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The Application of Augmented Reality to Reverse Camera Projection

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Abstract

In 1980, research by Thebert introduced the use of photography equipment and transparencies for onsite reverse camera projection photogrammetry [1]. This method involved taking a film photograph through the development process and creating a reduced size transparency to insert into the cameras viewfinder. The photographer was then able to see both the image contained on the transparency, as well as the actual scene directly through the cameras viewfinder. By properly matching the physical orientation and positioning of the camera it was possible to visually align the image on the image on the transparency to the physical world as viewed through the camera. The result was a solution for where the original camera would have been located when the photograph was taken. With the original camera reverse-located, any evidence in the transparency that is no longer present at the site could then be replaced to match the evidences location in the transparency. Reverse camera projection is useful for both determining the location of historical evidence, where it is no longer physically in existence, as well as for directing the investigator to evidence still at the site that may otherwise have been overlooked during a site inspection. With the advent of augmented reality, an entirely digital process of this technique is now possible. This paper both presents a digital methodology and provides reference to a publicly available, augmented reality application developed specifically for this process by the authors. The accuracy of the application and methodology is then demonstrated through field studies with reported results.

Introduction/Background

Augmented Reality

Augmented reality is defined as "an enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device (such as a smartphone camera)" [2]. Presented in this paper is the use of augmented reality through an application developed for cell phones and tablets. This augmented reality application allows users to overlay a photograph containing evidence to be located, onto the live view or camera video feed of a device. The user can then adjust the field of view (FoV), position, and orientation of the device until an alignment between the photograph and the real-world environment is achieved. This enhanced view of the real world then allows a user to mark the historical location of the evidence such that it can be documented using a total station, 3D laser scanner, or other three-dimensional recording instruments.

Photogrammetry

Photogrammetry is defined as the art, science, and technology of obtaining reliable information about physical objects and the environment through process of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena [3]. The use of photogrammetry in the field of incident reconstruction and visualization is well documented [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33]. The specific technique described in this research extends the existing body of research through the use of modern digital imaging equipment and software; namely the use of tablets in the field, and augmented reality software features that allow the tablet to display an image overlaid on the live camera view.

Onsite Reverse Camera Projection

The onsite reverse camera projection photogrammetry method was introduced by Thebert in 1980 in research titled "Computer Dimensioning of Skid Marks from Photographs". The methodology included placing a transparency on top of a film photograph, tracing scene and evidence features, and reducing the transparency to a 35mm transparency which was then inserted into a F3 Nikon camera's removable viewfinder. Once inserted, the transparency image was visible overlaid on the live view from the view finder. The viewer then looked through the viewfinder seeing both the scene and the traced lines that include evidence. The onsite camera match was then solved for by adjusting the cameras focal length, position, and orientation until an alignment between the traced lines on the transparency and the scene was achieved. The viewer then directed another person to place markers at the scene to match the location of evidence as seen through the viewfinder. With the evidence markers placed on scene, their position was then documented using survey equipment [1].

Building on this method, Smith and Allsop introduced a method they referred to as "Analytical reverse projection". Their method utilized computer software to solve for a camera's position and orientation by comparing user-chosen 2D points on a photograph to their corresponding surveyed points at the scene. Then evidence was placed on a model of the roadway surface by taking rays from the camera through the evidence on the photograph to the point where they intersect the terrain. Smith and Allsop compared their analytical reverse projection method to Thebert's camera reverse projection method and a plane-to-plane transformation method. Both the analytical reverse projection method and the camera reverse projection method were found to be more accurate than the plane-to-plane method, and they were found to be comparably accurate to each other [4].

Woolley, White, Asay, and Bready also further developed Thebert's reverse camera projection technique by applying it to vehicle crush. Their procedure was developed by applying reverse camera projection methods to quantify vehicle crush when the accident vehicle was no longer available for inspection. In their methodology, referred to as "Two-image camera reverse-projection," two photographs of differing perspectives were overlaid with transparencies and references within the photographs traced. The transparency overlays from the photographs were then reduced to a 35mm format. This allowed for the reduced photo transparencies to be placed on the focusing screens of two Nikon F-3 cameras (inside the removable viewfinders). This resulted in the traced image being superimposed onto the focusing screen, when viewed through the viewfinders of the cameras. An exemplar (or undamaged) vehicle of the same year, make, and model was obtained, and the undamaged portions were compared such that the relative camera position was solved for iteratively by aligning the vehicle through the viewfinder of the camera containing the reduced photo transparency. After both cameras (from differing perspectives) had been properly aligned and the camera position determined, the exemplar vehicle was removed and points along the vehicle crush line determined. This was accomplished by finding the intersection of the two projected rays (for each unique point) from each respective aligned camera, by moving a visible target along the projected ray until both were in agreement. The intersection of the two rays defined the crush profile at that point which could then be documented using various measurement techniques, including total station survey equipment. This targeting procedure was repeated for each common crush point identified between the two aligned photographs and would ultimately define the previously unknown crush profile of the vehicle [5].

Main and Knopf built further on the idea of using transparencies to inform evidence placement, but without the need of visiting the incident site. Their method, referred to as "Scaled camera reverse projection," required that a physical scale model of the accident scene and vehicles was prepared. Large transparencies were then prepared by tracing photograph features, or by simply printing the photographs onto the transparencies. The photo transparency was then placed in front of a camera and positioned along with the camera so that when viewing the scale model through the camera, the scale model was in the same perspective as the photo transparency. After achieving this perspective, the scale vehicle models were placed using the camera's perspective. In the same way additional evidence such as tire marks could then be plotted onto the scene model. Main and Knopf noted that "Although one camera could be moved between two or more tripods, the analysis is greatly improved by having one camera for each perspective view used in the analysis" [6].

Benefits of Onsite and Post Site Inspection Photogrammetry

After a site inspection where equipment has been used to record three-dimensional data, a photogrammetry method referred to as camera matching can be utilized. With a representation of the site, including features that have not changed between time of incident and time of inspection, 3D modeling software can be used to create virtual cameras. These cameras can then be positioned within the three-dimensional environment to match the perspective of photographs that include relevant evidence. Once the camera matching process is complete, the locations of this evidence can be transferred from the photographs to the three-dimensional model of the site. This camera matching photogrammetry method has specific advantages over onsite photogrammetry methods. It requires less time at the site, limits any safety concerns since the work is performed off site, and does not require extensive preparation at the site such as lane closures or traffic control.

