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Video Projection Mapping Photogrammetry through Video Tracking

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ABSTRACT

This paper examines a method for generating a scaled three-dimensional computer model of an accident scene from video footage. This method, which combines the previously published methods of video tracking and camera projection, includes automated mapping of physical evidence through rectification of each frame. Video Tracking is a photogrammetric technique for obtaining three-dimensional data from a scene using video and was described in a 2004 publication titled, "A Video Tracking Photogrammetry Technique to Survey Roadways for Accident Reconstruction" (SAE 2004-01-1221). That paper described a method for generating a three-dimensional computer model of a roadway by using video of a drive-through of an accident scene and processing this video footage through available video tracking software.[1,2] The benefit of being able to drive through an accident scene to collect data lies in the speed of such a method, but also in safety, as some accident areas are too heavy with traffic, dangerous or otherwise inaccessible. Three-dimensional Camera Projection Mapping is a computer visualization technique of wrapping or mapping video or photographs onto three-dimensional geometry and adjusting the size and shape of the map so it follows the size and shape of the target objects. This rectification process results in a photo-realistic computer model that is accurate in detail, lighting and scale since it is built directly from the photograph. The result of adding the technology of video tracking with three-dimensional camera projection mapping is a scaled computer model of the accident scene that includes photographs of the evidence mapped onto the geometry at the correct scale and location - all from a single video drive-through. Developing both of these concepts into one method of Video Projection Mapping combines the ease of building a three-dimensional accident diagram from a video drive-through, with the accuracy and clarity of analyzing scaled photographic data.

INTRODUCTION

In accident reconstruction, photogrammetry processes such as photograph rectification and camera matching are widely used to obtain measurements of roadway physical evidence. [3,4,5,6] This paper builds upon existing methods by applying rectification principles to each frame, or photograph, from an entire video. The analysis results in numerous rectified images along an entire stretch of roadway. Using the same video, a three-dimensional survey can also be created using previously published methods.[2] The rectified images and video survey can then be combined to build a scaled three-dimensional computer model of an accident scene that contains photographic quality evidence mapped onto the geometry. This allows an accident reconstructionist to analyze physical evidence visible at the scene, scaled within a three-dimensional environment at photographic quality. And the process for collecting the data at the scene can be done with relative ease by filming from a vehicle. Projection mapping is a form of image rectification and is based on the same technology defining other photogrammetry and image rectification processes. Rectification is the process of taking a photograph of an accident scene and rectifying the photograph onto a planar surface such that the photograph is rescaled and mapped in a manner that allows one to view the photograph in a plan view. Since the photograph is remapped onto a planar surface, it is scalable from a top view, and distances and dimensions of objects in the photograph can be directly measured in the rectified photograph.

The second technology integrated into the process presented in this paper is the creation of a scaled computer model of an accident scene. Techniques for building accurate geometry of an accident scene have been extensively used in accident reconstruction from hand measurements to total station surveys, and more recently full laser scans[7]. Photogrammetry has also been widely used to create and supplement accident scene diagrams with evidence and features visible in photographs. Video tracking is a photogrammetric technique for using video from a drive-through of an accident area to collect data points of the roadway, surrounding terrain and features in areas where surveying by hand or equipment is not possible due to heavy traffic or safety concerns.[2] The research presented in this paper develops the video tracking methodology described in the 2004 SAE paper "A Video Tracking Photogrammetry Technique to Survey Roadways for Accident Reconstruction," (SAE 2004-01-1221) by combining this process with the technique of three-dimensional camera projection mapping. Techniques for surveying and documenting accident scenes are well established and widely used and accepted in accident reconstruction, and the use of single photograph photogrammetry is also widely used. The paper presented here combines these two processes into one, where the end product is a photorealistic three-dimensional computer model of physical evidence visible on the roadway, obtained from a single video drive through, with this evidence mapped onto the roadway at the correct scale and location.

BACKGROUND

The process of camera projection mapping described in this paper takes a frame from the video, and maps the information from the frame onto geometry representing the same shape and scale of the object visible in the photograph. The technique of projecting maps onto surfaces has been widely used in film, media, and the visualization industries primarily for rendering a computer model at photographic level. The basic concept of taking information from a photograph and mapping it onto a three-dimensional surface is illustrated in figure 1, below.

