# MLZ 3D Digitization Protocol

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# 1. setup

**1.1. Camera choice:**
Nearly any camera can be used to preform some sort of photogrammetry. The camera you choose will largely depend on your budget, and the circumstances of your digitization effort.

In scanning bird specimens, we chose a Sony a7rii. It is a full-frame mirrorless camera, and we went with it largely for its 42 MP sensor. The camera's sensor quality set a limit for the scan's geometric fidelity; high-res photos make it easier to resolve high-res scans. The sensor size let us get the most out of the lens we use, providing enough resolution for the fine detail of macro shots to resolve into 3D geometry .High resolution photos lead to longer processing time. This also means that fewer photos are required for the reconstruction process.

Transparency, reflectivity, and fine detail such as hair, can also be difficult or impossible to scan. Transparency/reflectivity can be obscured, or diffused with filters in order to avoid problemed scans. Fine and high-res detail can be accounted for with enough resolution or specialized lenses.

**1.2: Lens choice:**

The lens used depends on your subject matter and desired scan resolution. Choosing a camera platform will affect the variety of lens available. In order to capture the fine detail of bird skins, we use a 90mm macro lens.  Larger specimens will require a lens with a wider field of view and deeper depth of focus. When capturing larger specimens, we use it in tandem with a 15mm wide-angle lens. Since we are using a macro lens, we have to keep a couple of variables in mind to maintain sharpness and a proper representation of the subject. The depth of field will be shallow, so we need the fstop to be high. The magnification should be 1:1 magnification and the focal length should be fixed. We will get to this when discussing camera settings. Future setups may resort to focus-stacking, but current methods multiply the time commitment for image capture.

- Specular highlights and reflections will confuse the scanning process. A polarizing filter can be used to polarize the light, in order to remove reflection and capture diffuse albedo in the final scan.

**1.3: Light Setup**:

Lighting can drastically change the outcome of a scan. Excess light and shadow will bake itself into the model's texture. Reflections and bounce-light can make subsequent photos, creating gaps in your image registration.

It is important to set up even, diffuse lighting. Since both a scan's texture and geometric form are constructed from pixel color, it is important that light produces colors accurately, evenly, and predictably. Diffused, even light will help you fight highlights and shadows that get in the way of good texture baking and accurate geometric capture. Hemispherical coverage is ideal.

To do this, we recommend setting up two boxes on either side of the scanning stage, and one above. A white backdrop is recommended, and while a green screen may help in masking, it also risks tinted bounce light. It can be useful to calibrate lighting ahead of time to ensure lighting is standard between shooting sessions and setups. Light is additive, so make sure to test them each individually then all together. (Depending on the shutter speed, kill the room lights so they don't interfere with the exposure.) The recommended exposure will depend on your camera and settings.

**1.4: Stage Setup:**

**[Camera setup diagram]**

While larger setups may use multiple cameras positioned in sync around the stage, smaller stages consist of a subject centered on a turntable in front of an even backdrop. We place a turntable evenly between the lights and the white backdrop. The tripod-mounted camera faces the subject from the open side. It should be at a distance where the subject is fully in frame, a distance which depends on the subject's size and the camera's focal length.

In order to have a better view of their underside, sufficiently small objects should be placed on a stand. Stands should be both non-invasive enough to minimize impact on the scan's surface, yet sturdy enough to stay rigid when the turntable actuates. The stand should not obstruct the view of the camera during a pre-set rotation. The stand is also a good place to affix scale reference such as a ruler or coded markers.

For our bird skins,  we use a small stage consisting of a motorized turntable [Comxim] that interfaces with the shutter release of our camera. Taking a picture actuates the turntable, which after turning, signals for another picture. We position coded markers and a scale marker in order to be visible along with the subject. For scale calibration, We place a scale bar right below the bird. For color calibration, we use an X-Rite Colorchecker color chart.