Onsite camera matching, or reverse camera projection as described by Thebert [1], has its advantages as well. While there may be more preparation required before a site visit, once at the site anyone can achieve an alignment or camera match. Achieving a match is also not dependent on costly software or a developed skillset. Some photographs that contain important evidence may be in an environment or site where there are no close-range features to assist with software-based camera matching. An example of this includes photographs that with far-away features, such as mountains in the background, that would be difficult to record using a 3D laser scanning or total station equipment. For this reason, the 3D site model would not contain this useful site information. This same limitation does not apply to onsite camera match. Distant site features, such as terrain elevation changes and landmarks, can be used in the onsite process to help inform an alignment. Onsite reverse camera projection also provides users with immediate feedback about changes to the site and has the potential to inform whomever is inspecting the site of evidence still visible at the site that may have otherwise been overlooked. From a legal perspective the onsite camera matching process can be easily demonstrated and understood by a factfinder of a case. These and other advantages are represented in this non-exhaustive list:

- No expensive software required
- No specific, and extensive skillset required
- Ability to utilize far-way site features
- Immediate feedback about changes to the site
- Potential to discover overlooked evidence
- Potential to locate evidence more quickly
- Potential to present analysis results more quickly
- Ability to perform additional onsite analyses based on resulting evidence locations (e.g. sun, shadow, acoustic studies)
- Judge and jury can easily understand the process and recognize its credibility.

Digital Reverse Camera Projection

This paper presents an onsite camera matching photogrammetry method that uses augmented reality. This method will be referred to in this paper as digital reverse camera projection. This method incorporates the potential advantages of reverse camera projection from previous research and also has some additional benefits. For instance, digital reverse camera projection allows image editing software to assist in automatically creating outlines on photographs, removing the need to manually trace them. Further there is no need to then digitize the trace, and scale it to the appropriate format. (Additional digital tracing may however still be of value when the location of smaller objects need to be highlighted or filled in for greater visibility). When used with multiple devices at once, as described further in the methodology, users can verify the placement of evidence from more than one vantage or camera match without the need for resolving. The application also gives users the ability to visually record the achieved solution showing both the line work from the original photograph and the camera live view. This can be useful to both demonstrate the process and to record the accuracy of the results. Users can quickly toggle between different evidence photograph overlays within the application, replacing the need to manually load new slides into the viewfinder. This ease of loading multiple images into the application allows users to maximize time spent in the field. The following list summarizes some to the advantages to digital reverse camera projection.

- No need for manual tracing and scaling of photographs
- Ability to toggle between photograph overlay and live view
- Ease of switching from one photograph to the next
- Ability to adjust image overlay opacity
- Digital adjustment of the field-of-view (FoV)
- Ability to digitally record camera match alignment
- A visual tool for demonstrating camera matching

Onsite camera matching has and continues to offer unique analysis and visual benefits. The digital reverse camera projection method can be useful for reconstruction of evidence such as placement of a vehicle based on photographs or video and for further onsite analysis such as line of sight, glare, and acoustics. Cases with tire marks in the snow where there is little corresponding information contained in the foreground but recognizable landmarks in the distance, water-based cases, snow sport cases, line of sight, and shooting incidents may all see specific benefit to the presented digital reverse camera projection methodology.

Methodology

Site Documentation for Known Evidence Locations

Three sites were chosen for testing the subject method. The first site was residential and located near an intersection. The second site was located at an urban intersection surrounded by businesses. The third site was located within a rural state park (Figures 1-3).

FIGURE 1 Photograph from first testing site within a residential neighborhood. Green spray-chalk (evidence) is visible in the traffic lane.

FIGURE 2 Photograph from second testing site, an urban intersection with surrounding businesses. Green spray chalk (evidence) is visible within the intersection.

FIGURE 3 Photograph from third testing site, a rural area located within a state park. Green spray chalk (evidence) is visible within the travel lane and shoulder.

Five spray chalk markings were placed on the roadway surface at each of the three sites to simulate paint markings for evidence locations as commonly placed by police personnel. The spray chalk evidence was then photographed from multiple locations using a Canon EOS 5D Mark II with a 24-105mm lens. All photographs were taken at the widest field of view (FoV) setting with a 35mm equivalent of 23.4mm. The 3D location of each evidence mark was then recorded using a Sokkia Set5 30R total station with distance accuracy of approximately ±3mm. Nails were placed as control points at each site and their locations were also recorded with the total station. These were placed for future reference and alignment of subsequent total station data.

Image Selection, Correction, Filtering

The photographs best suited for digital reverse camera projection or onsite camera matching were then selected. When choosing photographs for camera matching, some qualifiers for selecting the best photographs or video frames may include:

- Images containing both evidence to be placed and unaltered scene features for alignment
- Images without obstructions (e.g. passing traffic)
- Images containing features with varied distances such that foreground and midground, or midground and background, or all three are present
- Images recorded with a known camera and lens from EXIF (Exchangeable image file format, metadata stored within the photograph file) such that lens distortion can be easily corrected for
- Clear images with higher resolution
- Images from a variety of angles, ideally approaching a 90° angle difference from other images
- For safety purposes, images that have been taken on the roadway, within traffic areas, or near potentially dangerous areas should be avoided, unless a roadway closure has been scheduled.

Photographs and video containing evidence is rarely ideal. If photographs or video frames are not consistent with all items on this list, it does not disqualify them from being used for photogrammetry. Images to be used in photogrammetry need to be evaluated on a case-by-case basis.

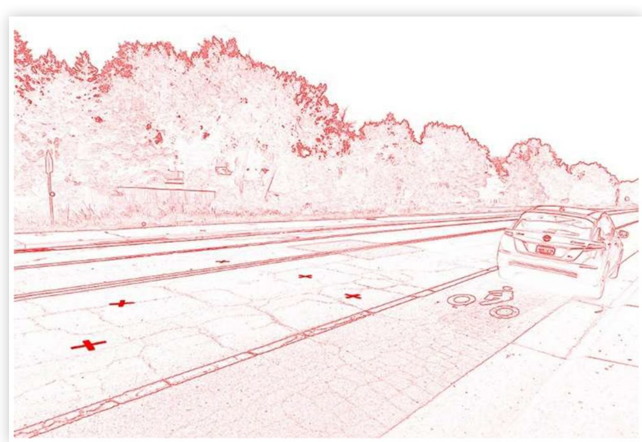
After selecting the photographs to be used, lens distortion was removed using PT Lens v.9.1. There are other programs and methods available for removing lens distortion which have been successfully utilized in photogrammetry projects [34, 35, 36]. Once lens distortion was removed, the photographs were filtered in Adobe Photoshop CC 2018 to create an outlined version of the photograph that can be described as a coloring book version. Additional colorization was performed to make the lines red for easier viewing within the digital reverse camera projection application (DRCP). It may also be useful to use another color to indicate the evidence or to fill in the outlined evidence as illustrated in Figure 4. The authors have created an Adobe Photoshop action that can be used to create similar outlined imagery from evidence photographs. This action is available for download at: http://kineticorp.com/reverse-camera-projection-app/.

Once lens distortion was removed and filtering had been applied to the photographs, they were ready to be loaded onto the device(s) for use at the incident site. The photos used in the camera matching process are loaded into the application by copying image files to the DRCP application installation folder on the device.

