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Noncontact Modeling of Structures Using Close-Range Digital Photogrammetry

Kenneth R. Leitch, M.ASCE¹; and Malcolm B. Coon, S.M.ASCE²

Abstract: Recent years have seen a vast change in measurement technology. Data that were once extremely difficult and possibly dangerous to collect can now be collected and processed using only a digital camera and off-the-shelf software. Currently, digital close-range photogrammetry has made it possible to efficiently model a variety of structures in a budget-friendly manner. In this paper, a range of different types of structures were modeled. The viability of using this type of measurement is studied for different structure types, and the feasibility of using this method in conjunction with or as a replacement of other means is discussed. DOI: [10.1061/\(ASCE\)SC.1943-5576.0000124](https://doi.org/10.1061/(ASCE)SC.1943-5576.0000124). © 2012 American Society of Civil Engineers.

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Introduction

Photogrammetric measurement of structures is a field all its own. This technology can be used to measure, document, or monitor almost anything that is visible within a photograph (Matthews and Noble 2006). Although modern photogrammetry employs digital cameras and sophisticated computer programs, the concepts can be traced back to the writings of Leonardo da Vinci, who penned (Doyle 1964) “Perspective is nothing else than the seeing of an object behind a sheet of glass, smooth and quite transparent, on the surface of which all the things may be marked that are behind this glass. All things transmit their images to the eye by pyramidal lines, and these pyramids are cut by the said glass. The nearer to the eye these are intersected, the smaller the image of their cause will appear.” These principles allow multiple perspectives to be captured, processed, and combined to create a three-dimensional (3D) representation of visible subjects. Currently, photogrammetry can be divided into two subtypes: aerial and terrestrial (also known as close range). Aerial photogrammetry utilizes photographs taken from airborne platforms, while close-range photogrammetry uses photographs captured from the ground and generally from a distance of less than 300 m (Matthews and Noble 2006).

This study employs close-range photogrammetry to model a variety of structures. The tools utilized included the software package *Photomodeler 6* by Eos Systems (2008), a Canon EOS Digital Rebel XT 8.0 megapixel camera with a Canon EF-S 18–55mm lens, and a consumer-grade laptop running Microsoft Windows 7 for a total cost of under \$2,500.

To complete a project using *Photomodeler*, several steps must be taken. First, the software must be calibrated to the specific camera

and lens combination that will be used to take the needed photographs. Photographs of the subject are then taken, making sure to get sufficient coverage of the subject and plenty of overlap between shots. The photos are then transferred to the software package, where they are oriented and referenced before a 3D phototextured model is created. This model can then be scaled and used to determine various dimensional attributes of the subject. The model can also be exported to produce orthometric photos and files for use in AutoCAD, Google Earth, 3D Studio, and several other drafting and 3D model-based programs (Eos Systems 2010).

Three structures, all of different types, were selected to be modeled using *Photomodeler*. In choosing subjects, a variety of criteria were considered. Because a portion of the purpose of this study was to determine what types of subjects are suitable for this type of modeling, the selected structures had to be substantially different in construction, size, and form.

Camera Calibration

Before beginning a project, it is important to calibrate the photogrammetry software for a specific camera and lens. By calibrating, *Photomodeler* can determine the camera’s focal length, lens distortion, format aspect ratio, and principal point. The camera calibration process uses a grid of printed circular dots including four coded dots that help the program determine the orientation of the camera. The calibration grid must be printed from the program on a white background. Calibration can be performed using a grid as small as 216 × 279 mm (8.5 × 11 in.), but the closer the size of the grid is to the intended subject, the better. In this project, the grid was plotted on a 914 × 914 mm (36 × 36 in.) sheet, which was the largest format allowed by the equipment available for this project.

The calibration sheet must be secured to a flat surface for photographing. Photos of the calibration grid are then taken from multiple angles and camera orientations. Once the photographs are complete, they are transferred to the *Photomodeler* program, and a camera calibration project is created. The photographs are then processed by an automated program, and the values for the camera are calculated. These data will be used when processing modeling projects to properly orient the camera’s position in relation to the subject as well as to correct for any lens distortion (Eos Systems 2008).

