

Photogrammetry for 3D Content Development in Serious Games and Simulations

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ABSTRACT

Photogrammetry is, at its base, the process of measuring distances using photographs. It is a science that has been around since the early days of photography, but with recent advances in computing, photogrammetry can now be used to create highly detailed 3D reconstructions of physical objects using only photos taken with commercial cameras. The 3D model which results from this process is a dense, highly-realistic model which can be incorporated into the content development pipeline for games and simulations, allowing accurate models to be created quicker and at a lower cost than traditional methods. It is not a panacea for every situation but rather a tool in the toolkit, to be evaluated and used when appropriate. However, even when the model created using photogrammetry cannot be used directly to create the game-ready model, the photogrammetry-made model can be used as scale, proportion, and color reference in the model development process.

Through our research and testing, we have developed a process which results in high-quality reconstructions with accurate coloring. We have also developed a pipeline for incorporating photogrammetry into the 3D content development pipeline, replacing the time-consuming process of hand-sculpting and hand-painting a model using reference photographs. Photogrammetry is currently being used by some companies in the AAA and independent commercial game development space, but it can, and should, be employed effectively for Serious Games and Simulations as well.

ABOUT THE AUTHORS

Joel Ryan is a 3D Modeler and Game Developer at SAIC, in the Big Timber Games group. He has an interest in new technologies, and has worked with AR, VR, Mixed Reality, Machinima, Photogrammetry, and 3D Printing. He is currently working on pilot training simulations for the U.S. Air Force using Virtual Reality. Joel has a Bachelors in Game Design from George Mason University, and has been with SAIC since 2015.

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BASICS OF PHOTOGRAMMETRY

Photogrammetry has been around in different forms since the mid-19th century, and was originally used to create measurements for landscape surveying. During WWII, physical landscape topology models were created by hand using information gathered through aerial photographs, which assisted the allies in locating and identifying German V1 and V2 missile sites.

Photogrammetry in the field of 3D content creation uses the same techniques, but applied to free-standing three dimensional objects rather than landscapes. In order to create the model, the user has to take a series of roughly 30-300+ high-quality photos of the object of interest from all angles and feed it to a reconstruction software. The software analyzes these photos, looking for areas of color or value contrast that it can track across photos. Each photo is compared to each other photo, and the location of millions of tracked points are determined, creating a point-cloud in 3D space.

This point-cloud is then triangulated into a mesh. Each vertex can be assigned a color based on the software's best guess from the photo analysis. These vertex colors can be exported alongside the mesh. Alternatively, a procedurally-generated UV map can be created with accompanying diffuse color texture sheet. If the model is going into a game engine, this UV map can then be baked in the UV layout of the re-topologized, game-ready model.

CHARACTERISTICS OF PHOTOGRAMMETRY MODELS

The models which result from the photogrammetry process are not instantly ready to be placed in a game engine. Rather, these are triangulated meshes, usually consisting of around one to ten million triangles. In addition, these reconstructions often have small surface issues, such as bumps or jagged parts. While the coloring of reconstructed models is often fairly high quality, it can have some of its own issues, including different levels of sharpness of detail, some blurriness, and some lighting artifacts.

Because of these issues, the reconstruction will need to go through a process of cleanup before it can be used in the content-development pipeline. While the quality of the photoshoot directly affects the quality of the resultant model, some errors are inevitable. The goal is to create a model which is high enough quality that the cleaning up process doesn't outweigh the initial benefits of using photogrammetry in the first place.



Figure 1: Reconstructed backpack

PHOTOGRAMMETRY SETUP

Object Preparation

Photogrammetry handles certain kinds of objects much better than others. Ideal objects have colorful, textured surfaces, like stone statues or pieces of clothing. Objects that have reflective, clear, or metallic areas do not reconstruct well because they will appear different from different angles as the light reflects off them or refracts through them. This makes it hard for the program to track specific points on the surface. Similarly, objects with smooth surfaces and flat color present difficulties in the reconstruction process because there isn't enough visual information for the photogrammetry program to work with. For example, a photoshoot of a room with a flat, blank wall will result in a reconstruction with a large hole where the wall should be. Despite these difficulties, even glass objects can be reconstructed with adequate preparation. If you are able to modify the object, you can spray paint a glass object with a matte white paint, and then speckle it with black paint. The speckles create enough visual information for the photogrammetry program to track the topology of the surface.

