

# Extracting Accurate Measurements from Single Surveillance Camera Images

By Eugene Liscio



The vast majority of people nowadays own a camera, whether it is a digital SLR, smart phone camera or even a home or work security camera. Many police agencies are starting to implement body-worn cameras as part of their safety protocol and the amount of crimes and traffic accidents caught on surveillance cameras is now more than ever. Newer and easier to install security cameras are no longer at low quality resolution. Both HD and Infrared options are making clearer and better quality images which is beneficial to the field of forensics. Utilizing this data, it is possible to get a better understanding of events and perform a virtual 3D reconstruction for a sequence of events.

One of the ways to get an accurate reconstruction is through a process known as ‘camera matching’ or camera resection. Creating a robust camera match for 3D reconstructions is a method which allows the analyst to “look through” the same perspective of a security camera by using a virtual camera. This can aid in estimating a suspect’s height, taking measurements of objects which were removed from the scene, reconstructing shooting incidents based on the shooter’s position and even determining speeds and positions of vehicles in traffic collisions. As an example, imagine there was a shooting incident in a bar, and a surveillance camera shows the suspect firing a gun near the entrance. Doing a camera match in this scenario can aid the analyst in performing bullet trajectory analysis by placing the suspect in a 3-dimensional space and extending the trajectories to his location. It can also be used to estimate a suspect’s height

and serve as a guide if 3D reconstruction of events is desired.

Eos Systems recently updated their PhotoModeler software to allow users to enhance the single image camera match called “inverse camera”. It includes a field calibration option, which allows users to correct for the camera’s distortion using control data. The control data may come in the form of laser scan point clouds, total station data or even manual measurements. A general workflow is outlined below.

## Scanning

A laser scanner is a useful instrument for capturing millions of points in a scene. If an analyst wants to perform a suspect’s height analysis or try to locate the relative position of an object in an image, it is possible by combining known control points which exist in the reference image and still present in the scene. These control points can be captured using a laser scanner or other 3D documentation tools.



Figure 1. Various 3D terrestrial portable scanners. From left to right: DotProduct, Z+F Imager, Artec Spider, Leica Total Station, Faro Focus 3D, Artec Eva

It is recommended that at least one scan position be captured as close as possible to the security camera’s actual position in order to provide a similar perspective and the field of view. This ensures the best chance of choosing the same reference points for camera matching (Figure 2). There should be sufficient resolution in the laser scan data to be able to mark and identify objects accurately. If multiple scans have been captured, then the data should be aligned and registered before exporting to PhotoModeler. Different file formats are possible, but a PTS or text file format will work well. Although it is possible to import point clouds directly into PhotoModeler, we

found it more efficient to identify and extract control points from large point clouds using a different program, such as FARO Scene, Cyclone, 3ds Max, AutoCad or other software



Figure 2. Faro laser scanner positioned close to the cameras position to provide similar field of view for matching common reference points between the security camera image and the laser scan data.

and export a smaller 3D point set in a DXF file for later import into PhotoModeler (Figure 3). This will minimize any performance issues that arise as a result of loading massive point clouds and will keep things clean and efficient in PhotoModeler's viewport. Control points should be chosen according to the field of view of the camera's image and should be identifiable on the image frame.

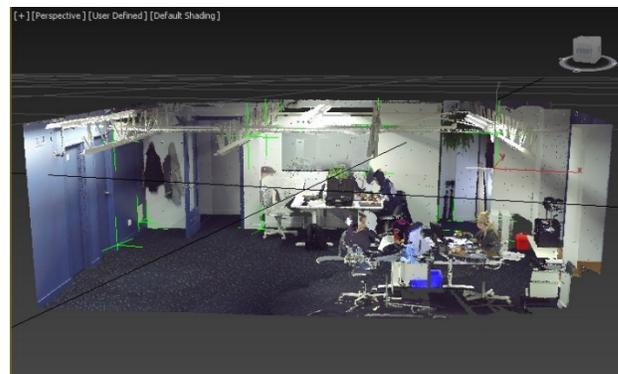


Figure 3. 3ds Max screenshot of identified control points in the point cloud of a sample office space

