Supplemental Information Section

# Scanning a Specimen with a NextEngine Desktop Scanner

Creating a surface scan is fairly straightforward. To begin, the user will want to set up in a well-lit room, with access to additional light sources that can be moved around as needed. A power strip to plug everything in is helpful, as well as a sturdy table that is not affected by vibrations and is large enough to accommodate both the NextEngine scanner, and turntable. If the user is working from a laptop, having room to place the laptop on the same table is optimal, but not necessary; keep in mind that the scanner is tethered to a computer via a USB cord so as to transmit the mesh data. It is best to face the scanner itself towards a blank wall so that it does not accidentally pick up background noise while scanning the object. Instructions for set-up and hook-up of the scanner are included with the hardware. Please note that the user will have to register the scanner online, as well as download the software prior to scanning. However, the software does not work on Apple computers. A computer with 4 gigabytes (GB) of Random-Access Memory (RAM) and a 250 GB hard drive will be powerful enough to handle the scanner, software, and file sizes (Means et al., 2013a). Once preliminary set-up is complete, the user can begin setting up the scan. This tutorial will focus on MeshLab for cleaning up and repairing 3D meshes.

# Scanning an Object

Means et al., 2013b created a comprehensive protocol for scanning specimens using a NextEngine scanner. This protocol can be adapted for other scanner types. The following steps for scanning have been distilled and adapted from the Means et al., 2013a protocol:

1. Selecting an object: the best type of object to begin with is one that demonstrates simple geometry, is between 10-20 cm in all directions, and does not have excessively reflective surfaces.
2. Placing object on turntable: using the rubber stoppers on the holding arm, place the object in a fashion that demonstrates the most surface. The object will be rotated 90° from starting position after the initial scan, to capture the surfaces not exposed to the laser.
3. Software Scan Set-Up: In the fill-in box next to *Model* enter the file name for the scan to save as. The user has the ability to select the folder where to save the scan.
	1. *Scan Family*: Unless using the multi-drive option, keep the setting at *Auto.*
	2. *Positioning*: On the opening screen of the ScanStudio HD Pro software, the user can select from three (3) *Positioning* options: “360”, “Bracket”, and “Single”. “360” will scan 360° of the object; “Bracket” will scan three (3) views of the object. The user can see the three views that will be scanned under the bracket setting by using the *Turn* arrows at the top of the software screen; and “Single” will only scan one view of the object. These positions can be used interchangeably with an object to capture missing data as needed.
	3. *Divisions*: This option allows the user to select how many panels will be scanned for the object. The more panels, the longer the scan will take. This parameter can be adjusted based on the complexity of the specimen being scanned.
	4. *Points/IN.2*: To create high resolution scans, it is recommended to use the “High Definition (HD)” option. This will create a larger file but will capture the most data to build a reliable surface scan.
	5. *Target*: The user can select the *Target* option between “Dark”, “Neutral”, or “Light”. These options refer to the reflective quality of the object being scanned. Neutral is usually the best option, but users will learn to adjust this setting as needed.
	6. *Range*: This option refers to the distance between the scanner and the object being scanned. The user can physically move the turntable closer or further from the scanner, using the view finder on the software screen to select the distance. The object needs to fit completely within the viewfinder and be in focus. Using the *Turn* arrows at the top of the software screen, rotate the object to ensure it does not extend past the edges of the view finder. Small objects (10–15 cm) are best scanned at *Macro* range.
	7. *Time*: This is not an option that the user can manipulate but provides an estimate on the length of time the scan will take to complete. The time estimate changes with changes to *Positioning*, *Divisions*, and *Points*.
	8. *Memory*: This also is not an editable option, but an estimate on the amount of the amount of memory being used to capture the scan. The memory estimate changes with changes to *Positioning*, *Divisions*, and *Points*.
4. Click *Start* to begin scanning.

Tips during scanning: It is best to stay near the scanner to monitor the first couple of panels that are scanned. Sometimes the color or reflectivity of the object will not be adequate, and the scanner will not pick up a good signal. When this happens, it is easy to stop the scan, and manipulate the settings, background and auxiliary lights to create the proper surface for scanning. It is important to note that the NextEngine scanner has difficulties picking up thin edges (i.e., cutting edge of a shark tooth) and the user will have to manipulate the placement of the object and other settings to capture the data. The user can also dust a fine talc-powder (provided with NextEngine scanner) to decrease reflection and increase texture. This powder is safe to use with fossils.

