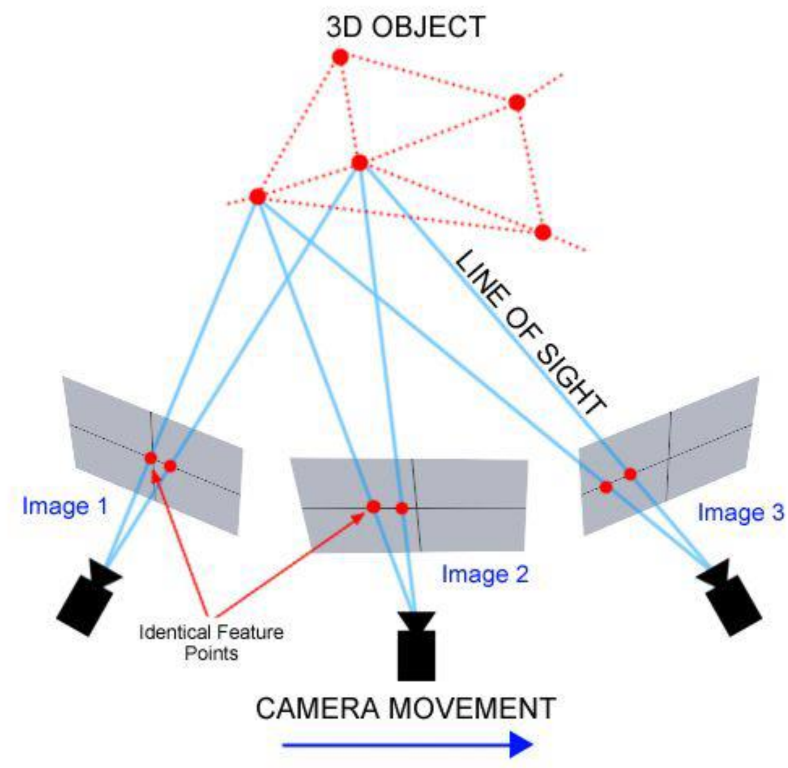
3D Model Construction Using Photogrammetry

Photogrammetry: is the technique of taking multiple overlapping photographs and deriving measurements from them to create 3D models of objects or scenes. Similar to the way many cameras these days allow you to create a panorama by stitching together overlapping photographs into a 2D mosaic. Photogrammetry takes the concept one step further by using the position of the camera as it moves through 3D space to estimate X, Y and Z coordinates for each pixel of the original image; for that is also known as structure from motion or SfM. The technique is gaining in popularity and usage since it produces very impressive results comparable to high-end laser scanning technologies for a mere fraction of the cost. Plus, it's easy to get started!

Structure from Motion: photogrammetric range imaging technique for estimating three-dimensional structures from two-dimensional image sequences that may be coupled with local motion signals. It represents an effective, low-cost topographic surveying tool.



3D model construction using photogrammetry is a technique that involves creating three-dimensional (3D) digital models of real-world objects or scenes using a collection of photographs. Photogrammetry uses the principles of geometry and computer vision to reconstruct the shape and appearance of objects from 2D images.

Here is how the process generally works:

1. **Image Collection:** A series of photographs are taken of the object or scene from various angles. These photos should ideally cover the object from all sides and perspectives. The more photographs you have, the more accurate and detailed the resulting 3D model will be.
2. **Feature Extraction:** In each photograph, distinct points or features are automatically identified and tracked. These features could be corners, edges, or other unique parts of the object.
3. **Matching and Alignment:** The software compares the features across the different photographs and identifies corresponding points in multiple images. This allows the software to determine the relative positions and orientations of the cameras used to capture the images.
4. **Point Cloud Generation:** Based on the matched features, a point cloud is generated. A point cloud is a collection of 3D points in space that represent the surface of the object. Each point in the cloud corresponds to a feature that was identified in the images.
5. **Surface Reconstruction:** The point cloud is used to create a surface mesh, which is a representation of the object's shape as a network of connected triangles. This mesh defines the geometry of the object.
6. **Texture Mapping:** The original photographs are then used to project the colors and textures from the images onto the surface mesh, giving the 3D model a realistic appearance.
7. **Refinement:** The generated 3D model may undergo various refinement steps to improve its accuracy and quality. This could involve removing noise from the point cloud, smoothing the surface mesh, and optimizing the texture mapping.
8. **Export and Use:** The final 3D model can be exported in various formats (such as OBJ, FBX, or STL) and used in different applications. These applications could include video games, virtual reality simulations, architectural visualization, cultural heritage preservation, and more.