In figure 1, a photograph of a cube where each side is a different color is shown being projected by the camera onto coordinates of a computer model that are associated with the same points that appear in the photograph. This relationship allows a photograph containing information about color, light, and value to be directly transferred to an object matching its actual three-dimensional scale. The process of projecting an entire video is based on the same technique for projecting one photograph, differing only in that video contains multiple single images, and that these projected images must be stitched together seamlessly to form one large photographic map for the geometry onto which it is being projected. In the process of projecting video onto geometry of a roadway, video is a useful way of collecting multiple still images of the road when using a high-resolution camera. And since the video is continuously recording as a vehicle travels down the roadway, the video will continually collect high-resolution data along the road since objects that are at first in the distance will get closer, larger and appear in greater detail and clarity in the video. Unlike a photograph where objects in the distance have a limited resolution due to perspective, a drive-through video will get closer to an object in the distance, thus capturing the image to video at a higher resolution since the object will appear larger the closer the video camera gets to it.

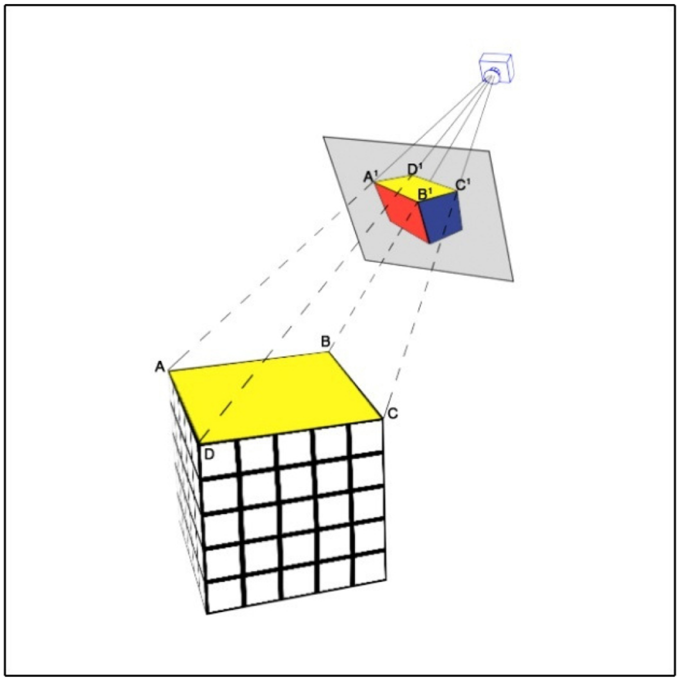

Figure 1. Concept of projection mapping

The process of video tracking utilizes principles of photogrammetry to determine three-dimensional data from two-dimensional images. In the same way that video projection mapping is really projection mapping of single photographs multiple times and over the course of a distance traveled by a camera, video tracking determines three-dimensional data for each frame of a video in the same way that the photogrammetric process will determine data for a single photograph. Video tracking simply does this process for each frame. And the additional benefit of video tracking is that the computer-generated camera solved in the video tracking process can be used to project the video frames onto the roadway geometry built from video tracking. It is in the automatic solving of the camera that the two processes of projection mapping and video tracking can be used to create photorealistic three dimensional computer models of a roadway complete with any visible evidence scaled correctly and positioned correctly on the computer model for analysis purposes.

PROCEDURE

To analyze and evaluate the process of video projection mapping described above, a stretch of roadway was selected that included curving, banking, and uphill and downhill characteristics. Roadways that are flat, and straight, and contain evidence that can be photographed, already have image rectification processes that can be used to create a scaled diagram of a photograph.[3,4] However, roadways that are curved, on hills, or have crowns, super-elevations or evidence on vertical surfaces can be more difficult for existing rectification programs since they generate flat projected surfaces. On this roadway, spray paint similar to what first responders might use to mark evidence was placed on the roadway to represent two tire mark paths of a vehicle yawing off the right side of the road. Figure 2 shows a downhill stretch of the roadway where two tire mark paths are painted that exit the right side curb.