Solving for FoV before Site Visit (Optional)

The authors found it was useful to obtain photograph FoV information prior to solving for the camera matches onsite. This was performed initially by looking at the EXIF data for each photograph to be used for camera matching. There are many free or low-cost EXIF readers available. For the

FIGURE 4 Photograph ready for loading into the DRCP application. Lens distortion has been corrected, and outlines have been created and colorized. Evidence has also been filled with solid red for easier identification.



purposes of this study, ExifTool version 7.8.6.0 was utilized, and the FoV value from the photographs as reported by the software was 75.1°. This value was verified to be the same for all photographs to be used in the study and was noted for use as an input while camera matching onsite. It is worth noting that the EXIF reported FoV value is not always correct in offering the best solution for camera matching, but it provides a good initial value to work from. It is possible for this value to be recorded incorrectly by the camera, and simply correcting for lens distortion on a photograph, which involves cropping in some software titles, can alter the actual FoV of the photograph.

The application interface currently contains two text input fields allowing the user to adjust both the device FoV and the photograph FoV. Should the values reported in photograph EXIF need adjustment, controls for making refinements are provided. The photograph FoV information is used to scale the image overlay to conform to the FoV of the device camera. The application will automatically detect the device FoV if available, and that value will be displayed alongside the device FoV text input field. This too is editable, should the values generated from the device need adjustment.

To determine the correct relationship between the photograph and device FoV, a sample camera match can be performed prior to visiting the incident site. If an exemplar camera of the same make, model, and lens is available, the DRCP application can be utilized to determine the correct setting for the device FoV. Having an accurate determination of the device FoV can save time at the incident site, such that the camera's position and orientation are the only variables to be considered.

FoV determination was completed for this study by taking pictures within a nearby parking lot, correcting for lens distortion, filtering the image in Adobe Photoshop CC 2018, and creating the red outlined version of the photograph. Then this photograph was loaded into the DRCP application and an onsite camera match was performed. In this instance the device FoV reported by the application was 62.2°. With the sample camera match, we were able to achieve a good alignment with a device FoV value of 64.7° (Figures 5-7).

FIGURE 5 FoV determination: Solving for camera field-of-view in a nearby parking lot prior to visiting incident site.

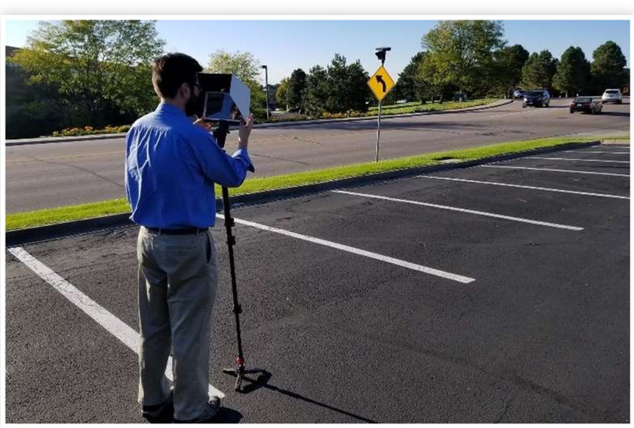


FIGURE 6 FoV determination: The outlined photograph, colorized red for easier viewing as overlay within the DRCP application.

FIGURE 7 FoV determination: The resulting red outline photograph and live view alignment, with the photo FoV solution visible in the application interface.

During testing, the authors found that it was quicker to achieve an alignment or camera match without using a tripod because they can be cumbersome and make small translational and rotational adjustments difficult. Unfortunately, without using a tripod, it is difficult to hold the device still during the placement of evidence markers, and impossible to place evidence markers without the help of another individual. For this reason, the authors used a monopod for both its ease of transport and maneuverability during the camera matching process. As stability is also desired, the monopod that was used included 3 small feet near the base. Once a match is achieved, a bipod can be attached to the monopod to give it more stability while placing evidence markers or solving for additional cameras with additional devices (Figure 5).

A single tablet setup including the equipment shown in Figure 5 can be purchased for approximately $520 (Table 1). The hoods in this purchase list are useful for blocking some of the reflected light on the device screen. Unfortunately, the hoods do not come with a hole for the camera lens, so small modifications will need to be made before use.

TABLE 1 List of equipment used and recommended for the digital reverse camera projection process.

Device	Brand	Description/Model	~ $
Phone	Samsung	Galaxy S8 Active	NA
Tablet	Samsung	Galaxy Tab A 10.1″	$ 230
Monopod	IFOOTAGE	71″ professional video monopod	$ 140
Bipod	SOKKIA	Thumb release bipod	$ 90
Tablet Hood	SummitLink	10 inch tablet iPad sun hood	$ 15
Phone Hood	iKNOWTECH	3.5-5.5 inch, FPV Monitor Sunshade	$ 10
Tablet Hood Mount	Gilmars	4 button, universal tablet clamp holder	$ 10
Tripod Ball Head	Sunpak	620-PISTOLGRPQR tripod, ball head	$ 25

Augmented Reality Application Warnings

The DRCP application utilizes augment reality by overlaying outlined imagery or graphics on top of the live camera view. This overlay informs the user as to how to position and orientate the device to achieve an alignment between the overlaid graphical image and the real world. Similar to other augmented reality applications, before using the application users are presented with a warning screen. For safety, this warning reminds users to stay alert and to be aware of their surroundings. Photographs taken by emergency personnel are frequently taken on a roadway after it has been closed or blocked off. Photographs where it is clear that the camera position was on a roadway should not be selected for use with onsite photogrammetry unless a roadway closure has been scheduled. Similarly, caution should be used if attempting to use the application to camera match photographs taken within close proximity of traffic areas. The attempt to match any photograph where a potentially dangerous condition exists, or could exist during the camera matching process, should be abandoned for safety. Augmented reality applications can be immersive. For example, 17 deaths and 56 injuries have been catalogued in relation to using the Pokémon GO application. Some of these incidents are directly related to stepping into traffic while using the augmented reality application [37]. When possible, it is recommended that users setup a physical boundary, such as a tape line, to avoid dangerous areas while using the DRCP application to solve for the camera location.

Application Setup Notes

The DRCP application is available on the Google Play Store and may be installed on an Android device running Android 4.3 or higher. A link to the installation files and a recommended purchase list for the equipment used in this research can also be downloaded from the following website: http://kineticorp.com/reverse-camera-projection-app/. The authors intend to continue developing this the application adding features and support for more device models. Currently the application is known to work with the following devices: Samsung Galaxy Tab A 10.1, and Samsung Galaxy S8 Active Phone. Compatibility with other devices may vary, given variation in camera hardware across devices.

Using the DRCP Application (Augmented Reality)

The three testing sites were revisited to ensure there was no remaining spray chalk to serve as a visual bias for placing evidence at the site. The spray-chalk had not yet disappeared as expected, so it was scrubbed off of the roadway surface with water and a course brush to avoid creating a visual bias when recreating the locations using the DRCP application.