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Structural Modeling

After the calibration process is complete, photos of the subject are taken. When taking photos, it is important to remember that quality shots of the entire structure being modeled are needed. All corners, faces, and complex sections of the structure warrant more attention when taking photos, as these will be very important when creating the model. While it may not be possible to capture photographs of some hidden parts of the structure, this can be usually be compensated for by taking extra photos of the area surrounding the hidden area from a closer vantage point.

Once the required photos are taken, the photogrammetry project can be constructed. A point-based project is then created, and the project photos are loaded into the project and matched to a calibrated camera. The user then uses the built-in drafting tools to draw points, lines, shapes, and surfaces on the photo. Great care must be taken to ensure that the objects drawn correspond to those depicted in the photograph as closely as possible. Either during this process or after its completion, the created objects must be referenced across photos. For example, a certain corner of an object in one photo must be selected, and using the referencing tool, the program must be told that the point selected in the reference photo corresponds with a point in another photo. The same is done for all types of objects selected in the photo.

When enough objects have been referenced, the project can then be processed to build a 3D representation of the points. To do this, the software uses sophisticated algorithms to determine the position of the camera station for each photo. *Photomodeler* then calculates the intersection of light rays from each of the photo positions and projects the points out into 3D space. The more photos a point is referenced in, the more accurately the program can calculate its actual position (Eos Systems 2008). The project can also be scaled and oriented to a coordinate system by inputting the known coordinates of two or more points. Once the entire project has been referenced and processed, the resulting photorealistic 3D model can be used to determine several dimensional attributes. The distance between any two points on the model can be measured, and the volume and surface area of the model can be calculated. The model can also be exported to a variety of CAD and 3D modeling programs, where it can be used in design and engineering work.

Three structures were studied using this process. The first is the First United Bank Center (FUBC), an event center on the campus of West Texas A&M University (WTAMU) in Canyon, Texas. The second structure chosen was a gabion mattress protecting a culvert outfall channel from erosion along Texas Park Road 5 in Palo Duro Canyon State Park, approximately 20 km (12 mi) east of Canyon, Texas. The last structure studied was an approximately 13-m (44-ft) tall steel and stucco sculpture of a cowboy named Tex Randall, also located in Canyon, Texas.

Field Study 1: First United Bank Center

The first subject studied using *Photomodeler* was the FUBC, an event center on the campus of WTAMU in Canyon, Texas. The FUBC is a 7,200 m² (77,000 ft²) facility with seating for over 5,000. The event center hosts WTAMU graduations, concerts, high-school basketball playoffs, and WTAMU basketball and volleyball games as well as other events. The center is primarily conventional steel-frame construction with a mainly stucco exterior. The architecture of the building features sleek straight lines, almost all at right angles. This structure is made up of one large rectangular prism with four smaller rectangular prisms at the corners offset slightly away from the center.

In this field study, *Photomodeler* was used to create a 3D photorealistic model of the structure and determine measurements of several appurtenances of the building for comparison with as-built plans provided by the WTAMU Physical Plant Department. This structure was modeled using a total of 34 photos taken from approximately every 15 m (50 ft) around the perimeter, taking care to get coverage from the roofline to the foundation when possible. Extra photos were taken at the building corners and around the alcoves in the front and back of the building to increase the likelihood of obtaining acceptable photographic textures for the model. Most photos were taken to obtain an approximately perpendicular viewpoint to the facade of the building, while some photos were taken from a greater distance to get an overview shot to two faces in one photo.

No artificial targets were mounted on the building, as there were an adequate number of structural features (such as edges and corners) to obtain a usable model, which can be seen in Figs. 1 and 2. After the photos were processed, they were imported into a new point-based *Photomodeler* project. Points and lines were then marked and referenced, and then a 3D model was built and exported to a .kmz file, which was uploaded to the web and can be viewed using various freely available platforms.

The length of the north facade was then matched with the corresponding length in *Photomodeler*, and several dimensions were chosen and compared with the as-built plans as provided by the university. The results of this comparison can be found in Table 1.