# 2. image capture

**2.1: Camera settings**:

When capturing images for a scan, you must consider both resolution and reliable image registration. Like with lighting, camera settings affect the pixels and thus affect both texture quality and accurate geometric reconstruction. Because image quality directly affect scan resolution, it is important to minimize noise and maximize sharpness in every photo. Blurry photos will both hamper image alignment later on in the process, as well as forming artifacts during texture generation.  If a low ISO and a high f-stop significantly decrease the exposure and begins to crush colors, consider using stronger lights or a slower shutter speed.

Considering we use a lens with low depth-of-focus, we use an f22 aperture for maximum depth of field in each shot. Considering our strong lights, we also are able to drop the ISO to 400-800 in order to avoid noticeable noise. We take photos at full resolution, formatted in RAW+JPG. Since we are using an automated setup, we make sure to check the subject's framing and focus before each rotation.

**2.2: Documentation**:
When recording camera settings, we also take time to document the subject and the shoot. This is done in two steps.
1. Document the name, tag, number, and any other data relevant to the subject and its organization. We take a hand-held photo of the collection tag.
2. Document the ambient color of the setup, for white-balancing and color correction later down the pipe. This can be done by taking a single photo of a ColorChecker or other similar color chart. Make sure the chart is fully in frame and in focus, and using the same camera settings and lighting conditions that you plan to use for the scan.

**2.3: Capture**:

**[Camera angle setup diagram]**

Photogrammetry software requires consecutive series of photos (at varying angles) to accurately assemble or "solve" the 3d model. In order for photos to a successive series of photos require 50% or higher overlap in order to effectively collaborate towards the solvee. When automating the capture, it’s important to keep overlap in mind when determining photo count. When using our turntable, we set it to take a photo every 3-4 degrees until a full rotation has been captured.

We use 96 shots and three different angles. The first at a low 45, the second level with the turntable, the third from higher up. The process takes 7 minutes per rotation, and the tripod is manually adjusted to the next position between rotations. With the use of three cameras, the shooting time would be cut from 21 minutes to 7 and require no manual adjustment.

# 3. image processing

**3.1 File Organization**
File management is crucial to maintaining an automated/procedural workflow, as mismanaged file paths can break your pipeline. Choose a reliable format, stick with it, and try not to move anything.

We store each scan in the following format:
*Date(YYYYMMDD)_Name_Collection#*

Each folder contains the following subfolders:

*0_raw*
*0_jpg*
*1_tif*
*1_mask*
*2_scan*
*3_mesh*
    *0_scanpoly*
    *1_highpoly*
    *2_lowpoly*

**3.2: Photo Processing**
**Process RAW images in Adobe Lightroom**:
**i.** Out-of-focused or obviously troubled photos are removed from the set.
**ii.** The color checker profile is exported as a new color profile.
**iii**. Lightroom is restarted, and the color profile is loaded into the photo of the color chart.
**iv.** The exposure of the photo will be raised or lowered until the 2nd grey square on the chart is within a 1% margin of 75% grey.
**v.** The photo is white-balanced using the 75% grey color chip.
**vi.** Lens profile corrections are applied to the photo, reducing photo distortion and color aberrations according to the make of the camera and lens.
**vii. (**Optional) Sometimes, a photo set is manipulated to encourage better photo alignment. Settings that affect alignment include lowering highlights and raising shadows in order to flatten the images as much as possible, as well as increasing contrast from 5 to 15%.
**viii.** The total exposure values are matched across the photoset, using the color checker photo as reference.
**ix.** The photo settings (minus exposure) are synched across the photoset, using the color checker photo as a reference
**x.** The Photos are exported in one of two formats:

- 8-bit TIFs: the smallest lossless filetype that contains all the information useful for a scan. These photos are lossless, but due to the volume of photos taken, take up significant space.
- High-quality JPEGS. From our testing, high-quality JPGs rendered models of comparable resolution, and take up significantly less space to store.

- Export the photos to the 1_TIF folder (or folder for an equivalent filetype)

**3.3: Masking**
To optimize photo alignment, the exported photos should be masked. Different subject matter will require different types of masking. Generally, a mask modifies an image in order to obscure the backdrop and isolate the subject. When using photoshop, different masking processes or 'actions' can be batched.