The sites were then visited again to test the digital onsite methodology. This was done by solving for the camera match alignment, placing tape on the roadway surface consistent with the camera match, and surveying the placed evidence locations so that they could be compared to known evidence locations. The participants were asked to solve for evidence locations initially using only one camera match. This was achieved using a Samsung A10 Android tablet with the DRCP application installed. The participant then aligned the red outlined photograph overlay with evidence to the live view from the tablet camera by moving, rotating, and adjusting the FoV settings. Once an alignment was achieved, the monopod was anchored using a bipod, and the match was reevaluated to ensure there was still a good alignment between the photograph outlines and the live camera view of the scene (Figures 8 and 9).

FIGURE 8 Tablet at site 1 camera matched position (CMA) with bipod legs attached to monopod for stability.

FIGURE 9 Application interface showing camera live view (Top) and red outlined photograph overlay aligned on top of live view (Bottom).

The participant then directed another individual to place orange tape representing the green spray-chalk evidence in the roadway as located using the application. This was accomplished by using a laser pointer and by verbal commands. Once the participant felt the orange tape placements were consistent with all five evidence marks visible on the photograph, the center locations of the orange tape was surveyed using the same total station as previous (Figures 10 and 11).

The participant was then given two additional tablet devices to solve for two additional onsite camera matches. These camera matches were achieved using the same process as previous. Orange tape was then placed based in the same manner for each match, creating a pattern of three orange tape placements at each of the five evidence locations. When the participant felt that each of these were consistent with the camera matches, the visual center of the tape was again surveyed using the total station for future comparison (Figure 12).

To evaluate the effect experience has on the accuracy of this methodology, a participant with minimal experience with the application was chosen. The other two participants were more experienced with the application and methodology. The same process of solving first for a single camera match, placing orange tape for the evidence, and surveying the placed evidence locations for comparison to known evidence locations was accomplished by all three participants at all three

FIGURE 10 Directing placement of orange tape through use of laser pointer (green light). This is a useful method but does not work as well on bright sunny days.

FIGURE 11 Placing orange tape through verbal commands.

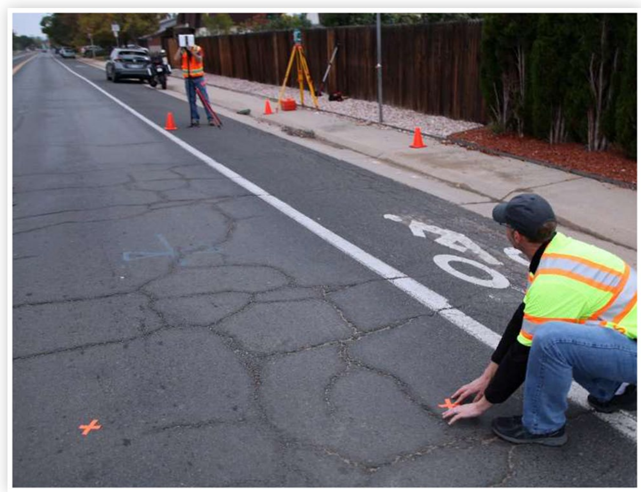


FIGURE 12 Placing tape at testing site, with 3 tablets positioned to solve for each camera as labeled: CMA, CMB, and CMC.

sites. In the same way, all three participants were then given two additional tablets to solve for two additional camera matches. Evidence placements based on all three camera matches were then surveyed for comparison to known evidence locations.

To evaluate the ability of using this application on a phone, this same process of onsite camera matching with a single device was completed again by a different participant at each site. This was done using a Samsung Galaxy S8 Active phone instead of a tablet. All three participants noted that the size of the screen made it more difficult to achieve an alignment, to see the evidence within the photograph overlay, and to place the evidence markers at the scene. Once an alignment was achieved, and the makers were in place, the evidence placements were once again surveyed for comparison to know evidence locations (Figures 13-15).

FIGURE 13 Site 1evidence locations with known evidence shown in red.

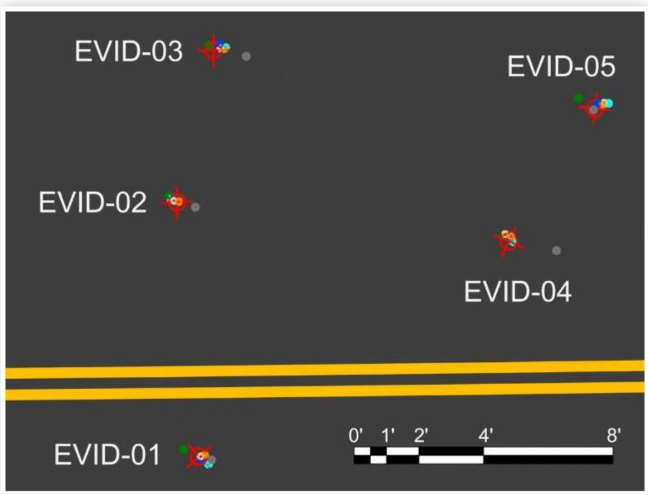
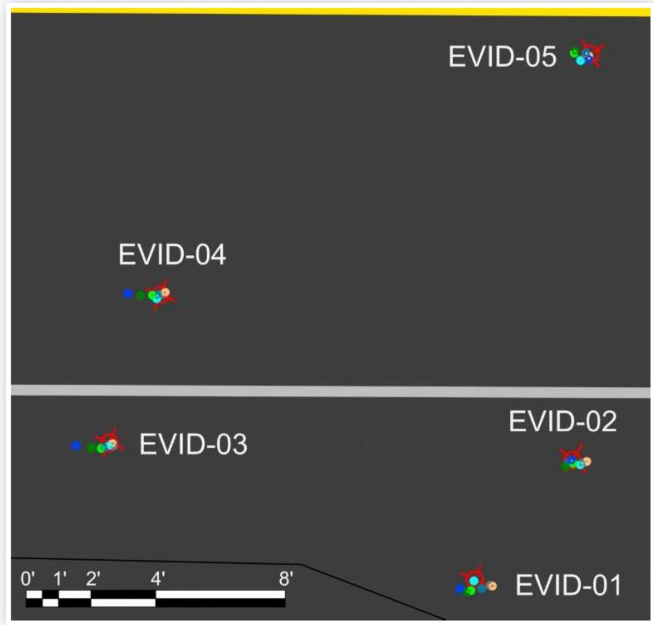


FIGURE 14 Site 2 evidence locations with known evidence shown in red.

FIGURE 15 Site 3 evidence locations with known evidence shown in red.