As shown in Table 1, this type of data collection may not be accurate enough for a conventional survey, at least for the number of photos and reference points used in this model, but it very well could be useful as a tool to supplement the conventional survey. A 3D model created using this technique could easily be combined with a traditional survey using a standard total station to add many of the aboveground features that would not be observable without the use of a much more expensive reflectorless total station or a light detection and ranging (LIDAR) setup on jobs without strict accuracy requirements. A total station can also be used to establish control points of known coordinates on or around the structure to improve the accuracy of the calculated coordinates within the photogrammetry software as well.

The event center presented a range of attributes that were found to be both beneficial and detrimental to modeling using *Photomodeler*. On the positive side, the center had many regular features. The edges are all straight, making it easier to mark using the drafting tools.



Fig. 1. Model of FUBC

Table 1. Dimensional Variances

As-built dimension, m (ft)	<i>Photomodeler</i> dimension, m (ft)	Percent difference (±)
8.992 (29.50)	9.062 (29.73)	+0.78%
8.001 (26.25)	8.099 (26.57)	+1.22%
73.152 (240.00)	74.713 (245.12)	+2.13%
8.001 (26.25)	7.998 (26.24)	-0.04%

The site also had few obstructions with the exception of landscaping such as small trees and bushes. This helped in marking and referencing, as a greater portion of the buildings features were visible from relatively large distances. The event center also is unobstructed by buildings, which would necessitate more photos to get good coverage of all surfaces. This subject also had features which were easily identifiable between overlapping photos, which helped not only in orientation of the photos, but also in creating surface points with a higher degree of locational confidence. The presence of natural tie points also allowed the project to be photographed and processed without the use of artificial targets which would have had to be placed at regular intervals and at key points on the surface of the building. Overall, this model took approximately twenty hours to complete.

The primary difficulties in modeling this type of structure have to do with hidden features. To complete the model, several points had to be approximated using intersecting and parallel lines. This was because the only position available for taking photos was from ground level. This could have been resolved by using a man-lift or similar device. The accuracy of the project is not believed to be materially affected, but pictures of hidden features would have made for a better photorealistic appearance.

The final model of the FUBC may be viewed using the freely available Google Earth software package. The 3D model is selectable from a map of Canyon, Texas, and may be rotated within the software to view the relative size and configuration of the building.

Field Study 2: Gabion Mattress

The second subject studied was a gabion mattress located at the outfall of a drainage culvert in Palo Duro Canyon, approximately 20 km (12 mi) east of Canyon, Texas. The gabion mattress was installed by the Texas Department of Transportation in 2001 as a part of a larger project to combat erosion at the outfalls of twelve drainage culverts along Texas Park Road 5, the access road for Palo Duro Canyon State Park. Many of these mattresses have begun to fail because of extreme erosion at their downstream ends. A construction project will soon be let to extend and repair the gabions. The outfalls are all along Texas Park Road 5, which is approximately 2.4 km (1.5 mi) long from the rim to the canyon floor 240 m (800 ft) below with several 10% grade sections, requiring the erosion control structures to prevent damage to the road. The gabion mattresses are constructed of heavy-gauge galvanized-wire—fabric cells filled with

stone and tied together to resemble large stairs. The particular gabion mattress studied is composed of seven steps and ranges from approximately 12 m (40 ft) wide at the outfall to 6 m (20 ft) at the point it ties in with natural ground with elevation changing approximately 1.2 m (4 ft) between the tops of steps. Fig. 3 shows a perspective view of the gabion mattress and camera stations, while Fig. 4 shows one of the photographs utilized for the model.

This structure was initially modeled from a total of 38 photos, of which approximately 15 were then eliminated without having much effect on the model calculations. The gabion mattress project was relatively simple to model, because it is made up mainly of fairly straight lines and had discernible features for referencing. The only problem with this type of structure is that, because the mattresses do not have well-defined corners and edges, the points and lines must be placed using the operator's best judgment. This model only took approximately four hours to complete all of the steps necessary. The usefulness of a model of this type comes into play when monitoring of a structure is needed over a certain time period. Given the history of these gabion mattresses failing and subsiding downstream after considerable erosion, *Photodeler* could be a very useful monitoring tool.

With an investment of a few hours each month or after each significant rainfall the status of these types of structures could be monitored very easily by comparing attributes such as the elevation of each step, the angle between steps, and the overall shape of the structure with previous observations. The surrounding erosion damage could also be modeled over time to determine the effect specific rainfall events have on the surrounding embankment.