Figure 2. spray paint evidence- tire marks

Prior to the area shown in Figure 2, is a curved section of roadway with a crest and additional spray paint. This spray paint was put on the roadway in three patterns - a circle, a square and an equilateral triangle. These shapes were chosen because they often appear distorted in perspective. Circles appear as ovals, squares as rectangles, and other shapes are stretched because of the low viewing angle. So while these shapes appear distorted in video, the projection mapping process should be able to represent these shapes in their platonic forms, correcting the apparent distortion. The two images in Figure 3 show this section of roadway and the spray painted shapes.

Video was taken along the roadway where spray paint was placed, and was processed through the methodologies described below, to produce a three-dimensional computer model of the roadway. In addition, the video was processed to provide projection mapping onto this three-dimensional model. The end product is a fully scaled computer model, with photographs rectified onto the surface for use in analysis. To evaluate the accuracy of the projection mapping process, a Sokkia Series 30R Reflectorless total station survey was performed for the same area of roadway that was videotaped. This survey included documentation of the location, shape and dimensions of all the same spray paint that was recorded in the video. The survey was then compared to the results of the projection mapping. For the tire mark spray paint, the location, length and curvature that resulted from the projection mapping was numerically compared to the survey. For the three distinct shapes, the results of the projection mapping were graphically compared to the survey data. These two methods, then, provide both a quantitative and qualitative way of evaluating the results of the projection mapping methodology in this paper.

Figure 3. spray paint evidence- shapes

DOCUMENTING THE ACCIDENT SCENE

In order to collect video of the scene for use in this paper, a high definition Canon 5D Mark II camera was setup on top of a vehicle. The option to mount on the top of the vehicle was to minimize any veiling luminance from the dashboard and sun, and to have an elevated view of the roadway which provided better definition of the painted areas. Having a camera mounted higher decreases the angle relative to the roadway which, in turn, reduces the effects of perspective on the captured image. The more orthogonal the camera angle, the more consistent the quality of the captured image will be across the entire image. The camera was mounted on a 2002 Ford Escape SUV at a height of 7.5 feet, and attached using a Manfrotto tripod rigid mount system that stabilized the camera. The lens used was a Canon EF 16-35 mm f/2.8L II, with a shutter speed of 1/1000 with the aperture set to f8.0 in order to obtain a correct exposure. Either a fixed lens or a variable zoom lens can be used though the optimal focal length should not be too zoomed or too wide. This helps avoid unnecessary cropping and minimizes lens distortion.[9] For this study a focal length of 31mm was also chosen to match a field of view of 60 degrees. Video was recorded at 1080 P (progressive) with a frame rate of 29.97 frames per second. These settings were chosen to maximize the resolution of the final rectified projection. Figure 4 depicts of the video camera setup on the Ford Escape.

Figure 4. Video Camera setup

The vehicle was driven at 30 mph in the left lane for approximately 800 feet. At the time the video was taken the weather was clear and the roadway was dry, and the paint on the roadway was clearly visible. Figure 5 shows a view along the roadway in the left lane, with some of the spray paint in the roadway that was recorded by the camera.

Figure 5. Series of images from the captured video

In addition to video recording the spray paint, a survey was performed using a Sokkia Series 30R Reflectorless total station with a 5-second angular accuracy. The survey data consisted of 1,650 points and include roadway features such as lane lines, seams and curb edges, as well as surrounding buildings and signs. In addition, the spray paint marks on the roadway denoting the tire marks and platonic shapes were also collected during the survey for later comparison. This survey was processed using Carlson Survey 2012, then exported into AutoCAD 2012. Figure 6, below, shows a plan view diagram created in AutoCAD of the scene survey.