## Working in PhotoModeler

### Creating a new project

Camera matching is by nature, a manual operation and is not automated. Therefore, when starting a new project, be sure to choose "Manual Modeling Mode". The software will then ask the user to load an image or series of images so that it can be loaded for processing. Unless you know the camera's information such as the focal length or other specifications, choose the option with the unknown camera with control points. The loaded image will be visible in the viewport and can be maximized by double-clicking.

### Point Marking in the Photograph

There are different ways to work through the process of marking and referencing the image using the "External Geometry Explorer" (EGE). You can start by marking the points on your photographs and then referencing them to the imported points file, or you can mark and reference control points at the same time. Let's assume a user wants to separately mark the points on the photograph and then reference them to the control points later. This can be achieved by clicking on the "Marking" tab and selecting "Mark Points" option. You can then create marks which correspond to each of the control points in the DXF file. When selecting control points, it is best to choose points across the entire image and

it is advisable that the points are well spread out, if possible. The greater the number of points and the more evenly distributed they are, the more robust the solution. (Figure 4). It is always important to choose points in the image that are not likely to move such as walls, corners, buildings etc. Also, never choose all reference points to be on one plane (such as the floor).

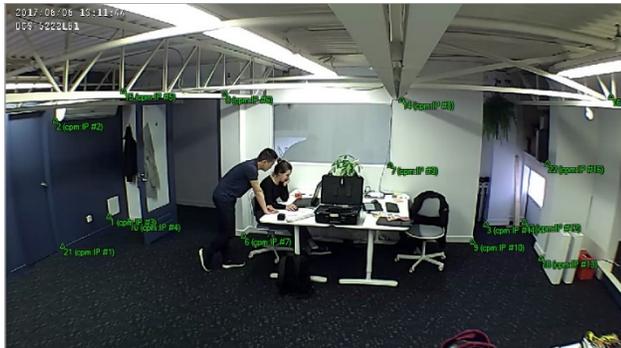


Figure 4. Points marked on the surveillance camera image in PhotoModeler. Note that the points are spread out as far across the image

The greater the variation and depth of the chosen control points, the more likely to have a robust solution. PhotoModeler requires 4 control point marks (5 if focal length is being solved as well) for a camera orientation solution, but if possible, 20 or more points is recommended to undistort the image and calibrate for the field of view. As a general rule of thumb, more points is usually better than less.

### Assigning the Points to the 3D Control

In order to associate the marked points with the 3D control points, start by opening the External Geometry Explorer (EGE) located above the picture thumbnail on the top left corner of the screen (Figure 5).

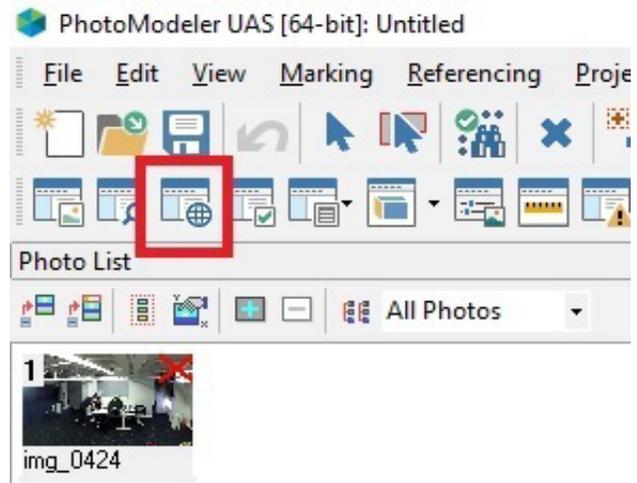


Figure 5. Red square shows the location of the External Geometry Explorer icon

Click “Control the Solution” and then choose the option “Points, Lines and Surfaces from a file...” (Figure 6). You can then choose the points file which was exported as a DXF file from another program. Make sure to choose the right units based on the instrument’s default settings.

