Safety Cover Pool Measurements Using iWitness™ and iWitnessPRO™

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Abstract
This paper discusses the use of close-range photogrammetry for dimensional measurement of swimming pools, to aid in the accurate fabrication of Safety Pool Covers. Two methods of image-based measurement are reviewed, user-assisted *manual-referencing* as well as *fully-automatic* 3D model generation via red-coded target technology. In addition, consumer grade digital camera types; camera settings; camera calibration; network geometry; project accuracy; site time for the imaging work; and post data processing on a PC, are also discussed. The photogrammetric software systems utilized were iWitness and iWitnessPRO.

Introduction
Traditional Safety Pool Cover measurement has long been recognized as the *A-B method* using a fiberglass roll tape and measuring the pool's periphery from two locations (i.e. staked "index" monuments). Triangulation is then used to determine the pool cover's X & Y coordinates. The two X &Y measurements for each point of interest are then manually recorded, usually by a sheet of paper on a clip board, with follow-up data entry at the office into a CAD program to "plot" the pool cover's geometry. Depending on the complexity of a free-form pool's shape, the actual time on site using the A-B method, as well as data entry, can be time-consuming and in some instances error prone.

Safety Pool Cover manufacturers usually see their business season peak in fall of each year, as pool owners look to replace their existing (worn or compromised) covers. Proper dimensioning of the pool is an integral part of the production work flow for manufacturing new custom safety pool covers. Close-range photogrammetry has been proven to reduce time, and improve the safety pool cover's manufacturing process.

With today's low-cost consumer grade digital cameras and modestly priced PC-based photogrammetric software systems, a number of Safety Pool Cover manufacturers and their dealers are utilizing *iWitness* and *iWitnessPRO* for image-based dimensional recording, for the fabrication process of Safety Pool Covers.

General requirements for photogrammetric processing of Safety Pool Covers
Regardless of which approach is used (i.e., photogrammetric *manual point referencing or fully-automatic processing*), requirements exist for the digital camera settings to be employed, as well as the actual imaging method used on scene. There are also requirements that must be considered for the data processing phase, and the process for exporting the results to CAD for subsequent design use in the fabrication process.

The Digital Camera
Inexpensive Point & Shoot (P&S) digital cameras will work with most photogrammetric software, but are not recommended due to their typically inferior lens-sensor stability and therefore relatively low potential for accurate 3D measurement. P&S digital cameras weren't designed for user-invoked "manual settings", thus limited to operate in autofocus. An autofocus camera is not recommended for close-range photogrammetry as the focal length (i.e., principal distance) is required to be a fixed

(constant) distance. This fixed focal distance requirement rules out the operation of an autofocus camera, as it conflicts with the fundamentals of metric measurement. Studies have been accomplished and presented in a 2012 SAE paper (co-authored by the writer), where P&S cameras can be successfully used if calibrated, specifically with use of the iWitnessPRO *Zoom Dependent (Z-D)* camera calibration. However, Z-D calibration requires the P&S camera be initially (i.e., one-time) calibrated at four different focal distances. Z-D is somewhat impractical time-wise for Safety Pool Cover dealers to contend with, so there are better options for digital camera use in this particular industry for "metric" measurement, which will be further discussed.

In the Safety Pool Cover industry there can be dozens of sub-contractor (dealers) working for a pool cover manufacturer that accomplish both residential and commercial pool cover survey measurements. Experience reveals many dealers are not prepared to buy an e.g., $2,000 Digital Single-Lens Reflex (DSLR) camera, and as a result, their first question usually is: "*what is it going to cost me to measure using close-range photogrammetry?"*

Ideally, a DSLR camera should be used with close-range photogrammetry software systems, with a lens that can be manually "locked" to focus at infinity. However, there are several model cameras available (known as "*bridge*" type cameras) that fulfill the necessary metric requirements providing medium-accuracy and reliable image-based measurement, after photogrammetric camera calibration. Bridge cameras fill the niche between the single-lens reflex cameras (SLRs) and the point-and-shoot camera, and are typically sold for less than half the cost of DSLR's.

Bridge type cameras such as the recent generation of the higher-end Canon Powershot, and Nikon Coolpix, are just a few examples of "bridge cameras". Bridge cameras can typically be purchased online for only a few hundred dollars (in 2013).