Photogrammetry has numerous applications in fields like archaeology, architecture, entertainment, manufacturing, and geospatial mapping. Successful photogrammetry relies on good-quality images with clear details and adequate overlap between images. Additionally, more advanced photogrammetry setups may involve specialized hardware like calibrated cameras and controlled lighting environments to ensure accurate results.

Algorithms & Techniques Used

Several algorithms and techniques are used in the process of 3D model construction using photogrammetry. These algorithms work together to extract information from photographs and reconstruct the 3D geometry of objects. Here are some of the key algorithms commonly used:

1. **Feature Detection and Matching Algorithms:** These algorithms identify distinctive points or features in images, such as corners, edges, or key points. Examples of such algorithms include SIFT (Scale-Invariant Feature Transform), SURF (Speeded-Up Robust Features), and ORB (Oriented FAST and Rotated BRIEF). These features are then matched across images to establish correspondences.
2. **Bundle Adjustment:** Bundle adjustment is an optimization technique used to refine camera poses and 3D points based on the matched features and their observed positions in multiple images. It minimizes the reprojection error, adjusting camera parameters and scene geometry to achieve the best alignment of images.
3. **Structure from Motion (SfM):** SfM algorithms estimate the 3D structure of a scene from a collection of 2D images. These algorithms infer the camera poses and 3D point positions by iteratively minimizing the geometric discrepancies between the projected points and the observed key points in the images.
4. **Triangulation:** Triangulation is the process of determining the 3D position of a point by intersecting the lines of sight from multiple cameras. In photogrammetry, triangulation is used to compute the 3D positions of key points or features detected in multiple images.
5. **Depth Map Generation:** Some photogrammetry methods involve creating depth maps for each image, which represent the distance of objects from the camera. These depth maps can be fused together to create a complete 3D representation of the scene. Algorithms like PatchMatch and graph-cut-based methods are used to generate depth maps.

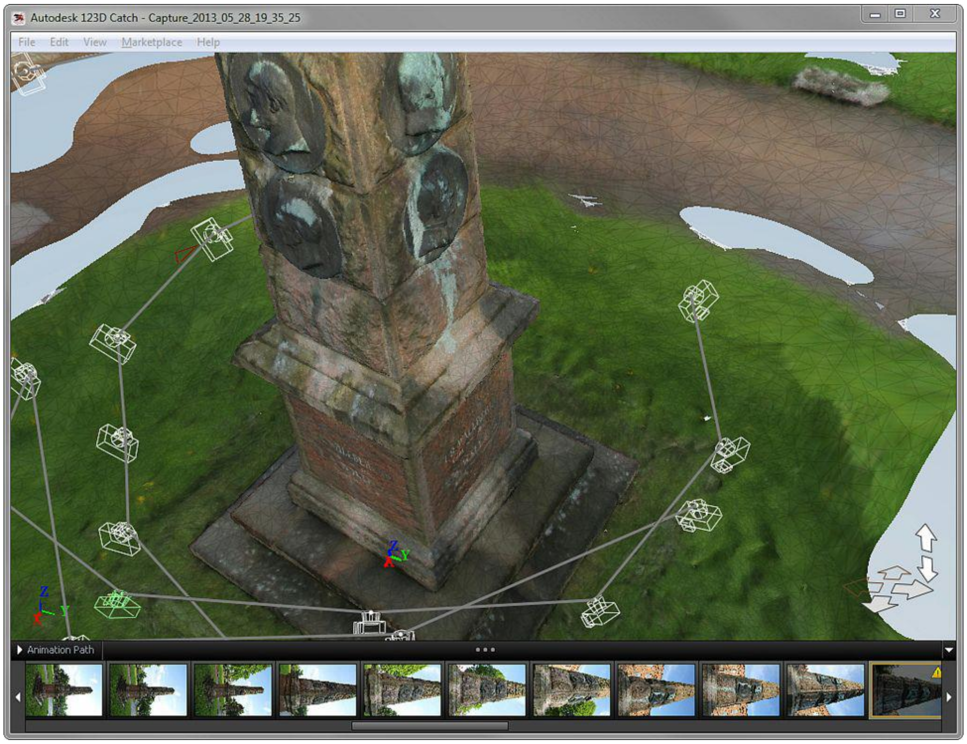
6. **Surface Reconstruction Algorithms:** Once the 3D points are estimated, algorithms are used to generate a surface mesh that represents the object's geometry. Delaunay triangulation and Poisson surface reconstruction are examples of techniques used for this purpose.
7. **Texture Mapping:** Texture mapping involves projecting the original images onto the surface of the 3D model to give it a realistic appearance. This process requires mapping the 2D pixel coordinates of images onto the 3D surface coordinates of the model.
8. **Mesh Smoothing and Refinement:** After the surface mesh is constructed, algorithms can be used to smooth and refine the mesh, improving its quality and reducing artifacts.
9. **Texture Blending and Seam Removal:** When applying textures to the 3D model, techniques are used to ensure that textures from different images blend smoothly and seams between different texture patches are minimized.