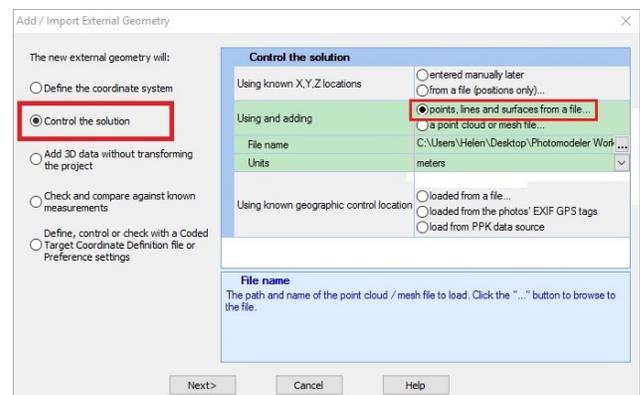


Figure 6. Screenshot showing how to load point data into PhotoModeler

After the points have been imported, you can view them in the EGE 3D window. Click the “3D” tab at the bottom of the screen with the list of imported points (Figure 7).

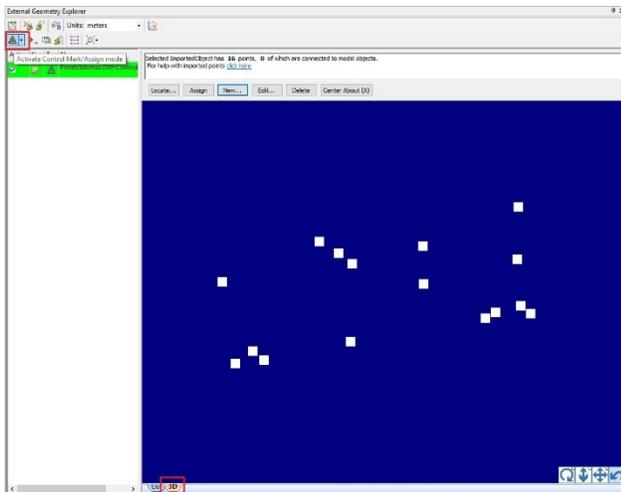


Figure 7. External Geometry Explorer with highlighted 'Control/Mark Assign Mode' button and '3D' view buttons

Click on the Control/Mark Assign Mode on the top left of the 3D point screen (Figure 7).

You can then click individual points on either the photograph or the point data and assign them back to one another. The assigning order is not important so long as each point is assigned to its respective control point at the same time (i.e. point 1 on photo → point 1 in 3D, point 2 on photo → point 2 in 3D).

### Optimization and Idealization of the Image

After all points have been marked, it is advisable to save the project. Before proceeding to the next stage, check the minimum number of points that PhotoModeler will use to perform image optimization. This can be found in Options → Preferences → Processing and Calibration → Self and Field Calibration (Figure 8). Note that you should be using close to 20 points which are well spread out for the best solution. It is then possible to proceed to optimize the image by clicking Project → Process → Optimize.

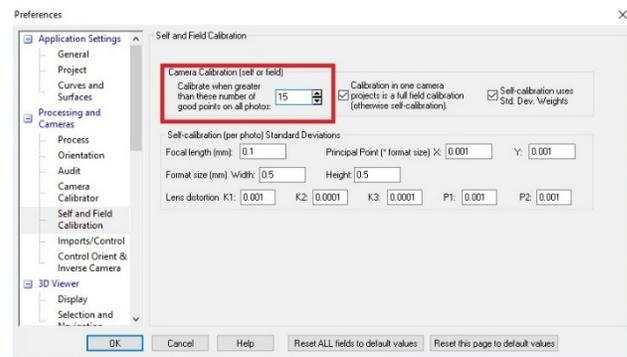


Figure 8. Processing preferences window

Adjust the optimization settings as per Figure 9 below. If only a few control points are used, you might not be able to solve for all the lens distortion parameters (K1, K2, K3, P1, P2 on the image below). In our scenario, we have enough control points for PhotoModeler to solve for lens distortion.