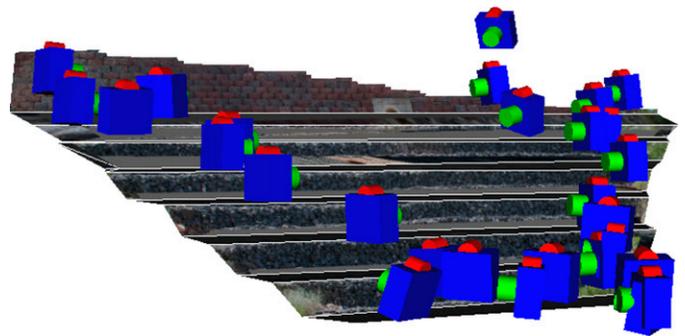


Fig. 3. Gabion model with camera stations



Fig. 2. Front facade of FUBC



Fig. 4. Gabion and outfall

Field Study 3: Tex Randall

The third subject studied using this method of modeling was Tex Randall, a 13-m (44-ft) tall steel and concrete sculpture of a cowboy in traditional western wear, hat, and boots (Figs. 5 and 6). Tex Randall was built in 1959 as an advertisement for a now-defunct western curio shop in Canyon, Texas, near the intersection of U.S. Highway 60 and 15th Street (Ely 2010). Very little is known about the true internal construction of the sculpture, because no plans exist or are on file with local government, but it is assumed to be a steel-pipe structure with a steel-wire frame and stucco exterior



Fig. 5. Tex Randall 3D model

based on visual observation. Currently, the sculpture has deteriorated and is in need of repair. To accomplish this, Canyon Main Street, a civic organization, has partnered with the Canyon Chamber of Commerce and WTAMU to develop a plan to refurbish the structure and surrounding area. The data collected in this project will be used to develop preliminary plans and estimates for the renovation.

In this field study, *Photodeler* was used to (1) create a 3D photorealistic model of the structure, (2) determine surface area for wind-load calculations, and (3) determine general dimensions for the initial phase of reconstruction. Tex Randall was modeled using a total of 31 photos, all taken from ground level at various locations in the area immediately surrounding the sculpture. Photos were taken with attention being paid to good overall coverage and overlap. Additional photos were also taken of more detailed areas to assist in modeling.

No artificial targets were needed in this project as the surface of the subject contained many irregularities that can be used as reference points. The photos were imported into *Photodeler*, and a new point-based project was created. *Photodeler* has several different methods of handling surfaces, and almost all of them were needed to successfully model Tex Randall. The sculpture has very few straight lines and even fewer well-defined corners. The subject is composed of two cylindrical legs connected to a torso resembling an elliptic cylinder. Attached to the torso are two cylindrical arms as well as a fairly cylindrical head topped with a large cowboy hat.

The first method used in modeling the sculpture is called fit NURBS surfaces. NURBS is an acronym for nonuniform rational basis spline. This method uses a tight network of points to create a best-fit surface. Fit NURBS creates a nice smooth surface that works well for this type of project. The limiting factor in using this method is the number of referenced points required to create a surface. This method was used on Tex Randall's left leg. To make the surfaces for the left leg, over 1,500 referenced points were needed. To get all 1,500 referenced points, each point must be marked and