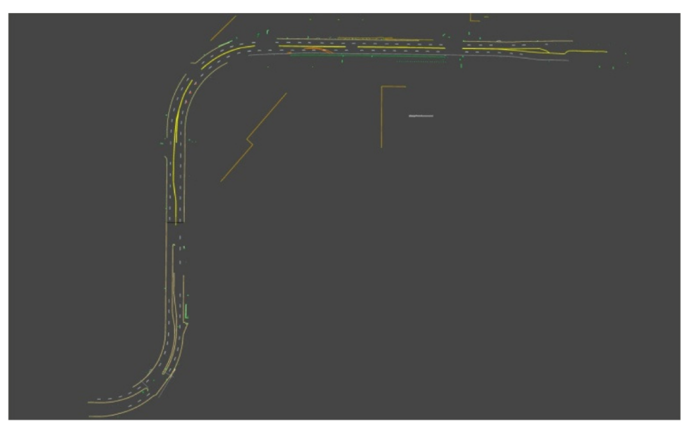

Figure 6. AutoCAD diagram of scene survey

PROCESSING AND TRACKING THE VIDEO FOOTAGE TO MAKE A 3D COMPUTER MODEL

After videotapping the section of roadway containing evidence, the video is first processed in video editing software.[8] In this case, Adobe After Effects CS6 was used to process the video captured at the scene. After the footage was placed on a timeline, markers were added to denote the beginning and ending points in time of the area that includes the roadway features and evidence needed to create a useable scene. After the timeline is established, the footage must be corrected to remove lens distortion so that it can be accurately tracked.[9] Lens distortion is removed using the Optics Compensation filter to un-distort until the edges of straight objects, such as buildings, have been straightened out.

In order to generate a computer model of the accident scene directly from the video footage, the processed and corrected video footage is imported into video tracking software.[1] For this study, PFTrack v. 2012.3 was used. Video tracking software utilizes principles of photogrammetry to create three-dimensional points of objects visible in the video such as the edge of the road, lane lines, and signs. The process of tracking video footage proceeds as follows. First, the footage to be tracked is loaded into the program and the frame rate and film back or sensor size are entered. Second, the footage is tracked and during this process features of non-moving objects are located over multiple frames. Once completed a series of points are created representing non-moving objects in the scene. By creating planar surfaces from these points, the roadway geometry can be formed into a computer model. Third, from the data points established through tracking, a three-dimensional camera can be solved that has the same motion as the camera that shot the original footage. At this point the roadway geometry and the computer generated camera can be exported for use in other modeling and visualization software. A screen capture from the tracking software process is included in Figure 7, along with the final results of the computer generated point cloud and roadway built directly from the video.

In order to scale the point cloud and surfaces that were obtained through the video tracking process, Google Earth images were used to scale features both visible in the Google Earth image and visible in the point cloud. While the Sokkia survey could have provided dimensions for scaling the video tracking, one of the purposes of this process, and a unique benefit, is its application in situations where performing a traditional total station survey or a laser scan is not a good option. Driving through an area can be both safe and inexpensive, and since only a single measurement is needed for scaling, Google Earth is a good source for a dimension, and in areas where traffic is high, Google usually has fairly high resolution image. For areas where Google earth may not have high resolution images, obtaining a measurement by hand would be sufficient.

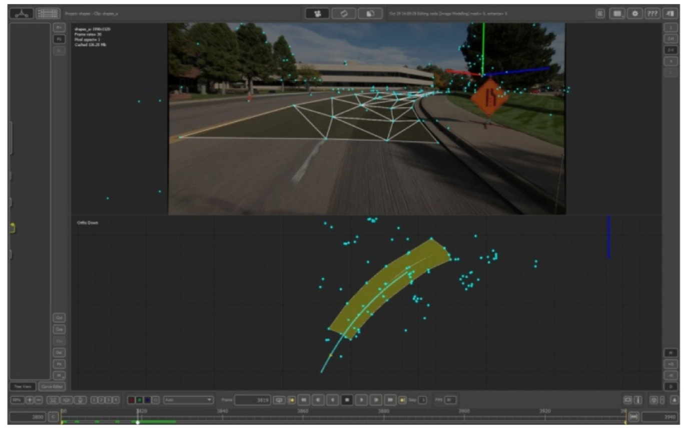

Figure 7. Generating 3D terrain from video-tracked footage

Visible in both the Google Earth image and in the video are two seams showing a section of different pavement. The distance between these seams was measured in Google Earth as 180.8 feet, and this measurement was then assigned as the scale for the resulting video tracked geometry by referencing the same seams. Once scaled, the computer model can be exported to other modeling programs for use in accident reconstruction analysis such as AutoCAD and 3ds Max. In this case, and for the purpose of receiving the projection mapping sequence, the computer model produced through PFTrack was scaled and exported to 3ds Max 2012. Figure 8 is an image of the computer model that results from the video track, imported into 3ds Max prior to receiving the projection mapping sequence.