**i.** The type of masks we generate depends on which software we are using for image registration. [See c) image registration]

- When using Reality Capture, we create masks in the Alpha channel of our exported TIF images. These masks will use transparency to mask out the background of each image.
- If we are using Metashape, we store the masks as separate greyscale JPEGs. The white portions will be enabled during image registration, while the black portions will be masked out. Because these masks are generated from the JPEGs captured by the camera, this action can run concurrently to image processing in Lightroom.

**ii.** In Photoshop, an 'action' macro is automatically applied to the photo set, and the photos are exported under 2_mask with the suffix "_masked"

- If Alpha masks are required, we import the TIF photos from 1_TIF. The Alpha Mask macro writes the mask directly into the alpha channel of the images that will be used for image registration.
- If Greyscale masks are required, we import JPEG photos from 0_JPG. The Greyscale macro keys out the background, turning it black, and turns the subject white. The exported file will correspond to its 1_TIF counterpart, over which it will be overlayed inside of Metashape during image registration.

**iii.** Oversized or oddly-shaped subjects may require the fine-tuning of masking macros. Backup macros are used in these cases, that key the backdrop at different tolerance levels, as well as batches that use other methods of background-detection such as the selection of a color range. Photoshop's "Select Subject" tool has been our most error-free means of quickly producing accurate selections for both Alpha and Greyscale macros.

# 4. image registration and point-cloud generation

Now that the images have been processed, photos are loaded into software that aligns them and generates the initial 3D data that will become your final scan. While there are multiple scan-solving software to choose from, the best one depends on your use case, subject matter, computer hardware, and experience. When the photos are correctly captured and processed, aligning them should be simple and hands-free.

## 4.1. Software Choice

First, we choose the appropriate software. We use two different image registration packages. Along with registering images and generating point clouds, they both offer meshing and texturing capability. While Reality Capture is the better option for large collections, both programs are recommended according to their particular advantages:

**Agisoft Metashape**

Positive:

- Forgiving and consistent image alignment, and intuitive image alignment troubleshooting.
- Supports 32bit images, and exports 32 bit textures
- User-friendly and intuitive interface
- Supports automating point-cloud registration.

Negative:

- Significantly longer processing time than reality capture.
- Asset resolution is limited by the PC hardware being used

**Reality Capture**

Positive:

- Extremely fast processing time
- Less dependent on high-end PC hardware
- Able to generate extremely sharp and detailed results

Negative:

- User interface less friendly
- Less forgiving with
- Point-cloud registration is manual, and less intuitive

## 4.2 Image Registration

**i.** After the software has been chosen, we import the TIF photos for registration. When using reality capture, the masked TIFS can be imported straight from 1_mask. When using metashape, the TIFS can be loaded from 1_TIF and the masks can then be loaded separately from 1_mask.

**ii.** Photos are aligned, automatically generating a point cloud. In Metashape, this process takes anywhere from 1 to 4 hours using our recommended settings. In Reality Capture, it takes between 10 and 30 minutes. When using default or medium settings, a decent point cloud will have in excess of 200,000 points and should recognizably resemble the subject.

**iii.** When correctly aligned, the camera positions should read as three perfect rings per rotation set: each ring representing a 360 degree rotation of 96 individual photos. At this stage, remove any photos that fall outside of these rings or that don't contribute to the visible point cloud.

**4.3 Point Cloud Editing**

Before generating a mesh from the point cloud, it is important to double-check image registration to make sure that the photos have properly aligned. After a point cloud is generated, you should have enough visual feedback to note the incomplete data of the scan, usually towards the direction of the stand the subject was resting on.

**i.** Look for misaligned cameras. They will fall outside of the uniform circular rings visualized in the software's viewport, and often correspond with errors in the point cloud. Reset misaligned cameras, then try re-registering them.

**ii.** Look for missing data in the point cloud. If the subject's silhouette is visibly noisy or isn't visible at all, some of the cameras may have failed alignment. Try re-registering photos using different alignment settings, such as image overlap and alignment quality.

**iii.** If automatic photo registration is failing, you can manually adjust photo alignment align by placing markers. Some software, like Agisoft Metashape, allow you to place markers directly onto the 3d model in the viewport. Otherwise, you can place markers directly onto the photographs. Place them on visual landmarks visible from multiple photos. Often three or more photos are required for proper alignment.