For reflective objects, you can spray paint them with a clear matte spray, or even hair spray. This won't completely remove the reflectivity, but it will reduce it. You can also use a polarizing lens to remove glare, which will increase the quality of the reconstruction. Polarizing lens do also decrease the overall amount of light that enters the camera, so the overall light level of the scene will need to be increased to compensate.

Even objects that are great candidates for photogrammetry can benefit from some cleanup. In many cases you can save hours of post-processing with minutes of preparation. As an example, when we did a photoshoot of a military-style backpack, the backpack had straps all over it to cinch areas around the wearer's chest and waist. These straps would be very difficult to reconstruct with photogrammetry because they laid across the surface of the backpack, making the re-topology process much more difficult. In addition, the buckles had hard, flat surfaces with flat color. However, they are fairly simple to model by hand, and so we cut off the excess straps, and took photos of them separately for reference and texture development.



Figure 2: Backpack photoshoot using fishing wire

Environment Setup

The space should be well-lit, preferably with lights hitting the object evenly from all angles. A cluttered room will work better than a blank room for your photoshoot, because the additional information in each photo will help the program to accurately guess the location that each photo was taken from. While clutter is good, moving objects are not. An animal or person moving around the room will confuse the program and lower the quality of the reconstruction. Try to remove clear or reflective objects from the room as well, and turn off any computer monitors or TV screens.

Camera Settings

It is almost always better to use a tripod to ensure that your photos are sharp. This is especially important when you are shooting indoors, because the optimal camera settings for photogrammetry will most likely require a slower shutter-speed, unless you have quite a lot of lights.

The ISO should be set to 100— an ISO higher than 100 will introduce graininess that will decrease the quality of the reconstruction. The F-Stop should be set to remove depth of field. Although the reconstruction will most likely still work if the background is blurry, you will get better results if everything in the photo is clear, as this gives the reconstruction software the most possible visual information to work with. Finally, it is best to take your photos in RAW format to get the most detail out of each photo.

Photos

In general, the more photos of your object the better, although a smaller number of high-quality photos is better than a larger quantity of lower-quality ones. Mixing low-quality photos with high-quality photos will also decrease the overall quality of the reconstruction because the program will blend the two on top of one another.

Make sure to take photos of your object from every angle. The software is going to need to stitch the photos together, so taking photos with significant overlap will give it enough points of comparison to work with. Your object should take up the majority of the frame, and you should rotate yourself around the object in a circle, taking photos roughly every 15 degrees. If you want especially clear surface detail, or detail on one specific area, you can zoom in and take close up photos of your object as well. Instead of immediately zooming in, it is better to take a few photos getting closer step-wise, to help the program understand where closeup shots are in relation to the whole object.

We often take three levels of photos—circling around every 15 degrees from a top-down angle, a straight-on angle, and a final, lower angle. It is better to not take any photos further away than you need to. This is because all of the photos in the photoshoot are going to be used to create the final model and texture, and the lower resolution of far-away shots is going to lower the overall resolution of the geometry and texture.

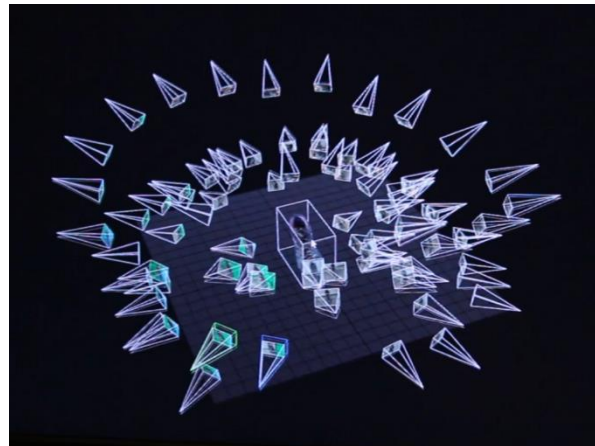


Figure 3: Locations of Photos

Equipment

The only piece of equipment that is absolutely necessary for photogrammetry is a camera. In our own works, we have used a Canon EOS Rebel T6s with a 50mm lens for most of our photos. Any digital camera will work, including a phone camera. The sharpness of each photo is extremely important, and so a digital camera with a tripod will often provide more clear photos. This is especially important in lower-light situations, where the exposure time needs to be increased to create a clear image. Wide-angle lens tend to reduce the number of necessary photos, especially when capturing a large object or interior space. For a more detailed explanation of equipment, see “A Guide to Capturing and Preparing Photogrammetry for Unity” by Andrew Yao-An Lee.