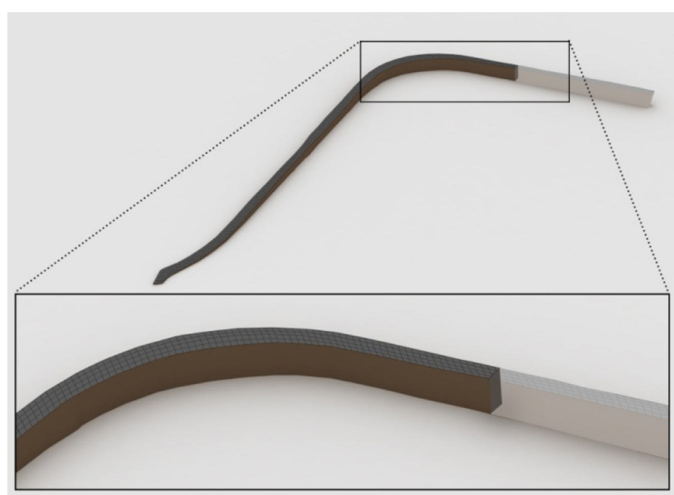

Figure 8. Computer model of roadway built from video tracking

PROJECTION MAPPING FROM VIDEO ONTO THE COMPUTER MODEL

Projection mapping using video is the same process as rectifying a single photograph on a three-dimensional surface, except that the rectification occurs for each frame of the video, and over a longer stretch of roadway. This means that objects in the distance (which might be of low quality in a photograph since it is represented with fewer pixels) will increase in quality as the video camera gets closer. Since the projection map is constantly being fitted with other maps, the video frames that offer the best resolution of an image can be utilized. Figure 9 is a graphic depicting the projection mapping process, where a section of the video is utilized and converted into a texture map. In this graphic, four separate sections of the video are outlined and labeled as 1, 2, 3, and 4. Each number represents a separate projection map, and these are represented as the actual maps in Figure 10. Also shown in Figure 10 is the stitching process for assembling the projection maps along the roadway into one long, seamless photo-realistic texture map.

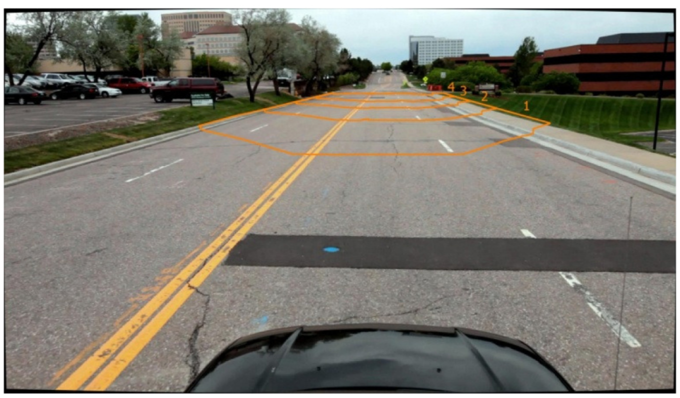

Figure 9. Projection zones of 4 frames of video

Figure 10. Top view of projected video frames

Because the projection maps show objects that are also computer geometry created through the video tracking process, the maps can be scaled and placed onto the computer generated roadway so that they fit the roadway in the correct location and scale. This final step yields a three-dimensional, photo-realistic computer model of a roadway with all the evidence visible on the roadway projected onto the computer model. Figure 11 shows the results of this process.