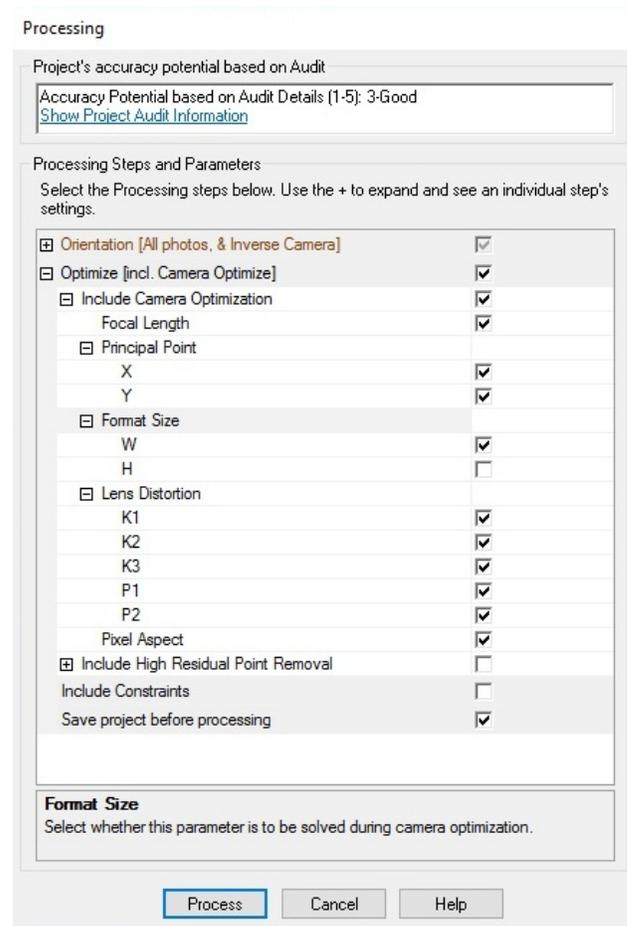


Figure 9. Optimization window settings

After the image has been optimized, it will report the maximum residual error and the RMS error as shown in Figure 10.

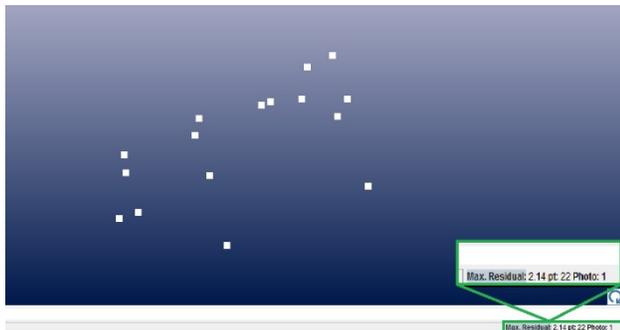


Figure 10. Screenshot showing maximum residual error window in a red box

The error represents the number of pixels (or residuals) that the points are away from their solved positions (i.e. Where a point was marked on a pixel and where the solution calculates the same point to be). You can also check which points have the highest residual by going into Project → Project Status Report. If there is one point that raises the average residual of the image, it can be checked and remarked so that the project can be reprocessed. After the optimization is completed, it is advised to save the project again.

At this stage, certain types of measurements could be made right within PhotoModeler. The following example will show how to measure the height of an object and will be applicable for suspect height analysis. First, it is important to define a plane from which the measurements will be made. In our example, we will measure the height of the window pane located in the right corner of the room. Since the window starts at the floor level, we will proceed in creating a plane on the floor. You can choose the points previously used for referencing, or create new ones. To create the plane, click on the path mode icon under the 'Options' button as per Figure 11. When marking the plane, it is important to do so

around the object you are trying to measure, since the flatness of the surface cannot be guaranteed.