Overview of Methodology

Onsite camera matching using the digital reverse camera projection methodology, can be summarized in the following steps:

1. Analyze photographs to be used and correct for lens distortion where needed.
2. Create an outlined version of the photographs using an image editor, making sure evidence to be placed is visible.
3. Download and install the DRCP application.
4. Consent to augmented reality warning screen(s).
5. Load the outlined images onto the device(s).
6. Take device(s), glare hoods, and monopod bipod or tripod setup and desired methods of documentation to the incident site.
7. Choose a photograph and iteratively adjust FoV *(using previously documented FoV values as a starting point if applicable)*, position, and orientation of the device until an alignment is achieved.
8. Place markers to indicate original evidence locations.
9. Verify locations on device(s).
10. Use application to take a screen capture documenting the alignment or match, and placement of evidence markers.
11. Document placed evidence markers and other site features using a total station, 3D laser scanner, or other preferred method of site mapping.

Additional, optional steps:

- If an exemplar camera is available, take pictures in a similar setting with easy access using the same FoV as reported by EXIF data. Run these through the same process creating an outlined version in an image editor.

- Take device setup to nearby site and follow step 6. When an alignment is achieved, document the FoV values for future use.
- If using multiple devices, continue onto subsequent devices loading in additional photographs and solving for camera match alignments.
- If using multiple devices, verify evidence locations on all, making adjustments to placement or camera positioning until evidence placement is consistent within all matches prior to documenting with screen capture, and total station or other equipment as in steps 9 and 10.

Results

Participants

There were three participants for this study. The first participant (P1) had little to no experience with the digital reverse camera projection application (DRCP). The second and third participants (P2, P3) were more experienced with the application. The onsite camera match evidence locations placed by P1, based on the three-camera solution, were an average of 4.6 in (11.6 cm) from known evidence locations for the first site. The onsite camera match evidence locations placed by P1, including both one-camera match and three-camera match solutions, were an average 3.4 in (7.3 cm) for the second site, and 4.7 in (11.9 cm) for the third site for an overall average of 4.2 in (10.5 cm) from known evidence locations. The onsite camera match evidence locations placed by P2, including both one-camera match and three-camera match solutions, were an average of 2.9 in (7.3 cm) from known evidence locations for the first site, 2.7 in (6.9 cm) for the second site, and 4.5 in (11.3 cm) for the third site for an overall average of 3.3 in (8.5 cm) from known evidence locations. The onsite camera match evidence locations placed by P3, including both one-camera match and three-camera match solutions, were an average of 2.4 in (6.1 cm) from known evidence locations for the first site, 2.4 in (6.0 cm) for the second site, and 2.7 in (7.0 cm) for the third site for an overall average of 2.5 in (6.4 cm) from known evidence locations. The average of all onsite camera match evidence placed by all participants for all three sites was 3.3 in (8.5 cm) from known evidence locations. This does not include matches achieved with the phone, but it does include all one-camera and three-camera solutions. There was one camera match as part of the three-camera match solution on site 3 that one of the participants (P2) felt they could not achieve a good alignment. This created an anomaly in the data with a value of 12.54 in (31.62 cm). While the authors believe with more experience and time this can be minimized or avoided altogether, this data was not excluded from the results. Aside from this anomaly, the highest value was 7.3 in (19 cm) and the lowest value was 0.2 in (0.5 cm) with standard deviation of 1.7 in (4.3 cm) (Tables 2-5).

TABLE 2 The average camera matched evidence distance from known evidence locations by participant for site 1. (P1 data was not recorded for a single camera match.)

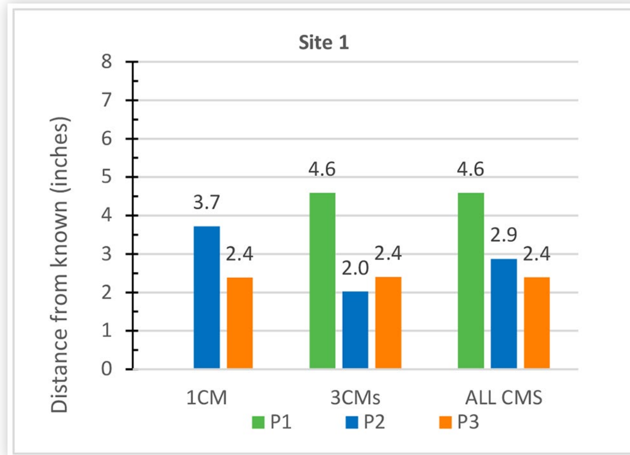


TABLE 3 The average camera matched evidence distance from known evidence locations by participant for site 2.

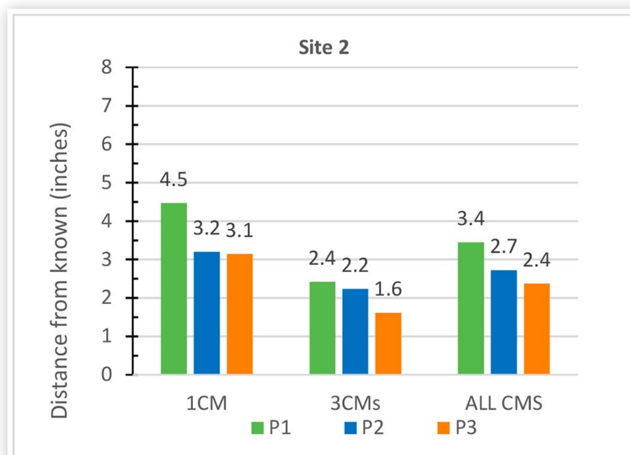


TABLE 4 The average camera matched evidence distance from known evidence locations by participant for site 3.

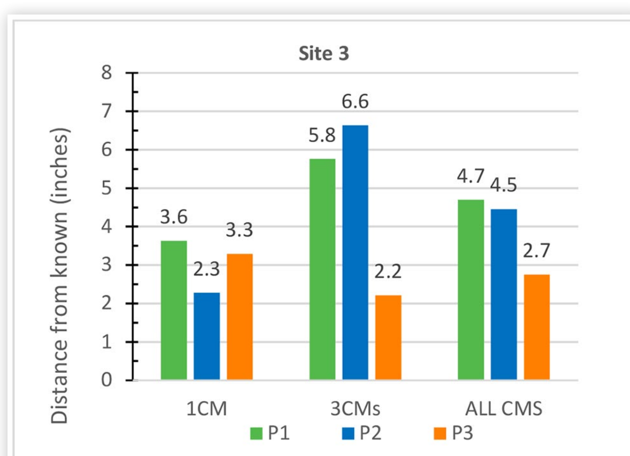
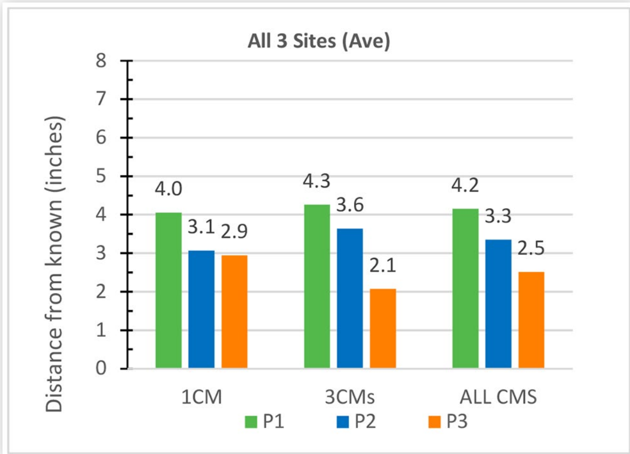


TABLE 5 Camera matched evidence distance from known evidence locations by participant for all 3 sites.



