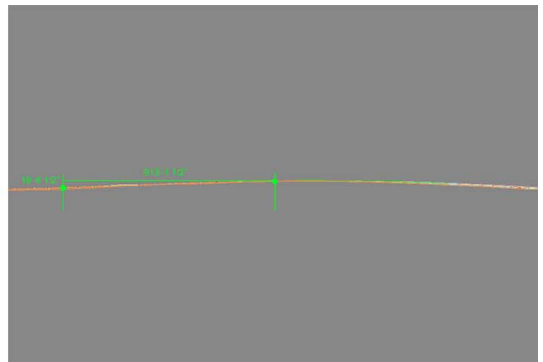


Figure 09h

- Figure 09a – Original video footage, eastbound
- Figure 09b – Video with tracked pixel comparison overlay
- Figure 09c – Video with 3D point cloud overlay
- Figure 09d – 3D point cloud and camera path
- Figure 09e – Radius Cad Survey drawn from 3D point cloud
- Figure 09f – Radius Cad Survey done by professional survey company
- Figure 09g – Profile view of Cad Survey drawn from 3D point cloud
- Figure 09h – Profile view of Cad Survey done by professional survey company

COMPARISON OF SURVEY ACCURACY FOR ROAD CURVATURE

Survey Method	Radius
Boujou Tracking	2484'
Laser Survey	2594'

Based on the analysis of the roadway curvatures from each survey method, the two radii differ by 4.2%.

COMPARISON OF SURVEY ACCURACY FOR ROAD PROFILE

Survey Method	Y distance	X distance	Grade
Boujou Tracking	913'-1"	18'-7"	2.04%
Laser Survey	913'-1"	19'6"	2.14%

Based on the analysis of the profiles from each survey method, the two grades of the roadway of each 3D survey differed by 0.10%. The Y distance for this comparison stays constant for both methods.

In summary, the comparison of the roadway profile and the roadway curvature, as analyzed by the video tracking photogrammetry technique, was within acceptable levels of accuracy when compared to the survey done by a professional survey crew.

RESIDENTIAL ROADS

The highway is the site of many severe accidents since the speeds on a highway are much higher than city streets. However, bicycle and pedestrian accidents often occur in residential areas and engineers must create scaled surveys of these areas as well. A case study below shows the raw video footage and the end product survey compared to an actual survey of the site (see images 10a-10d).