# Processing Scans

Once the scan is complete, some processing will need to be done prior to saving the volume file. Scans will need to be trimmed, aligned, and fused prior to exporting.

Trimming: It is important to clean up the scans prior to alignment. To do so, the user will need to use the *Trim* function found along the top menu. To trim:

1. Click the *Trim* icon after all scans are complete.
2. Using the “Selector” tools and making sure the + in “De/Select” is highlighted, begin trimming the excess material around scan. This will include scanning platform, stabilizing arm, etc. The “Polygon Region Selector” option under “Selector” tools will provide the most flexibility regarding what will be trimmed. If a portion of the object is selected to be trimmed that should not be, the user needs only to click on the – in “De/Select” and rehighlight that portion. This will deselect that portion and not remove it from the file during the trimming process.
3. Once all of the noise has been selected, click “Trim.”
4. Trimmed scan should only show the specimen of interest.
5. Repeat steps 2–4 for all of the scans of the specimen.
6. Once all trimming is complete, click the “Back” arrow.
7. Scans can be trimmed again after they have been aligned (see below).

Aligning the meshes: ScanStudio HD Pro does not align the scans automatically and will need to be completed by the user prior to exporting the mesh as a volume. Once all of the views of the object have been scanned, and trimmed, the alignment process begins. To align:

1. Click the *Align* icon along the top menu.
2. Place the matching colored dots on matching landmarks on the two scans. Users can toggle between the “Views” to find better views of the landmarks. The 4-colored globe will wrap the scan in its original texture; the plain blue sphere will remove the texture. Once a minimum of 3 dots have been placed on both scans, click “Align” along the top menu. If the “Align” function does not run automatically, more landmarks will need to be identified and tagged.
3. Once all of the scans have been aligned successfully, click the “Refine” function to finalize the alignment.
4. Once complete, click the “Back” arrow.

Fusing the meshes: Once all of the scans of the object have been cleaned up, and aligned, it is now time to fuse the meshes into one complete surface volume. To fuse:

1. Click the *Fuse* icon along the top menu.
2. Click the *Settings* option. These options can be modified as needed, but best settings include selecting *Volume Merge*, check *Create Watertight Model (Fill All Holes),* and *Include Textures*. Click “Apply.”
3. Once settings have been selected, click “Fuse.”
4. Once scans have been fused to satisfaction, click the “Back” arrow.

At this stage, the 3D model should be watertight, or contain no holes in the mesh (mostly; see Post-Processing Surface Volume section below). The capabilities of ScanStudio HD Pro have been reached by this point. Once the surface volume has been fused, the user can export the mesh as an .OBJ or .STL file for further processing in other software. To export the mesh:

1. Click the *Output* arrow icon along the top menu.
2. Select output file type; we recommend “STL.”
3. Select where the file should be saved.
4. Click “Save” and select “Ascii” format and “OK” in the next window.
5. Saving may take a bit of time depending on file size, but “Model Saved” will be displayed in top menu window in the ScanStudio interface.

# Post-Processing Surface Volume

MeshLab can be downloaded directly from their website. The software is compatible for PC, Apple, and Linux products. It is possible to manipulate the scans with a trackpad, but it is easier and more efficient to use a mouse with a center wheel. To post-process the scanned surface volume:

1. Start the MeshLab application.
2. Click and drag your .STL or .OBJ file onto the main application interface.
3. A warning message may appear: “Unify Duplicate Vertices”, select “Okay”
	1. This will simplify the meshes and visualize holes in the mesh that will need to be repaired prior to printing.
4. Once the file has loaded, the user can zoom in and out, rotate the object, and shift the object within the interface.
5. Repairing the Mesh: Repairing holes in the mesh is crucial to creating a water-tight model for printing. To repair the holes:
	1. Click on “Filters” in the top menu.
	2. Select “Remeshing, Simplifications, and Reconstruction.”
	3. Select “Close Holes.”
	4. A pop-up window will appear. The user can change the “Max Size” of the holes that will be closed. This feature can be manipulated to close only the holes in the mesh, not foramina that are a part of the object, for example in fossils. Click “Apply.”
	5. The mesh will repair itself and progress can be tracked in the command window.

References

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