Camera Settings

For optimum photogrammetric results, the digital camera should be set to Manual Focus, with the focus set to infinity. If using a compact (i.e. bridge) camera, set the lens to wide angle and do not zoom the lens. For the *manual referencing* method in iWitness, it is satisfactory to simply set the camera's dial to Program (P mode) where aperture and shutter-speed are automatically determined by the camera. For iWitnessPRO's *automatic measurement*, when using a bridge-type, or DSLR type camera, it is best to set the lens the same (i.e., widest field of view). However, the camera should be set to Manual (M mode) with Aperture set so that the image exposure is a few F-stops underexposed. For example, when using a DSLR, this exposure setting is typically about F9 to F11, with Shutter Speed set at 1/125th second, and ISO between 100 and 400. Always using the cameras' flash to properly expose the red coded targets.

The Field imaging requirements for Photogrammetry

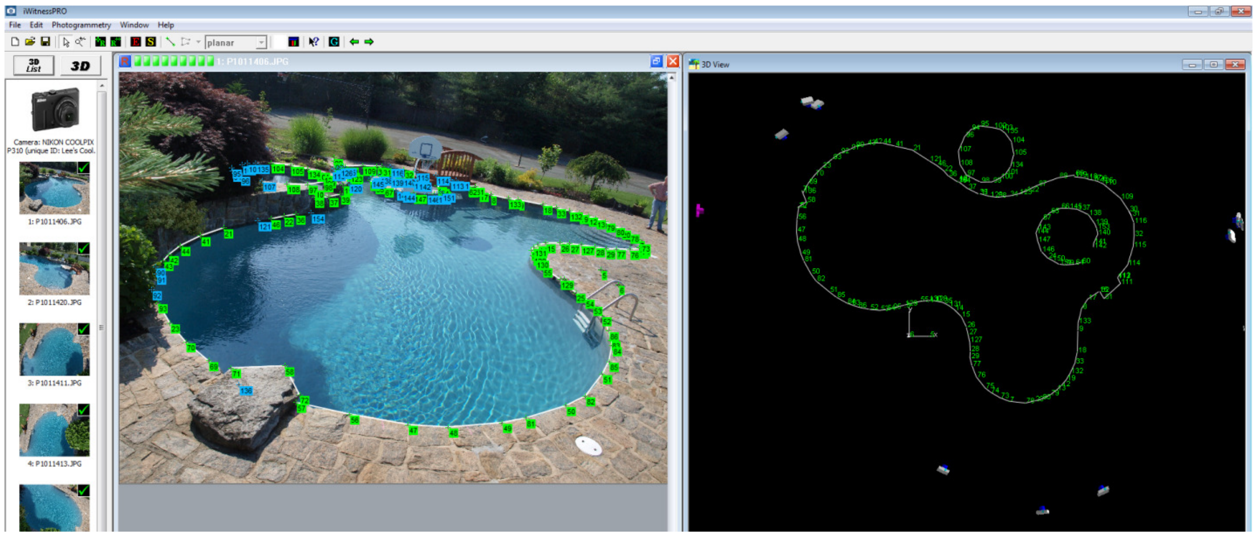
Regardless of the make/model/type of digital camera employed, multi-image triangulation is required for the photogrammetric process. It also depends on which method is used for measurement, be it processing via manual-point referencing between multiple images, or conversely automatically processed by way of the coded target approach.

Manual Measurement via User-Assisted Referencing

When measuring a free-form pool configuration it is best to use a tall ladder and move the ladder to several positions around the pool so there is plenty of perspective image overlap and strong photogrammetric network geometry. In the example illustrated in Figure 1, a total of 18 images were acquired, but only 10 were actually measured, providing an accurate 3D model of the pool configuration.

Figure 1 illustrates the project imaged with a Nikon Coolpix P310. The camera was set to wide angle zoom, manual focus, with focus set to infinity. Shutter speed and aperture were determined by the camera in Program "P" mode. Two scale distances used were 20' and 13', measured with a steel tape. The accuracy of the project was better than .5" (12.7mm) RMS.

FIGURE 1



This project required about 20 minutes at the site for imaging, and about 1 hour and 10 minutes for an operator to accomplish the user-assisted (*natural feature marking*) referencing in iWitness. The project was scaled and rotated using iWitness' 3-2-1 feature and the model was then exported as a DXF file. The results (not shown in CAD) closely matched a previously accomplished "A-B measurement method", with essentially the same overlay of the two different measurement approaches.