Phone & Tablet

To evaluate the ability to use this methodology and application on a phone, a Samsung Galaxy S8 Active was used for a single camera match by a different participant at each of the three sites. In general, the results participants had with the phone were not as accurate as the results achieved with a tablet by the same person using the same image to match at the same site. On site three, evidence located by one participant was more accurate than evidence located by the same participant using a tablet. This difference was marginal with the phone data outperforming the tablet data by an average of 0.4 in (0.9 cm). Overall, evidence placed while using a tablet instead of the phone showed a 40% improvement on average. The authors believe the biggest reason for this is the proximity of the camera to the evidence. The photograph that was camera matched at site 3 was taken approximately twice as close to evidence as the photographs used for site 1 and site 2. This is consistent with the limitations of the phone display size. The authors believe that at a closer distances evidence becomes clearly visible and can be placed accurately regardless of display resolution and screen size differences like those of a phone and a tablet (Table 6).

One-Camera and Three-Camera Match Solutions

It has been demonstrated that using more than one photograph or camera match image can improve photogrammetric accuracies [38]. The data collected from this study was consistent with the previous literature for site 1 and site 2. At site 1, evidence markers placed using one-camera match were found to be an average of 3.0 in (7.7 cm) from known evidence locations, and evidence markers placed using three-camera matches were found to be an average of 2.2 in (5.6 cm) from known evidence locations (Table 7).

At site 2, evidence markers placed using one-camera match were found to be an average of 3.6 in (9.1 cm) from known evidence locations, and evidence markers placed using three cameras were found to be an average of 2.1 in (5.3 cm) from known evidence locations (Table 8).

TABLE 6 Distances from known evidence locations for evidence placed by phone and by tablet by on participant at each site.

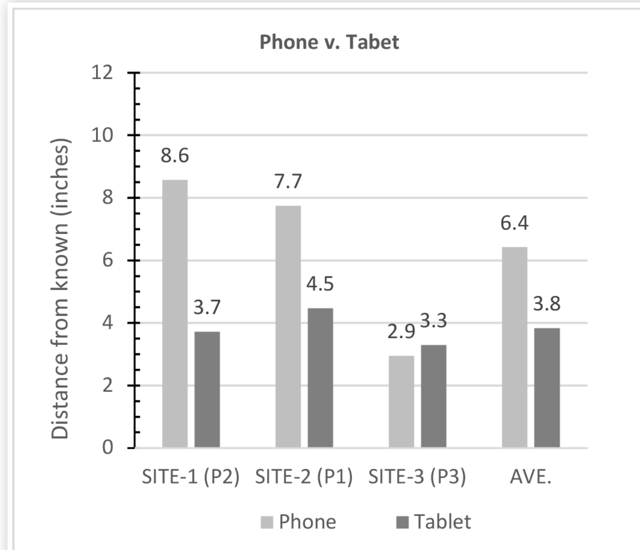


TABLE 7 Comparison of evidence locations from one camera match and three camera matches for site 1.

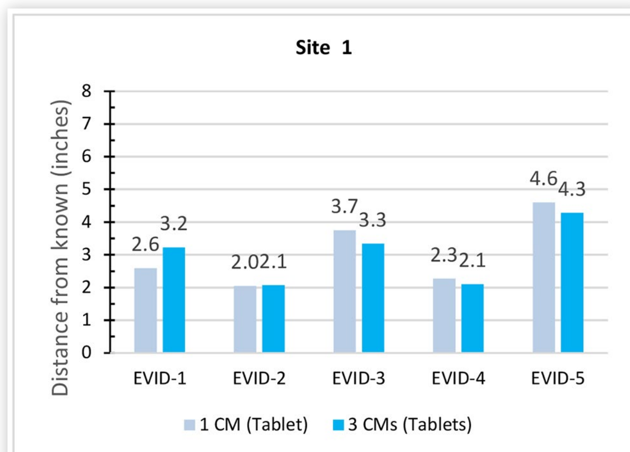


TABLE 8 Comparison of evidence locations from 1 camera match and 3 camera matches for site 2.

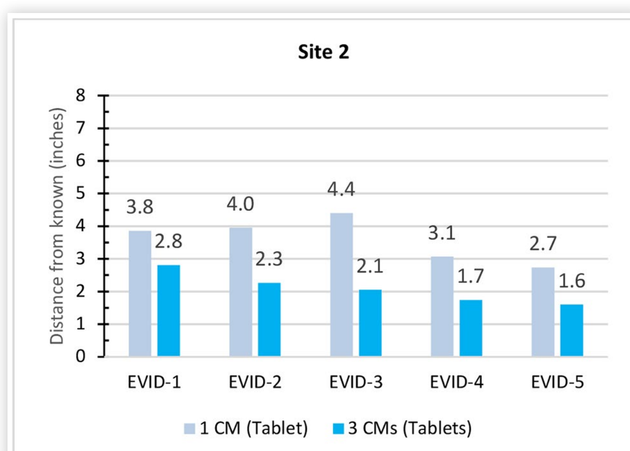


TABLE 9 Comparison of evidence locations from 1 camera match and 3 camera matches for site 2.

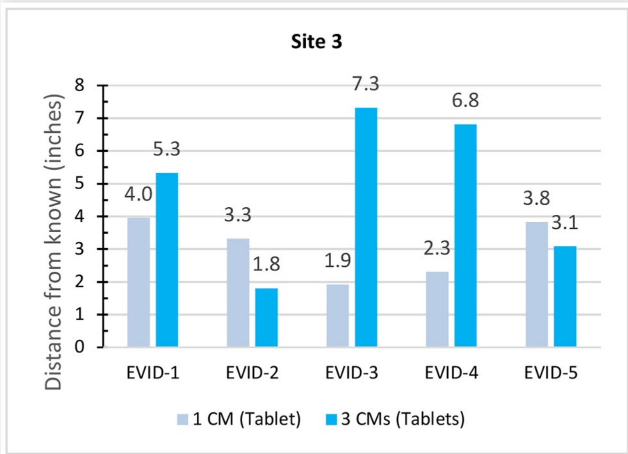
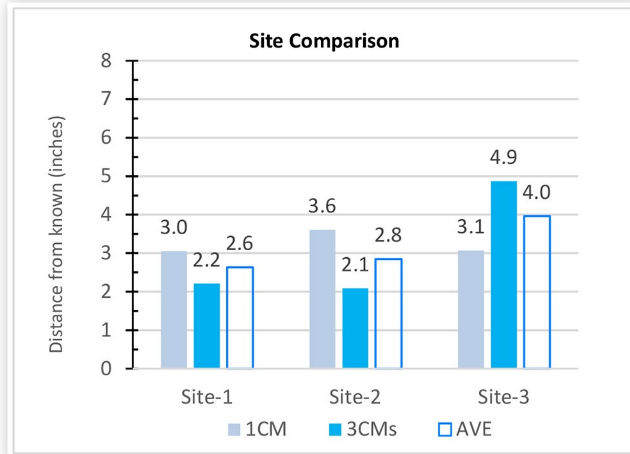


TABLE 10 Comparison of camera matched evidence locations to known evidence locations for each site.