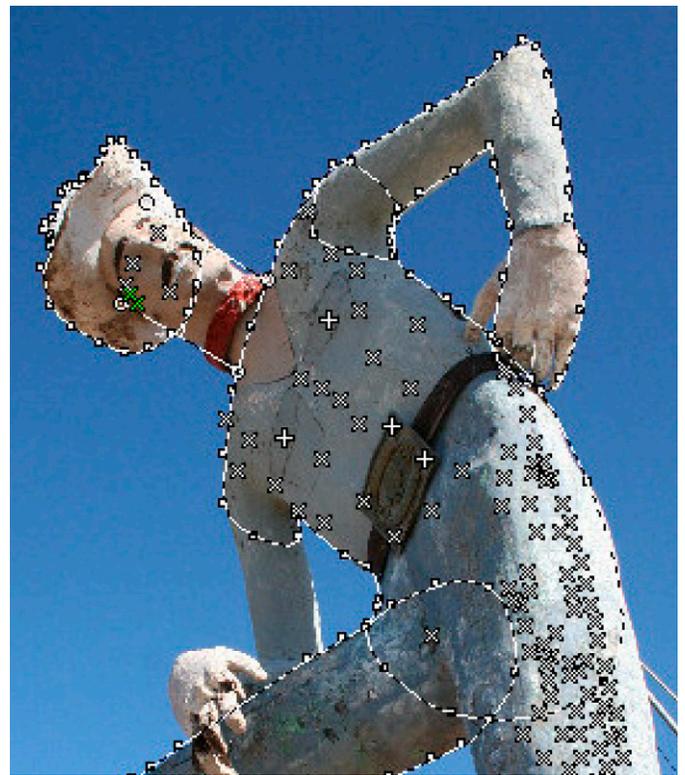


Fig. 6. Marked points and silhouettes of Tex Randall in *Photodeler*

individually referenced in at least three photos. In comparison, the much larger FUBC used a similar number of points for creation of the photogrammetric model. Small groups of points must then be selected, and a NURBS surface is then fitted to the group. Additional partially overlapping surfaces were then created using the same method until the entire left leg was surfaced. This process took approximately 30 hours. Although this method could have been used for the entire sculpture, it was determined that the time involved would put the completion of the model in jeopardy.

The second method used is called path mode. This method is fairly simple in that lines or curves are selected, and a surface is placed between the selected borders. The sign and rectangular prism under Tex Randall's right boot was modeled using this method. The flat surfaces and well-defined borders made this method the most appropriate for this portion of the project. Silhouette definition is the method used for most of the rest of the subject. To create surfaces using this method, silhouettes must be defined from several different views of the subject. The marked and referenced silhouettes are extruded and intersected for a visual hull approximation of the surface. This method worked well for the torso, arms, hat, and right leg. It should also be noted that individual features must be modeled separately using this method. Contiguous features sharing a common axis work best. The previously mentioned portions had their silhouettes marked, taking care to overlap into the adjoining feature, so they would appear connected in the 3D model.

The last method used to create surfaces is the mark cylinders mode. This method was used to model Tex Randall's head. The NURBS method and the silhouette method were both attempted on the head, but given the angle at which photos were taken from ground level, it was difficult to capture details for the left side of the head. Therefore, it was determined that a cylinder would best represent the shape of the head and neck.

Overall, Tex Randall was the most difficult of the three structures described in this paper to model using the base version of *Photomodeler*. The organic nature of his body and the lack of defining features proved to be very challenging to model. During the initial marking and referencing phase, it was thought that the irregularities in Tex Randall's surface would be beneficial in referencing points. After completing the NURBS surfaces on the left leg, it became apparent that the vague subtleties of paint chips and small cracks are very difficult to reference in photos taken from different angles and with different lighting. In all, the Tex Randall project took approximately 60 hours to complete.

Conclusion and Outlook

Close-range photogrammetry has been used for the noncontact measurement of structures, especially since the advent of powerful

digital cameras and personal computer systems. Whereas previous research has been conducted and published to determine the attainable accuracy and process for completing close-range photogrammetric jobs, the current study focused on determining the appropriate use of such technology using a simple low-cost system that costs under \$2,500. Projects that once could only be completed in an efficient and safe manner using close-range photogrammetry can now also be completed with either LIDAR or a reflectorless total station. However, these technologies are very cost prohibitive and may not be the best solution for many projects. For subjects that have well-defined lines, curves, and points, photogrammetric software such as *Photomodeler* is very useful. The model created of the FUBC is a great example of what this software can accomplish. From the findings in this paper, it can be extrapolated that any such similar structure having well-defined features and relatively few obstructions would most likely be an excellent candidate for modeling with *Photomodeler*. While the model of Tex Randall is definitely useful, based on the time required to complete this type of project it may be prudent to choose a more-advanced method of modeling. In any case, the ability to capture all of the field data needed for a project with only an inexpensive digital camera in a matter of minutes and with no specialized technical training or equipment setup required will remain one of the most significant advantages this technology has over all others.

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