**iv.** Lastly, the scale is defined by placing markers on a defined unit of measurement present within the photo. A scalebar appropriate to the subject's size is often placed on the stand for this purpose. Two markers should set the boundaries of the largest unit of measurement you want to use to calibrate the scale of your model. Once placed, a digital scalebar can be registered between the points. After the scale accuracy has been set and checked, the model must be updated with the new scale reference in mind.

**v.** We finish out work in the Image Registration software by generating a high-poly mesh from the finished point cloud. The geometry is generated at the highest resolution possible; a point cloud of 200,000+ should generate a mesh with a polycount exceeding 500,000 triangles. The new mesh is exported under 0_scanpoly withing 3_mesh as an OBJ file with the "_scanpoly" suffix.

# 5. mesh processing - manual

Image registration and Mesh Processing largely occur on their own. However, sometimes it is necessary, or preferred, to check the mesh for errors and remove extraneous geometry before sending it further down the pipe.

Manual cleanup of the mesh is done using a 3D sculpting package. We use Pixologic ZBrush because of its agility with very high-polycount meshes and its "tessemation" (tesselation + decemation) toolset. In ZBrush, we take the following steps:

a) Small excess pieces are removed.
   - Polygroup -> Autogroups
   - Select the body of the main scan geometry.
   - Geometry -> Modify Topology -> Delete Hidden

b) The Stand and other extraneous geometry is removed
   - The Sculptris and selection tools are used to remove the stand.
   - Holes are filled with Geometry -> Modify Topology -> Close Holes

c) The Export paramters are changed to match the desired output
   - Triangles, no groups.

The result is exported under 1_highpoly withing 3_mesh as an OBJ file with the "_highpoly" suffix.

# 6. mesh processing - procedural

To ensure the most flexible possible results, we run the "high-poly" mesh through a series of steps that control and refine its resolution settings, fix any topology errors, and smoothly export the remaining files.

**6.1:** The polycount is reduced through decimating the mesh according to a "quality tolerance" according to the shape of the original high-definition model. That way, each scan is reduced based on its own real-world topology rather than a fixed percentage or target polygon count. The quality tolerance should be adjusted with respect to your intended scale accuracy:

**6.2**: Next, the mesh is cleaned. Scanned meshes often have a high triangle count and contain detailed and often intricate shapes. This often leads to a number of topology defects, many of which are invisible to the eye but extremely visible to the shader later on. It is best to deal with these defects as soon as the scan is complete. Common scan geometry errors include:

- non-manifold geometry
- five-sided polygons

**6.3:** Next, the mesh is given UV coordinates. When choosing a UV algorithm, the aim is to balance maximally efficient texture-usage with even texile density across the model. We tend toward using 8 simultaneous planar projections using Houdini's automatic UV toolkit. For quicker results, Houdini's AutoUV SOP has automatic seam-drawing parameters that can be tuned to match the shape of your model.

**6.4:** The final node of the Houdini procedure exports the mesh in the 3_lowpoly subfolder of the 3_mesh folder in the main directory. This final 3d model, with a "_lowpoly.obj" extension, will be the most optimized version of the model to texture and upload.

# 7. texture generation

**7.1:** The retopologized low-poly model is imported back into the Image Registration software, replacing the previous high-poly model. From here, the aligned photos are used to generate a texture map using the previously generated UV coordinates. The resolution of your texture cannot exceed the resolution of your camera's sensor, so keep that in mind when rendering textures. We usually render 4k textures for our models.

**7.2:** After generating the texture, export it into the same 3_lowpoly folder from which you saved the low poly model with proper UVs.

# 8. finalization

**8.1:**The model is loaded into a 3D viewer to finalize geometry and positioning. The scale calibration should be double-checked by comparing measurements on the 3D model to its real-world counterpart.

**8.2:** Since these models are optimized for real-time rendering, they can be shared online and loaded into 3D viewers and other scenes. Additional texture maps and post-production can be applied for added authenticity or aesthetic purposes.