Lighting

Lighting is extremely important in a photogrammetry photoshoot. Even in rooms that feel well-lit, there may not be enough light for high-quality photos. Indoor lighting is usually exclusively overhead as well, and photogrammetry works better when you have consistent lighting across the entire object. If you don't have access to a professional photographer's lights, you can put pieces of paper or wax paper over your lights to soften/diffuse them. If you want to create a very accurate model or are especially concerned about getting accurate colors, a color-picker can help to color-correct your photos when you are processing them after the shoot.

When shooting in an environment where the light is coming strongly from one direction—for instance a cloudless day outside or in an indoor environment with only overhead lights—it can help to use tinfoil to reflect the light back up at your object. This works pretty well at reducing shadows.

Alternate Photoshoot

There is another type of photoshoot, as well, that is worth mentioning. Instead of moving the camera around the object and capturing the complexity of the background, you can use a completely featureless background, such as a white cloth, and simply rotate the object itself using a fixed camera position. If the background is absolutely featureless, the program will think that the photos were taken from different angles around the object, instead of the object itself being rotated. This method speeds up the photoshoot, and helps to control lighting. However, it requires some additional time to be spent in the setup. If the program recognizes any similarities in the background between photos it will realize that all the photos are from the same position, and it will project all of the photos on top of one another, creating an unrecognizable mess of an object. Try to avoid wrinkles, shadows, dirt, or overly textured cloth when attempting this method.

PHOTOGRAMMETRY POST PROCESSING

Processing

Although it is best to take your photos in the RAW format, RAW files can't be fed directly to photogrammetry programs. You will need to convert your photos to .jpgs first, which can be done in Photoshop. Photoshop can also be used to collectively adjust the white balance and other features of the photos for clarity and accurate coloring.

The cleanup process, and the rest of the workflow discussed in this document, relates to creating a game-ready model, complete with material maps. If you are only interested in experimenting with the photogrammetry process itself and creating high-definition 3D models, this information can be disregarded.

The quality of your model can vary greatly depending on the quality of the photoshoot. However, even with a high-quality photoshoot, there may be areas of the model that are messy. For our glove model, for example, the reflective areas and smooth areas did not reconstruct perfectly. To fix this, you can use ZBrush, smoothing and re-sculpting these areas. This is where spending more time in preparation can pay dividends by reducing the time required for this clean-up.

There may be areas that can't be easily cleaned. For example, areas with a regular pattern (stitching, mesh, etc.) that did not get reconstructed cleanly could be extremely tedious to recreate by hand. The best technique that we found was to take advantage of the high quality of the diffuse map, and use it to clean up the issues in the resulting normal map. The diffuse map that comes from a good photoshoot is usually very clean. Any cleanup that does need to be done can be accomplished in Photoshop, which has effective image cleaning tools.

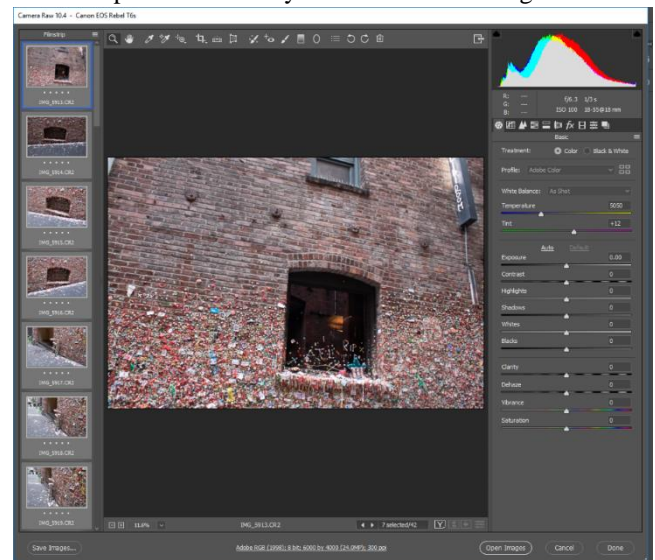


Figure 4: Processing in Photoshop

If you take the diffuse map and load it into a program like CrazyBump, you can create a new normal map. This new, clean normal map can be placed as a layer above the normal map that was baked between the high-poly and re-topologized models. The new normal map can then be masked out, and carefully painted back in to fix issues.