Site 3 was both more rural and contained the anomalies mentioned in the "Participants" section. The matches with less foreground information using photos that were taken farther away from the evidence showed better results using one camera match than when using three camera matches. The authors believe this is due to both placing evidence when a good alignment was not clearly defined and because the evidence was farther away and more difficult to see on the screen. For site 3, evidence markers placed using one-camera match were found to be an average of 3.1 in (7.8 cm) away from known evidence locations, and evidence markers placed using three-camera matches were found to be an average of 4.9 in (12.4 cm) from known evidence locations (Table 9).

Urban & Rural

For site 1 (urban residential), camera matched evidence locations using tablets were found to be an average of 2.6 in (6.7 cm) from known evidence locations. For site 2 (urban business), camera matched evidence location using tablet were found to be an average of 2.8 in (7.2 cm) from known evidence locations. For site 3 (rural), camera matched evidence locations using tablet were found to be an average of 4.0 in (10.1 cm) from known evidence locations (Table 10).

Summary/Conclusions

The presented methodology utilizes augmented reality within the DRCP application and has been shown to produce results with similar accuracy to other photogrammetric methods. The primary benefits of this methodology are its affordability, accessibility, credibility, and that it can be easily understood and demonstrated.

This onsite methodology using digital reverse camera projection offers the benefit of determining evidence locations while still onsite. Using this method requires only a general understanding of photogrammetry and limited experience using the application to achieve results as demonstrated in this research.

In summary, the DRCP application offers the following benefits:

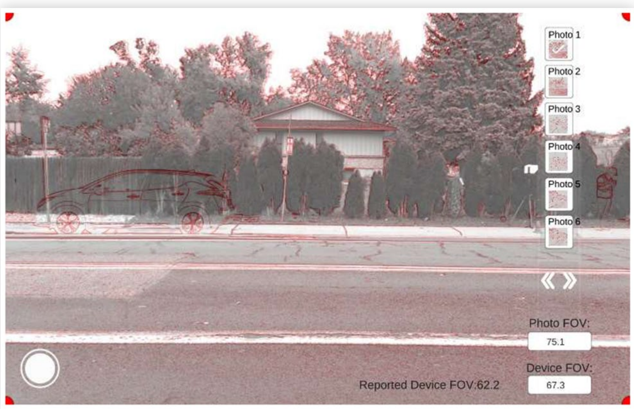
- No expensive software is required
- No specific and extensive skillset is required
- Far-way site features can be utilized
- There is immediate feedback about changes to the site
- Manual tracing of photographs can be eliminated
- Image overlay opacity can be adjusted
- Multiple photograph overlays can be swapped out
- Field of View (FoV) can be digitally adjusted
- Alignments can be documented with screen captures
- Otherwise overlooked evidence can be found
- Locating evidence onsite can be expedited
- Additional onsite analyses can be performed without need for a second site visit (line-of-sight, sun glare, shadow, acoustic, studies)
- Analysis results can be presented more quickly
- Onsite camera matching can be visually demonstrated
- A judge and jury can easily understand the process and recognize its credibility

Discussion

Onsite camera matching using the DRCP application is an iterative process. During the camera matching process, the user is continually evaluating the current match and making adjustments to camera height, distance from target, rotation, and field-of-view. Due to the visual nature of onsite camera matching process, it is apparent when a good camera match is achieved. The process itself relies on the constant visual feedback from the application. Likewise, it is visually apparent when there is a poor alignment (Figures 18, 19).

FIGURE 16 Application screen grab from a participant solution at site 1 with a single camera match. Areas of the photograph in the mid-ground and background where alignment has not been achieved are highlighted in yellow.

FIGURE 17 Application screen grab from a participant solution at site 1 with a single camera match. All areas of the photograph show visible alignment between the photograph with evidence visible (red lines) and the camera live view from the tablet.



In these instances, more time and more experience should yield better results as demonstrated by the participant with less experience. There may also be occasions where there is not enough visual information to determine a specific location, but rather a range. In these instances, it is best to rely on other camera matches where good alignments are achieved for placing evidence. This is demonstrated by the anomaly in data in P2's data on site 3, where P2 did not feel the camera match was well aligned but placed evidence regardless as part of the research process. This participant had already placed the evidence more accurately with the first, single camera match. This data is visible in Table 9 with evidence 4 and 5, and in appendix A.

Limitations

As mentioned in the *Image Selection, Correction, Filtering* section, care should be taken when selecting images to be used for photogrammetry. Not all images are suited for photogrammetric purposes. The accuracy of the camera matching process is dependent on the angle of incidence as determined by the elevation of the camera, the elevation of the evidence to be placed, and the distance between the camera and the evidence [11]. Similarly, lower resolution imagery can also limit the photogrammetric accuracy achievable. Lens distortion can also affect photogrammetric accuracy. The accuracy of evidence placement within this paper may not be achievable when lens distortion is not considered and when appropriate measures for lens correction are not implemented [34, 35, 36].

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Definitions/Abbreviations

ASPRS - American Society of Photogrammetry and Remote Sensing

Augmented reality - "An enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device (such as a smartphone camera)" [2].

Camera matching - A close-range photogrammetry method where known 3D models are aligned to a photograph within computer driven software. The software is utilized to solve for the camera location, orientation, and field of view.

DRCP - An augmented reality software application developed for digital reverse camera projection.

EXIF - Exchangeable image file format, metadata stored within photographs, videos, and audio files

FoV - Field of View: Commonly referring to the width of vision range through a camera.

Photogrammetry - Defined by ASPRS as: The art, science, and technology of obtaining reliable information about physical objects and the environment through process of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena.

Appendix A

Recorded known evidence locations and evidence placements from all 5 participants at all three sites.