These algorithms are often used in combination and may vary based on the specific photogrammetry software or pipeline being used. The choice of algorithms depends on factors such as the complexity of the scene, the quality of the images, and the desired level of accuracy and detail in the resulting 3D model.

Software Apps

1- Autodesk 123D Catch

Autodesk’s 123D Catch is a free app for mobile platforms that lets you quickly create scans from images and automagically process them into models. The software is very simple to use and produces decent, if messy results out of the box, which can be edited and refined using their related desktop application.



2- <u>Agisoft Photoscan</u>

https://www.agisoft.com/downloads/installer/

PhotoScan is a widely used application that has made the complex algorithms necessary for processing photos into 3D models accessible through a fairly simple-to-use graphical interface. It is not as simple as 123D Catch, but offers much greater control of each stage of the process, and will let us produce much more accurate results.

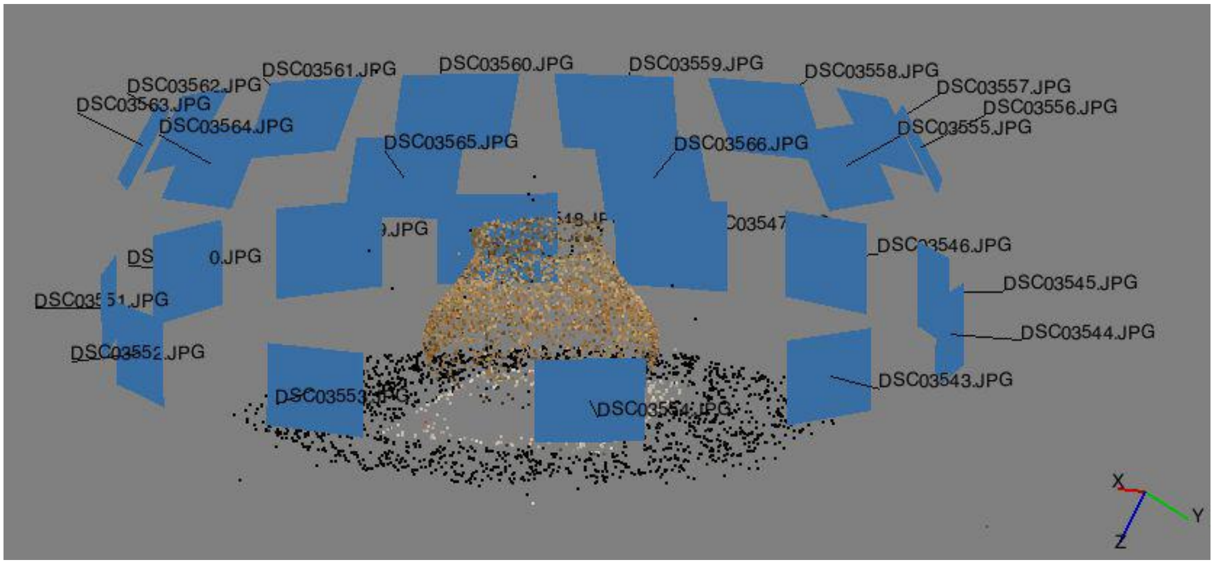
Order of operations:

- **Add Photos** (or **Add Folder** containing all photos from your shoot): this first step loads all of your raw images into the software's interface.

  <u>Note that</u> you will need to mask out the background behind your objects.