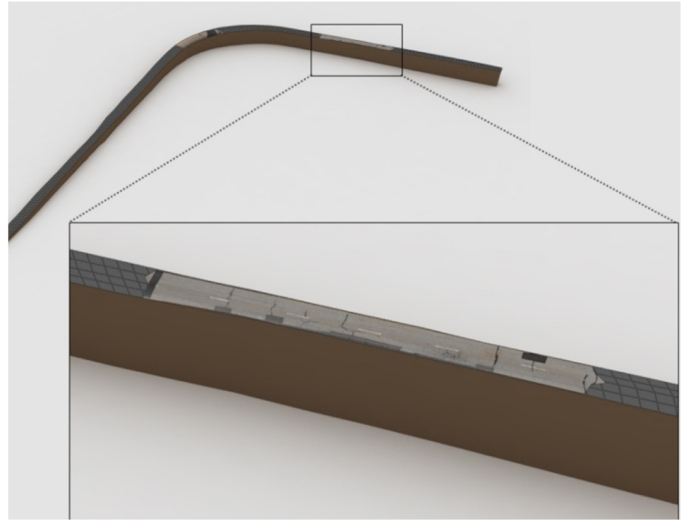

Figure 11. Computer modeled roadway with video images projected onto it

EVALUATION OF THE ACCURACY OF PROJECTION MAPPING

To evaluate the accuracy of the projection mapping process described here, the results from the projection mapping method were compared to the survey of the same roadway spray paint. Shown graphically in Figure 12 is the diagram created from the survey, and below it, the photo projected diagram created from the video projection process. Each diagram shows the two tire marks that start in lane one, and curve off the road to the right side.

The spray paint on the road that defines the shape of the tire mark and documented with the survey were compared to the same corresponding points observable in the video, and subsequently projected onto the computer generated roadway. By assigning one of the points in the survey to be the same Cartesian coordinate as the corresponding point in the projection map model, a comparison of all the remaining points can be done relative to each other. A matrix was created showing the difference in the points surveyed versus those in the projection map model. This matrix is shown in Figure 13, below.

To evaluate using the projection mapping in a critical speed analysis, the curvature of the tire mark was measured, and compared to the curvature of the tire mark from the survey. For the projection mapped model, the radius of the tire mark is 157.6 feet, and the radius measured in the survey was 158.4 feet. Measuring the curvature for the tire mark was done using the same method for both the survey and the projection mapped model, and the measurement was a best fit curve through the beginning middle and end of the tire mark. To illustrate how the different measurements obtained from the survey and the projection model would differ when used in accident reconstruction analysis, the radius measurements

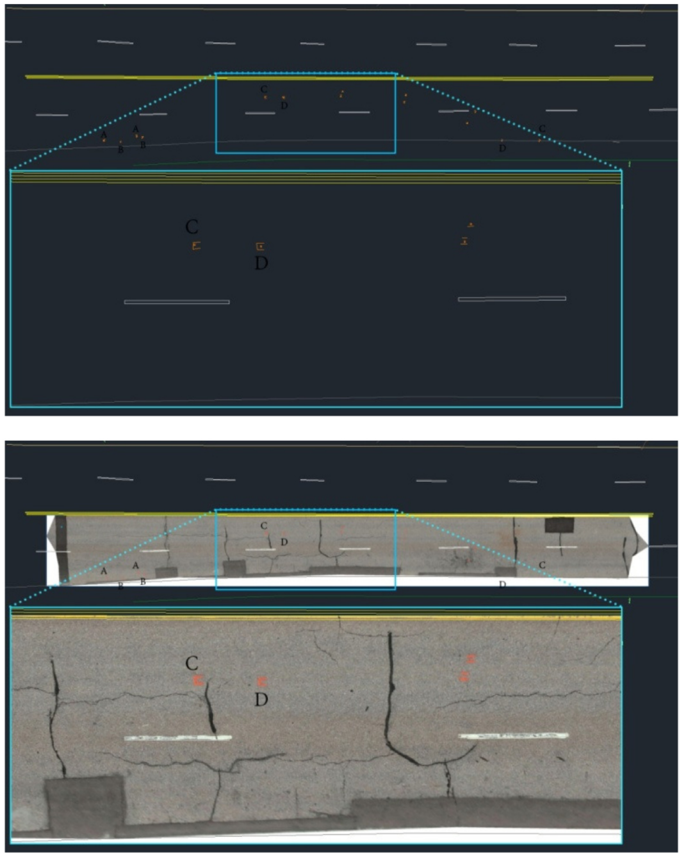

Figure 12. Image showing surveyed spray paint (top) and camera projected paint (bottom) marked with letters

Tire Mark	Length Projection	Length Survey	Radius Projection	Radius Survey	
A	12' 6"	12' 7"	NA	NA	
B	8' 6"	8' 5"	NA	NA	
C	108' 7"	108' 3.5"	157' 7"	158' 5"	
D	86' 7"	86' 5"	130' 3"	128' 6"	

Figure 13. matrix comparing survey points to projection mapped model.

were used in a speed analysis using the following critical speed formula.[10]

$$V_{cr} = \sqrt{g \cdot f \cdot R}$$

Where g is gravity, f is the tire frictional coefficient and R is the radius of the path of the leading front tire. A typical tire frictional coefficient of .75, for dry asphalt, was used in this analysis. The difference in radius yielded a difference in the speed calculation from 61.7 mph to 61.8 mph, a total difference of .1 mph.