Figure 10a



Figure 10b

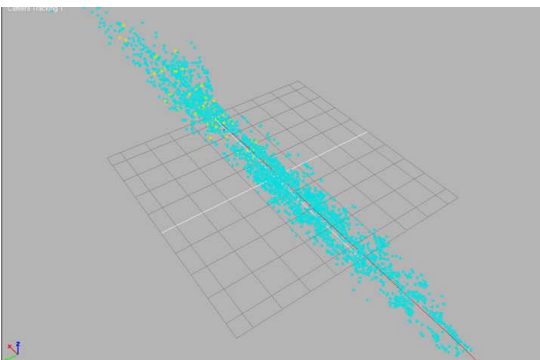


Figure 10c

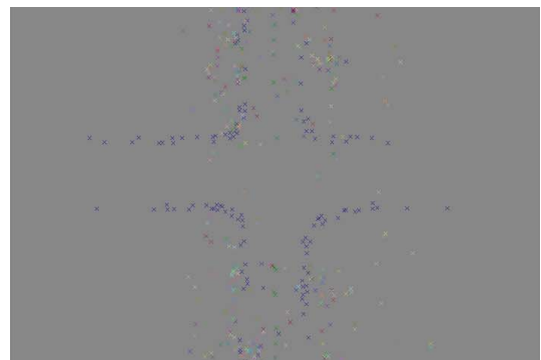


Figure 10d

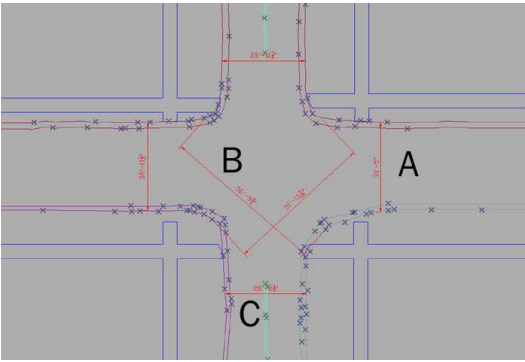


Figure 10e

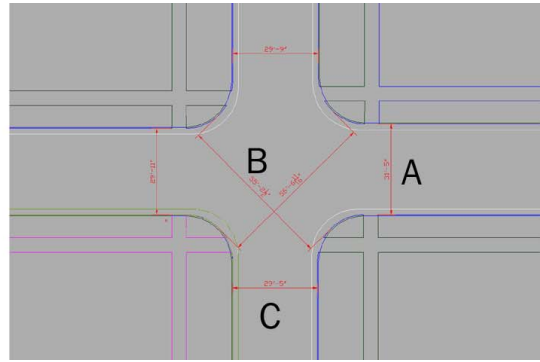


Figure 10f

- Figure 10a – Original video footage
- Figure 10b – Video with 3D point cloud overlay
- Figure 10c – 3D point cloud and camera path
- Figure 10d – Imported 3D point cloud
- Figure 10e – CAD survey drawn from point cloud
- Figure 10f – CAD survey done professionally on site

Comparison of Survey Accuracy:

Length	Survey by Boujou Tracking	Survey by Professional Crew	Percent Difference
A ¹	31'-5"	31'-5"	0%
B	56'-9-3/4"	55'-2-1/2"	2.8%
C	28'-5 1/2"	29'-5"	3.3%

FUTURE DEVELOPMENT

In July of 2003, lecturers presented papers on Video Photogrammetry at SIGGRAPH 2003⁷. These lectures presented technology much more accurate in detailing 3D models from video footage than is currently commercially available. In their presentations, video footage of buildings was analyzed with video tracking photogrammetry techniques. The end results were 3D point clouds that closely approximated the geometry of the building in the footage. Unlike Boujou and other video tracking software, the interest of these lectures lies in the 3D point cloud itself. This demonstrates both the interest in video tracking photogrammetry and the course that this technology is headed.

It is beyond the scope of this paper to identify the step-by-step procedures for creating 3D geometry from video, though in future papers this will be explored more thoroughly. Video tracking software packages are specifically designed to work with computer-generated images. The tracking software allows you to composite computer generated objects directly in the video sequence. It is beyond the scope of this paper to illustrate the techniques of compositing video tracked video with computer animations, though future papers

will address this issue in more detail. Please refer to the manuals of the software for instruction on how to use this software with computer-generated animations. Below is a list of Video Tracking software available on the market that will track video as described in this paper.

- Boujou by 2D3
- 3D MatchMover by Real Viz
- Live Matchmoving by Alias Maya
- Ras_Track by Hammerhead Productions
- 3D-Equalizer by Science D. Visions

As the technology of video tracking progresses and the quality of video equipment increases, so will the accuracy of the 3D point clouds that are generated through video tracking photogrammetry techniques. In time this easy to use process will provide enough accuracy for many accident reconstruction needs, such as tire mark analysis, critical speed analysis, crush measurements and site surveys. Its parallel use in the production of forensic animations will enable a more efficient and consistent process for producing realistic animations that are based on real physics and evidence.

¹Length A was measured on site and used to scale the Video Tracking point cloud. Therefore there is 0% difference between the two survey dimensions.

CONCLUSION

The results published by these engineers show that for certain needs in accident reconstruction, it is possible to get an accurate and detailed survey simply by taking video of an accident site. The case studies analyzed in this paper include several varying types of sites in which a vehicle accident occurs. These include straight highways, highways that have slopes and residential areas. In each of these case studies the results show that the tracking of this video and resulting 3D survey is accurate within a few degrees or percentages. If the accident reconstructionist is in need of a highly detailed and accurate survey, then a professional scene survey is probably a better option. However, for many accident reconstruction needs, the accuracy of this video tracking survey method will prove more than adequate.

REFERENCES

1. Benton, Arthur, Jr., Taetz, Philip, "Elements of Plane Surveying", McGraw Hill, 1991
2. Baker, J. Stannard, Fricke, Lynn B., "The Traffic-Accident Investigation Manual", Northwestern University Traffic Institute, 1986
3. Tumbas, Nicholas, S., Kinney, J., Rolly, Smith, C., Gregory, C., "Photogrammetry and Accident Reconstruction: Experimental Results," SAE 940925, 1994
4. Fenton, Stephen, Kerr, Richard, "Accident Scene Diagramming Using New Photogrammetric Technique", SAE 970944, 1997
5. Boujou v.2.1, 2D3 Ltd, USA, Lake Forest, CA
6. An AVI (Audio Video Interleaved) file is a sound and motion picture file that conforms to the Microsoft Windows Resource Interchange File Format (RIFF) specification
7. Mark Pollefeys from the University of North Carolina at Chapel Hill and Luc Van Gool from the Swiss Federal Institute presented papers on Video Photogrammetry at SIGGRAPH 2003.

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