Another method for the user-assisted referencing process is the use of *dual point targets*. Figure 2 illustrates a method used within iWitnessPRO for semi-automatic target centroiding, resulting in a 3D constructed point which is calculated from the dual white dots. The use of ample, inexpensive targets make the manual referencing process much more efficient based on discrete targeting around the safety pool cover, or the periphery of an un-covered pool's surround. The dual point targets are imaged from a tall ladder from about nine feet off the ground. A disadvantage may be viewed that this method is slightly more expensive for the site work. Its advantages are, it makes the photogram-metric referencing process less time-consuming on a PC with discrete points to easily manually reference; especially for pools with complex shapes.

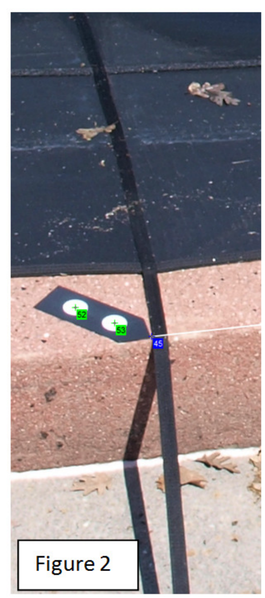


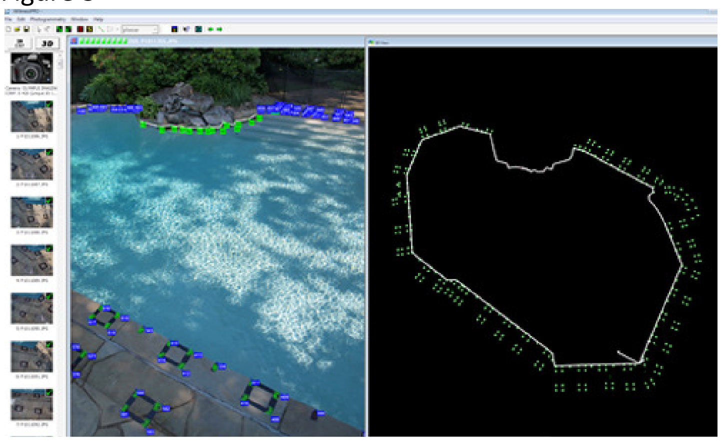
Figure 2

Automatic Measurement through use of Red Coded Target technology
Specialized red coded targets are available in iWitnessPRO V3 that permit them to be treated as 'feature point targets'. The software automatically calculates a point-offset distance for each code (*see the navy blue points as illustrated*

in Figures 3 and 4). The codes are typically indexed to the pool covers edge, or alternatively to the safety cover's points of measurement interest.

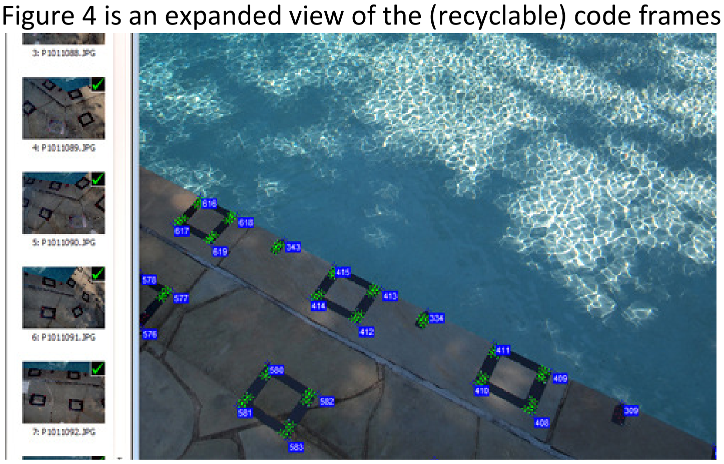
Using red coded targets have been proven to be more efficient vs. traditional tape measurements. *Code Frames and Code Pointers* are indexed around the pool as illustrated in Figure 3, for imaging with a digital camera.

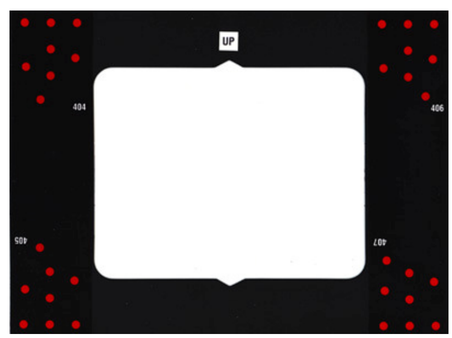
Figure 3



Code Pointer
52.7mm Wide x 96.5mm Height

Figure 4 is an expanded view of the (recyclable) code frames and code pointers defining the pool.