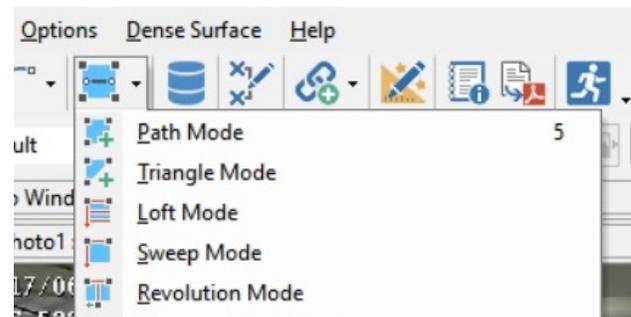


Figure 11. Plane creation using path mode in PhotoModeler

Click on several points to connect them with lines. A minimum of three points are needed to create a plane, but choosing more points can be beneficial if the surface is uneven. After the points are connected, click the right mouse button and choose 'Finish Surface' as per Figure 12.

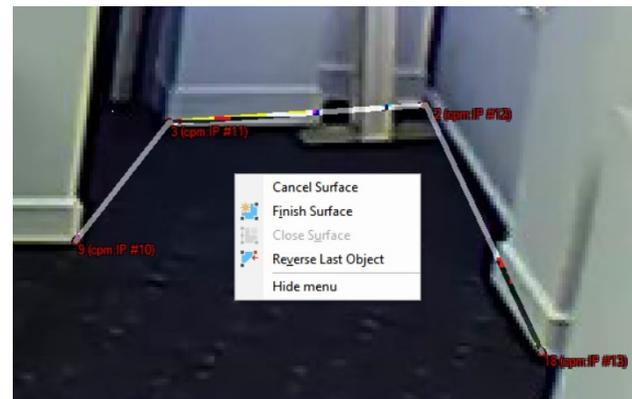


Figure 12. Four points defining the floor plane near the window

A plane will then appear in the 3D view (F7 shortcut). To enable the plane view in the photograph, go into the 'Visibility' setting located to the left of the EGE and check the appropriate settings as per Figure 13. After the options have been changed, proceed in creating a line to the object of interest by selecting Path Mode → Mark Surfaces Points – Line Mode. Start the line by clicking anywhere on the plane

and extend the line to the point on the plane from which you want to measure the object of interest.

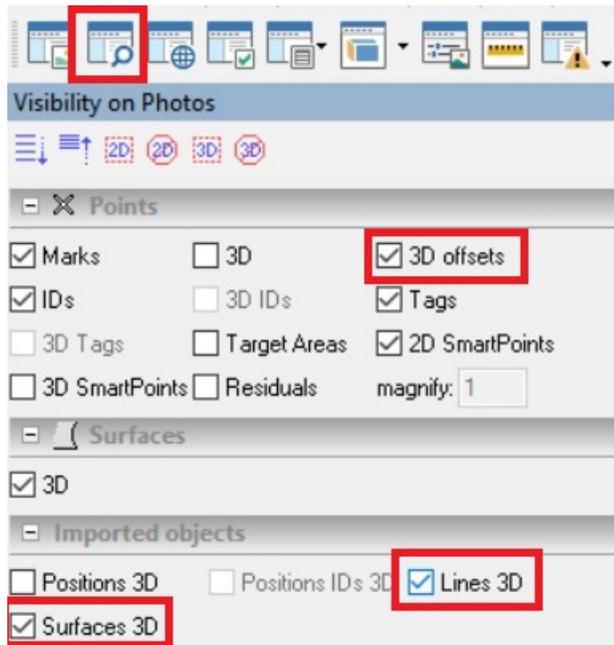


Figure 13. Visibility settings with 3D surfaces enabled

In our example, the ending point of the line would be the point directly under the corner of the window pane as shown in Figure 14.