In addition to the quantitative comparison of both the location of points and the curvature of the measured tire mark, a graphical comparison was also performed on a curve and over the crest of a hill to evaluate the projection mapping process under those circumstances. The sequence involved video recording and projection mapping three shapes; a circle, a square and a triangle. The circle, as painted on the roadway measured 3 feet in diameter, the square was 3 feet by 3 feet and the triangle was equilateral with all sides 3 feet long. As seen in Figure 3, video records the shapes spray painted on the roadway in perspective, and as a result the shapes appear stretched in the frame. Circles look more like ovals, squares look like rectangles and the triangle appears stretched when viewed at an angle. However, when processed through the methodology described above, and the same methodology for the tire mark analysis, the correct shapes are eventually projected onto the computer modeled roadway. Figure 14 shows is the comparison, graphically, of the survey of these platonic shapes and the projection mapped results of the same shapes.

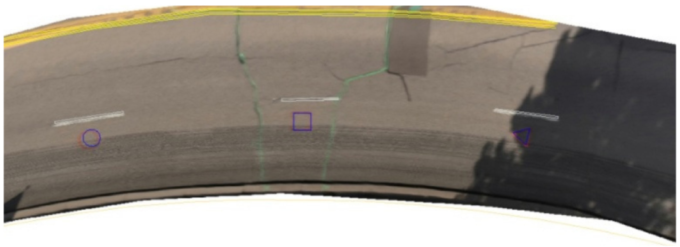

Figure 14. Overlay of surveyed shapes (purple) on the projected mapped shapes(orange)

CONCLUSIONS

This paper presents and evaluates the ability to take video footage of an accident scene that contains physical evidence on the roadway and, through photogrammetric and projection mapping processes, create a three-dimensional, scaled accident scene diagram with rectified photographs mapped onto the geometry. The projection-mapped images are a series of still frames from captured video, texture mapped to the surface of the computer model of the scene, and then scaled and rectified to properly represent the shape, position, and scale of the physical evidence. This process would be particularly helpful in situations where performing a traditional total station survey or laser scan is not a possibility, or where out-of-pocket costs are an issue. When photogrammetric camera projection is applied, it was found that roadway curves, grade and tire mark measurements were in agreement with the Sokkia laser survey. The final product allows one to view a mapped 3D terrain with correct roadway features, lighting and scale. In addition, the projection mapping properly positioned and scaled features that could appear distorted due to perspective. The projection mapped scene enables an accident reconstructionist to not only take accurate measurements of evidence, but also see this evidence at a photographic quality in a scaled three-dimensional environment. This paper explores mapping of roadways, which are relatively flat surfaces and particularly complex geometrically. Laser scanning can produce much higher resolution geometry, though for many applications video tracking and mapping would provide sufficient detail in the roadway geometry. This process in theory would also extend to mapping non flat surfaces that are visible in the video, such as curbs and walls, provided the detail of this geometry is not complex. Occluded surfaces would be an exception since these would not be captured by video, as would objects of geometric complexity such as trees, bushes and rocks. These objects simply have too many surfaces and varying geometry to be modeled and mapped from video.

Some other limitations in this process include pixel stretching due to a low angle between the roadway and the mounted camera. The lower the angle, the worse the effect. Perspective in the image makes objects in the distance a much smaller portion of the overall image and this makes projection of far away objects less accurate. Also, objects may appear blurry on the edges of the framed image particularly outside the 60 degree field of view. Finally, deterioration of the evidence, sun glare or other conditions that make the evidence on the roadway less visible, will likewise make the evidence as captured in the video footage less visible, harder to project and measure. As advances are made in better resolution, and better mounting systems, some of these limitations may be minimized. Further research in rigid camera mounts and the angle at which they are mounted relative to the road may help improve error.

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