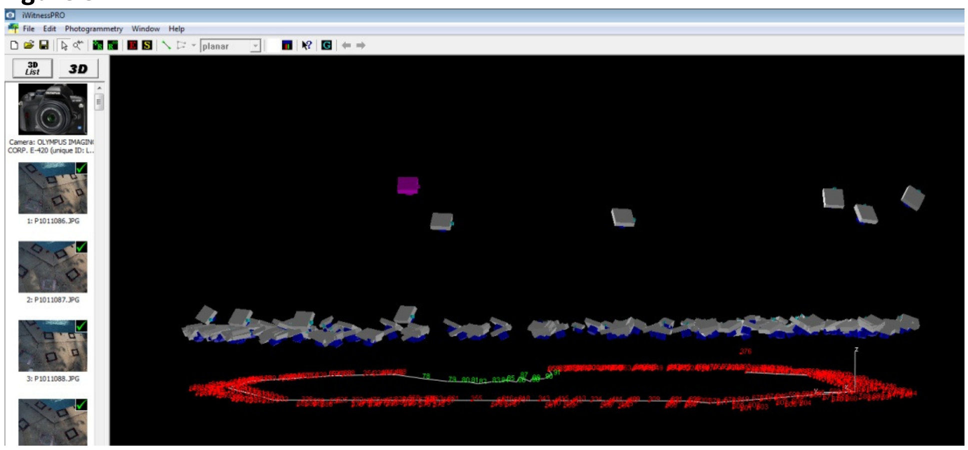
Code Frame
292mm Wide x 216mm Height

Camera Geometry and Photogrammetric Scaling

Figures 3 and 4 were imaged from the top of a six foot ladder. It is important to note the ancillary row of 'fill' codes, about three feet offset the pools edge. These fill codes are required as there needs to be a degree of code separation, i.e., without the codes being 'near' collinear, to aid in network strength. Photogrammetry is optimized when image points are separated in three dimensions. At the very least, imaged points need to be separated two-dimensionally for satisfactory camera orientation and for 3D point determination.

Figure 5 is an oblique view of the network's images, within the iWitnessPRO software environment. Approximately 120 images were recorded with most of them from about six feet off the ground, with a few higher shots from a ladder for the rockery measured points – which were manually referenced in this particular project. Camera positions were typically spaced about four feet apart, around the entire pool with use of a step ladder. From each camera position, the camera is pointed downwards, and then tilted about 45 degrees to the right, and the same to the left, where there is plenty of perspective view overlap required for photogrammetric triangulation. The camera is also "rolled" from landscape to portrait orientation in at least one-quarter of the images for camera self-calibration, accomplished within iWitnessPRO. The flash is used for each shot. Photogrammetric scale was applied by measuring two separate distances of twenty feet each. The project was scaled and rotated (*iWitnessPRO "3-2-1" feature*) via three selected red code construction offset points that were automatically generated / measured.

Figure 5



At the work site, it normally takes about 40 minutes to setup the iWitnessPRO codes and image them, along with the required scale distance measurements recorded via fiberglass or steel tape.

Although the network geometry in this application is far from 'ideal', it does work satisfactorily in iWitnessPRO based on its robust algorithms used for camera relative orientation and photogrammetric resection. The project accuracy achieved was better than 0.2" RMS.

It is always better to acquire more images rather than less, as the camera's orientation and 3D point determination is fully automatic within iWitnessPRO. Computer processing time on a PC is typically between 5 to 10 minutes for a project the size previously described. The 3D modeled points can optionally be line connected before DXF exported to CAD, to generate the Safety Pool Covers drawing, used for the fabrication process.

Summary

The overall time utilizing the *user-assisted manual-referencing* method described was equal to the standard A-B tape measure method, but much faster on scene for the person acquiring the pool's digital images and also less prone to error. The time required for the *fully-automatic measurement via red-coded targets* method was significantly faster overall on site and back in the office in order to produce the completed Safety Cover Pool geometry when compared to the traditional tape measurement approach.

Although there are modest costs associated with initially purchasing reusable photogrammetric targets and codes, they have been proven to pay for themselves in a short period of time through multiple project usage. iWitness and iWitnessPRO have been proven to save time and increase the quality of the manufacturing process of Safety Pool Covers. The camera used on site can be an inexpensive compact type for the image recording process. The entire process is usually equal to, or faster than, traditional methods employed in the past, with productively and project accuracy greatly improved, using a consumer grade digital camera and a close-range photogrammetric software system such as iWitnessPRO.