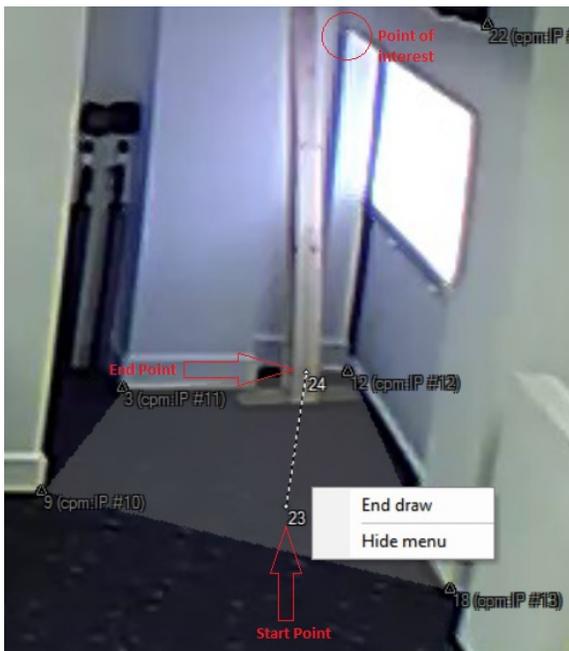


Figure 14. Line created on the plane using 'Line Mode' function. Please note, that when using this mode, the line will be created on the plane of interest

You can then proceed to offset the end point of the created line to get the location of the point of interest. To do that, right click on the end point and select 'Properties' option at the top of the list. Next, in the offset window, choose the axis that you want to use for offsetting the point. Since we would like to determine the vertical measurement of the window, Z offset would be the one to choose (Figure 15). Start offsetting the point by typing in different values until you see that the point lines up with the point of interest in the image. Adjusting the point size or colour may be helpful depending on the background colour of the image.

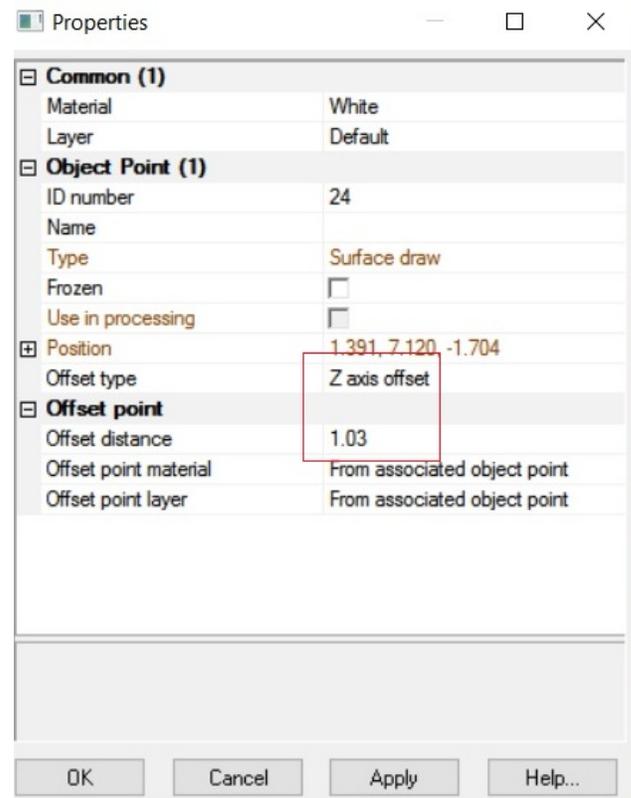


Figure 15. Point properties and offset distance

Once satisfied with the final point placement, you can measure the distance by pressing the "M" key to bring up the measurement window. Click on the end point of your line, press and hold the 'Shift' key and then click on the projected offset point. The distance between the points will

then appear in the right corner of the screen (Figure 16). The measurement will be the same as the offset number which you chose previously. The same result can be achieved if the points are measured in the 3D view (F7 key). To put this number in perspective, we used a measuring tape to measure the height of the window pane which was 1.04 m.