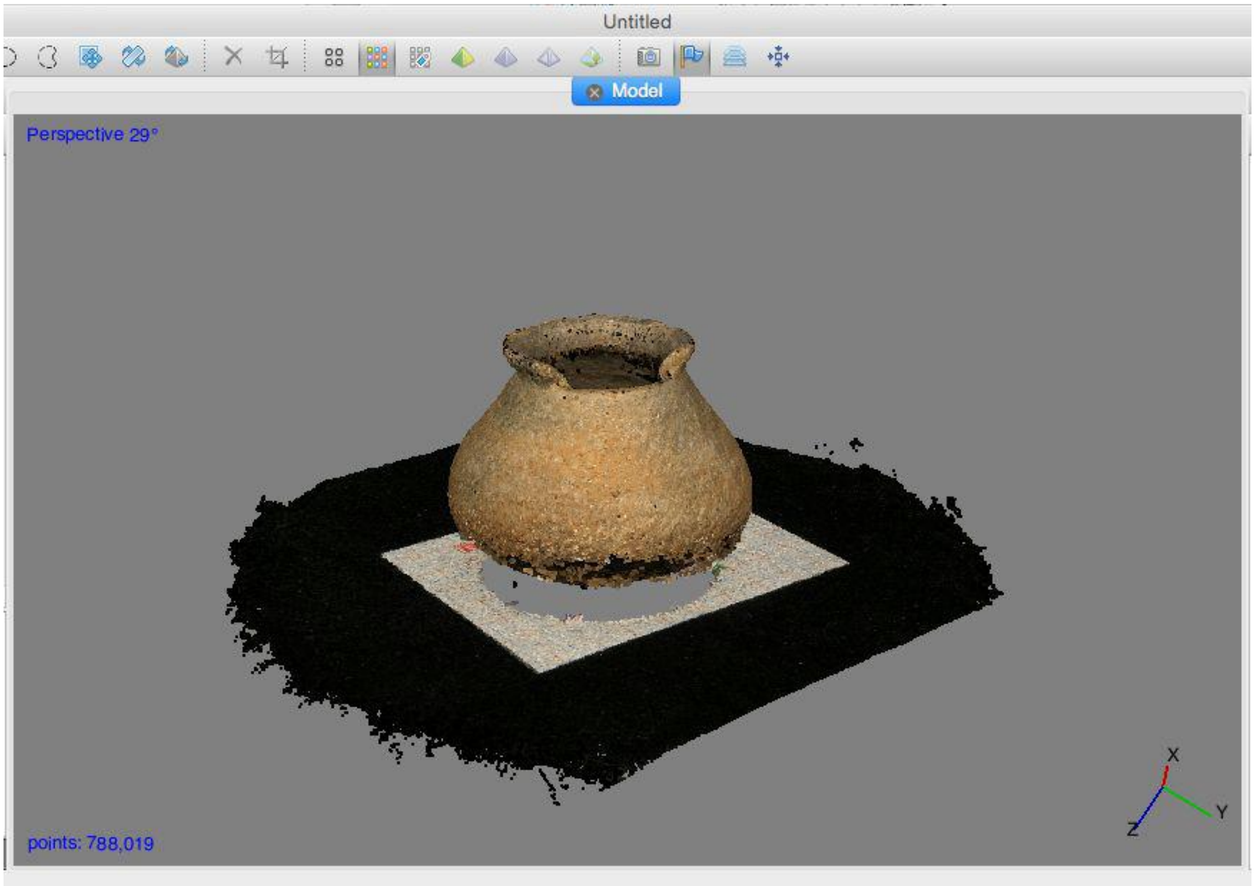
- **Align Photos:** the first processing step compares the pixels in your photos to find matches and estimate camera locations and 3D geometry from them.

The result of this process should be a sparse point cloud of your object that is spotty, but recognizable, surrounded by blue squares representing each camera position in 3D space. We have a 3D representation of our object! But now we have to refine it.



- **Build Dense Cloud: once satisfied with the alignment, the sparse point cloud (a mere fraction of the** total data) is processed into a dense cloud in which each matchable pixel will get its own X, Y, Z location in 3D space.

  This step will use the aligned photos to generate a point cloud that should be dense enough that it will look like a solid model from a distant zoom. This would be a good time to remove the table or surface your object was sitting on.



This cloud looks great from a distance, but if you zoom in you'll notice that it is really a cloud of points, as the name suggests. We need to connect them into faces to make a continuous surface mesh, which takes us to the next step.

- **Build Mesh:** this step connects each set of three adjacent points into a triangular face, which combine seamlessly to produce a continuous mesh over the surface of your model.
- **Build Texture:** In the final step, the original images are combined into a texture map and wrapped around the mesh, resulting in a photorealistic model of your original object.