De-Lighting

When doing a photogrammetry photoshoot indoors with additional flood lights, it is usually possible to get even lighting at all angles around your object. However, when additional lights are not available, or when doing a photoshoot outdoors, a part of the object you are shooting may end up in shadow. You may want to rotate this object in your game engine, or have light coming from another angle, so you will want to remove this baked-in shadow. Unity has a free de-lighting system for removing shadows from photogrammetry objects, as described in their article “How to Remove Lighting from Photogrammetry with the De-Lighting Tool.”

De-Lighting can also be achieved using your object’s World Normals map, which can be created in Substance Painter or xNormals. You will need to experiment with your model, but using the red, green, or blue channel from the World Normals map, copied and pasted as a layer on top of the diffuse map using the Soft Light or Screen layer blending option can counteract your shadows.

PHOTOGRAMMETRY FOR OBJECT RECONSTRUCTION

The incorporation of photogrammetry into the regular content-creation pipeline is fairly straightforward. The image below shows a basic outline of the process:

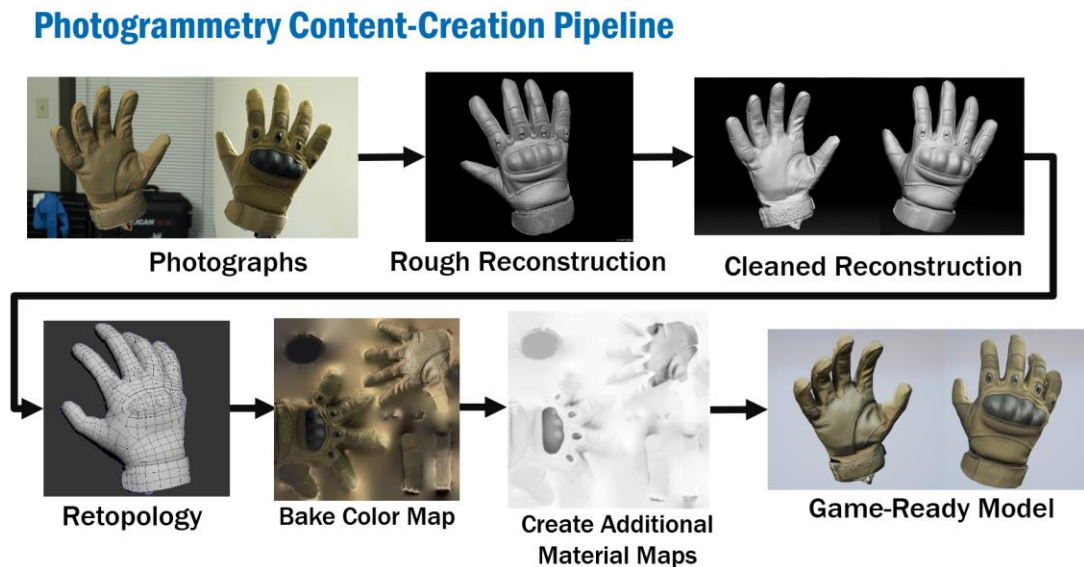


Figure 5: Photogrammetry Content Creation Pipeline

After the model has been cleaned, it can be re-topologized for use in the game engine. After the re-topology process, the new mesh can be unwrapped onto the UV space, and the color information gathered from photogrammetry can be projected on the new UV layout. The Ambient Occlusion map can also be created using the photogrammetry model. Other maps, such as Roughness/Smoothness, Metallic, will have to be created by hand.

PHOTOGRAMMETRY FOR ENVIRONMENTAL RECONSTRUCTION

There are two ways to use photogrammetry in environment modeling. The first is to use the photogrammetry model as a base mode for an environmental space.