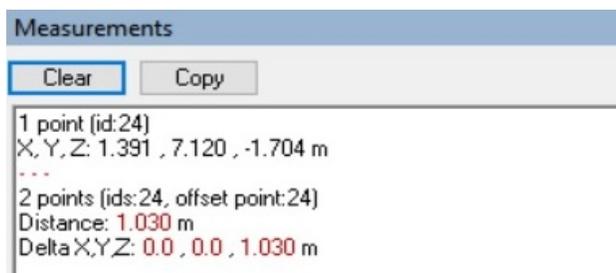


Figure 16. Measurement window which shows the distance between the two chosen points

If you want to create an animation or a 3D model of the scene, the image has to be imported to another software, like 3ds Max. Since 3ds Max does not work with distorted images, an undistorted version or ‘ideal version’ of the image is needed before proceeding to complete the camera match.

Idealization of the image is the process in which the camera characteristics and distortions get corrected based on the marked and referenced points as seen in Figure 17. This process can be performed by going into Project → Idealize → Execute. The software will ask whether you want to reprocess the image and you can click ‘Yes’ for a final solution. The settings for the processing optimization should be the same as before. The idealized image can then be exported along with the camera position to other software programs. PhotoModeler provides a convenient script which can be run in 3ds Max or Maya to setup the camera and image plane for further analysis.

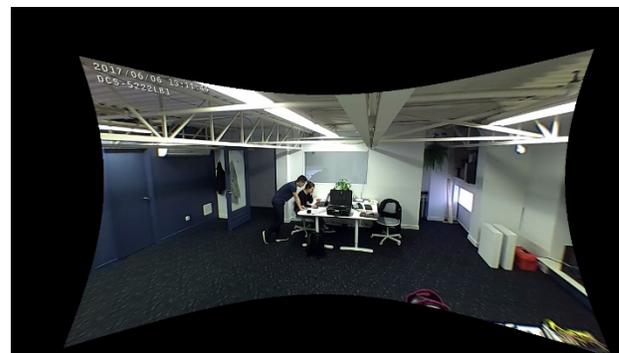


Figure 17. Idealized image with camera distortions removed by PhotoModeler

### Exporting the Script

Once the image has been idealized, the next step would be to export the script to be used in 3ds Max or other software of choice. The example here will illustrate how to proceed with doing so for further 3ds max import. The script can be exported by going into File → Export and Print Data → Export Model as shown in Figure 18.

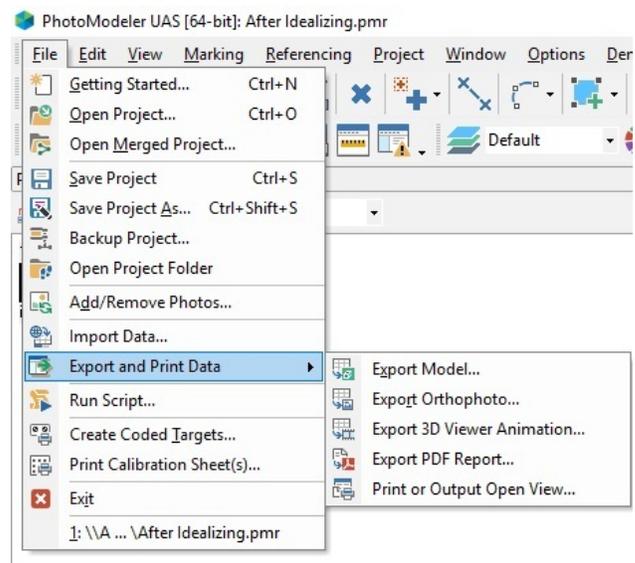


Figure 18. Process of Exporting the 3ds Max script

An ‘Export Options’ window will appear. Settings for the image should remain unchanged (Figure 19). The imported points option can be unchecked, since the marked points should already be present in the initial 3ds Max model in

which control points were made. Choose the Max Script as your export format.