Site 1: Known evidence locations (inches)

	Site-01		
	X	Y	Z
EVID-1	-437.36	53.45	5941.00
EVID-2	-370.50	120.42	5941.25
EVID-3	-318.71	146.39	5939.44
EVID-4	-302.33	16.93	5941.60
EVID-5	-244.09	24.20	5940.30

Site 1: Evidence placements based on one camera match (inches)

	1			Dif	2			Dif	3			Dif
	X	Y	Z		X	Y	Z		X	Y	Z	
EVID-1					-442.24	54.35	5940.88	4.96	-441.43	54.95	5940.61	4.36
EVID-2					-369.37	124.73	5940.06	4.61	-369.76	122.44	5940.43	2.30
EVID-3					-317.55	150.12	5938.56	4.01	-319.85	145.34	5939.26	1.56
EVID-4					-308.23	19.23	5941.12	6.35	-307.39	17.66	5941.32	5.12
EVID-5					-248.73	26.60	5940.08	5.22	-248.39	24.68	5940.61	4.33
			EVID				EVID	**3.72**			EVID	**2.38**
			STDEV				STDEV	**1.4**			STDEV	**1.1**

Site 1: Evidence placements based on three camera matches (inches)

	1			Dif	2			Dif	3			Dif
	X	Y	Z		X	Y	Z		X	Y	Z	
EVID-1	-438.95	59.59	5940.83	6.35	-437.26	52.28	5940.70	1.21	-435.64	52.26	5940.74	2.11
EVID-2	-370.47	124.20	5940.87	3.80	-370.32	122.11	5940.87	1.74	-369.95	120.19	5940.97	0.66
EVID-3	-318.40	149.04	5939.05	2.69	-315.49	145.92	5939.11	3.27	-315.68	143.75	5939.11	4.03
EVID-4	-302.01	19.67	5941.15	2.80	-300.88	17.38	5941.23	1.57	-300.50	17.50	5941.39	1.93
EVID-5	-245.06	31.43	5940.14	7.29	-241.80	24.55	5940.28	2.32	-241.07	23.03	5940.30	3.24
			EVID	**4.59**			EVID	**2.02**			EVID	**2.40**
			STDEV	**1.9**			STDEV	**0.7**			STDEV	**1.2**

Site 2: Known evidence locations (inches)

	Site-01		
	X	Y	Z
EVID-1	-412.11	472.04	5982.41
EVID-2	-297.45	385.49	5985.15
EVID-3	-263.50	325.19	5985.88
EVID-4	-417.60	317.75	5982.23
EVID-5	-392.37	261.79	5982.54

Site 2: Evidence placements based on one camera match (inches)

	1			Dif	2			Dif	3			Dif
	X	Y	Z		X	Y	Z		X	Y	Z	
EVID-1	-413.15	468.43	5982.55	3.75	-410.51	467.76	5982.56	4.56	-411.16	468.95	5982.38	3.23
EVID-2	-301.31	385.91	5985.24	3.88	-298.42	389.60	5985.25	4.22	-299.75	388.49	5985.06	3.77
EVID-3	-266.31	327.13	5986.01	3.42	-266.45	329.93	5985.91	5.59	-266.89	327.65	5985.79	4.18
EVID-4	-416.19	311.92	5982.42	5.99	-416.78	317.17	5982.35	1.00	-418.07	315.59	5982.20	2.20
EVID-5	-392.04	256.52	5982.69	5.29	-392.20	262.34	5982.72	0.60	-393.46	263.82	5982.51	2.30
			EVID	4.47			EVID	3.20			EVID	3.14
			STDEV	1.0			STDEV	2.0			STDEV	0.8

Site 2: Evidence placements based on three camera matches (inches)

	1			Dif	2			Dif	3			Dif
	X	Y	Z		X	Y	Z		X	Y	Z	
EVID-1	-415.10	471.05	5982.26	3.15	-410.03	470.19	5982.61	2.79	-410.26	470.39	5982.51	2.47
EVID-2	-299.07	384.05	5985.20	2.16	-298.42	387.40	5985.26	2.14	-299.45	386.95	5985.17	2.47
EVID-3	-262.36	323.06	5985.83	2.41	-265.33	326.65	5986.05	2.35	-264.78	325.74	5985.83	1.39
EVID-4	-420.19	318.55	5982.17	2.71	-415.41	318.24	5982.55	2.27	-417.66	317.54	5982.23	0.21
EVID-5	-394.01	261.57	5982.47	1.66	-390.82	262.25	5982.76	1.63	-391.12	262.62	5982.58	1.50
			EVID	2.42			EVID	2.23			EVID	1.61
			STDEV	0.5			STDEV	0.4			STDEV	0.8

Site 3: Known evidence locations (inches)

	Site-01		
	X	Y	Z
EVID-1	-663.55	-383.39	6003.42
EVID-2	-655.70	-326.77	6004.77
EVID-3	-805.58	-410.51	6005.02
EVID-4	-817.99	-353.82	6006.21
EVID-5	-728.31	-194.66	6007.28

Site 3: Evidence placements based on one camera match (inches)

	1			Dif	2			Dif	3			Dif
	X	Y	Z		X	Y	Z		X	Y	Z	
EVID-1	-662.67	-387.62	6003.49	4.32	-663.59	-383.99	6003.59	0.62	-656.75	-382.06	6003.55	6.93
EVID-2	-654.90	-327.62	6005.02	1.20	-652.28	-326.71	6004.96	3.43	-650.91	-324.45	6004.94	5.33
EVID-3	-807.04	-413.85	6005.21	3.65	-804.96	-411.19	6005.18	0.94	-804.48	-410.21	6005.19	1.16
EVID-4	-820.40	-355.50	6006.35	2.93	-818.37	-355.76	6006.29	1.97	-816.94	-352.12	6006.32	2.00
EVID-5	-733.64	-197.48	6007.51	6.04	-730.18	-198.65	6007.48	4.41	-728.51	-195.66	6007.42	1.03
			EVID	3.63			EVID	2.27			EVID	3.29
			STDEV	1.6			STDEV	1.4			STDEV	2.4

Site 3: Evidence placements based on three camera matches (inches)

	1			Dif	2			Dif	3			Dif
	X	Y	Z		X	Y	Z		X	Y	Z	
EVID-1	-663.66	-388.84	6003.49	5.45	-666.39	-389.07	6003.61	6.35	-659.64	-384.84	6003.43	4.17
EVID-2	-656.60	-330.02	6004.95	3.38	-655.83	-326.99	6005.11	0.43	-656.50	-328.15	6004.92	1.61
EVID-3	-810.23	-415.54	6005.23	6.85	-815.64	-417.85	6005.28	*12.45*	-806.36	-413.04	6005.20	2.65
EVID-4	-824.12	-357.86	6006.37	7.34	-828.54	-359.75	6006.43	*12.10*	-818.75	-354.43	6006.32	0.98
EVID-5	-733.66	-196.85	6007.54	5.79	-727.97	-196.45	6007.49	1.84	-729.85	-195.17	6007.48	1.64
			EVID	5.76			EVID	6.63			EVID	2.21
			STDEV	1.4			STDEV	5.0			STDEV	1.1

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