Figure 6: Reconstruction of Seattle's Post Alley Gum Wall

As mentioned earlier, large, flat color surfaces do not reconstruct well using photogrammetry. However, these sorts of surfaces are easy for humans to create by hand. When doing an environment reconstruction, you can use a combination of photogrammetry and hand-modeling to create an environment.

The basic workflow is to take photos and do a reconstruction in a program such as RealityCapture, and then take the reconstructed model into your modeling package (Maya, 3ds Max, etc.) and re-create parts of the scene that did not reconstruct cleanly. This will typically include walls and floors, even desks, tables, or other objects. The hand-created parts will have to be UV unwrapped—it is easier to give them their own UV sheet rather than incorporating it into the procedurally-made UV sheet created by RealityCapture. You can then take your hand-created models and import them back into RealityCapture and project the photo information onto their surface to create their diffuse map. Valve Corporation has created a successful reconstruction of their front lobby using this process, as outlined in their article “SteamVR/Environments/Advanced Indoors Photogrammetry.”

The second way to use photogrammetry in creating environmental models is to do photoshoots of surfaces, like brick, stone, carpet, or concrete, and create tile-able texture sets to use with your hand-created models. The process of creating tile-able textures using Photoshop’s Offset filter and clone-stamp tool is detailed in many places online, including an article on textures.com. This process is complicated when the normal and diffuse maps created by photogrammetry need to be made tile-able together in exactly the same way. One quick and easy solution is to use IMGonline, which automatically creates tile-able images. This method does not work for all types of surfaces. Other tiling applications are available as well.

Quixel MegaScans has thousands of high-quality, tile-able texture sets created using photogrammetry. In many cases it will be more cost-effective to use these pre-made texture sets, unless a specific custom material is needed.

PHOTOGRAMMETRY FOR SCALE REFERENCE

Photogrammetry can still be useful in the creation of 3D models even when the model is too reflective, too smooth, or has too large an area of flat color for a clean reconstruction. Similar to laser scan data, the rough reconstruction, while inaccurate on a small surface level, will still be accurate overall in terms of scale and large features. The reconstructed model can be used to check overall scale, the relative scale of large features, and the characteristics of angles and surfaces. This, along with the more traditional use of reference photography, can produce an accurate

model. In addition, because the photogrammetry model has physically accurate colors, its diffuse map can be used as color reference.

CONCLUSION

Inspired by Nick Lievendag's article on how photogrammetry and 3D scanning helped EA DICE reduce content creation time for Star Wars Battlefront, we tracked the amount of time-savings that we experienced compared to an estimate of a similar project using traditional content creation methods. We found that photogrammetry shaved off several days from the pipeline, in addition to producing high-quality and accurate models. The largest source of potential savings in the future will come from increasing the quality of our photoshoots—which will in turn increase the quality of the model, and reduce the time needed for cleanup.

Although photogrammetry does require an upfront cost in exploration, practice, and multiple attempts, we estimate that with a higher quality photoshoot and optimized process we will be able to reduce the time for creating game-ready models by roughly 40%.

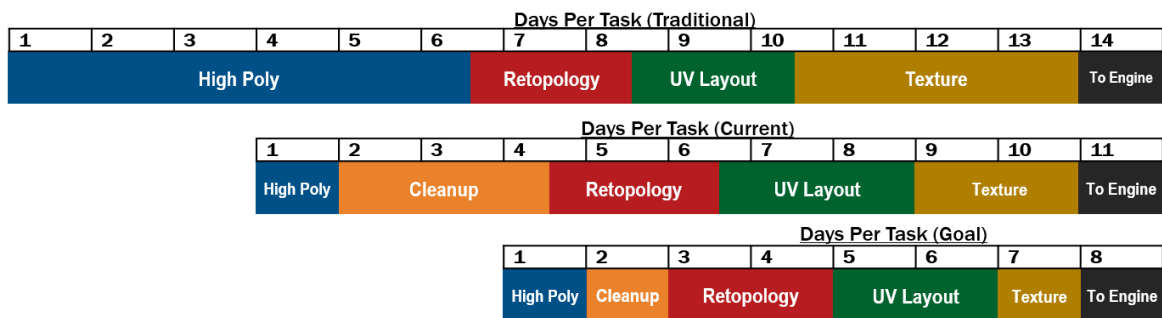


Figure 7: Time saved using photogrammetry

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