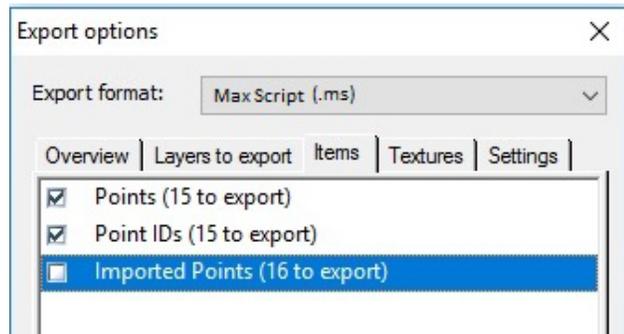


Figure 19. Export Options window

After the script is exported, you can proceed to 3ds Max for camera placement. PhotoModeler will usually save the idealized image automatically after idealization, but if the image was not automatically saved, user can do so manually by exporting it from PhotoModeler.

### Working in 3ds Max

The exported script can then be imported through the Scripting menu. Choose Scripting → Run Script. Select the script that you exported from PhotoModeler. You will immediately notice that a camera, points and image plane will be created in the 3ds Max viewport (Figure 20).

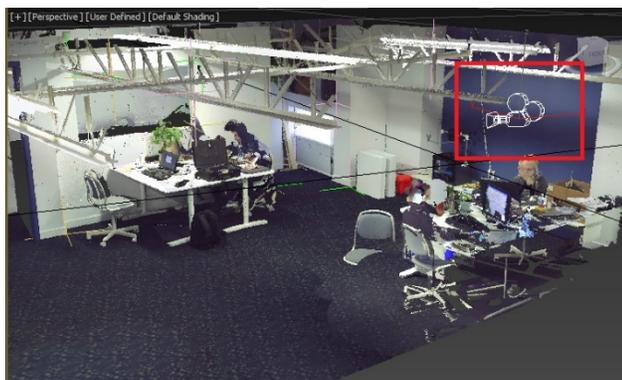


Figure 20. Position of the camera in relation to the point cloud

The position of the virtual camera should be located relatively close to the location of the true position of the security camera in the point cloud.

You can apply the idealized image to the plane to check the fit as shown in Figure 21.

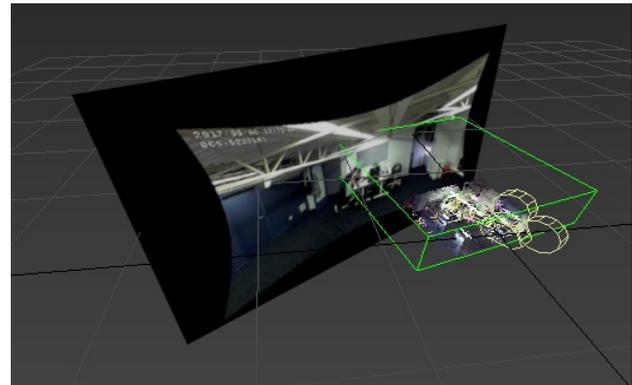


Figure 21. Shaded camera plane showing the idealized image. Viewport also includes the camera and the point cloud

You may also choose to go to the camera's view by pressing C and hiding/revealing the point cloud to check for the fit of the image relative to the point cloud. Slight movement is possible due to the variability during point marking. A side by side view of the point cloud and the fitted idealized image is shown in Figure 22.



Figure 22. Side by side view of the fitted idealized image (left) and partially hidden point cloud in 3ds Max (right)

Finally, the camera is now setup for the analyst to make measurements or to create 3D reconstructions using multiple image frames.

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