Using Structure from Motion (SfM) and 3D Printing as a Method for Preserving the Petroglyphs of Machias Bay, Maine

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Machias Bay is home to the largest concentration of petroglyphs (rock art) on the eastern coast of North America. These petroglyphs, pecked using hammerstones into exposed bedrock ledges on shorelines and islands, are now largely under the protection of the Passamaquoddy Tribe of eastern Maine and western New Brunswick, but are still threatened by factors such as erosion (exacerbated by the rising sea level in the Gulf of Maine) and vandalism, as well as accidental damage from well-meaning tourists. Many of the older petroglyphs are now underwater during the majority of the time, and are particularly endangered. They are estimated to range in age from approximately 3000 years BP at the oldest to 400 BP at the most recent.

Efforts have been made by the Northeastern Prehistory Laboratory at the University of Maine, supported by a Maine Academic Prominence Initiative grant, to digitally preserve these petroglyphs in a minimally-intrusive way. Previous efforts with a NextEngine laser scanner produced results that had some potential, but also had considerable issues. The process of getting the laser scans was time-consuming and laborious, as it required the transportation of considerable equipment to the ledges, and involved the creation of the resulting models in real time on a computer attached to the scanner. The project was put aside for a few years due to the discouraging results, with interest rekindled this year as in-house testing of structure-from-motion (SfM) methods was demonstrated to be a possible non-intrusive method of morphological data capture with the involvement of little personnel or field equipment.

The process used to create and then print a 3D model from photos of the Machias petroglyphs relied exclusively on open-source software. Test runs of the project utilized photos from a Canon PowerShot SX130 IS point-and-shoot camera. Approximately 80-90 photos were

The test petroglyph on one of the Machias Bay ledges.

used for each of the two test petroglyphs, with excellent results. Only one petroglyph has gone through the entire process from photographs to 3D print as of this writing, so the following will describe the steps undertaken for the creation of this particular model.

The workflow for processing the data began with the import of relevant photos into VisualSFM (ver. 0.5, Wu 2012), an open-source SfM program. Three steps of this process occured in VisualSFM following photo import (Compute Missing Matches, Compute 3D Reconstruction, Run Dense Reconstruction). Compute 3D Reconstruction created a sparse point cloud using information such as overlapping pixels and EXIF data, and then Run Dense Reconstruction generated a dense cloud using Yasutaka Furukawa's Clustering Views for

The meshed petroglyph model in Meshlab.

Multi-view Stereo (CMVS) software. CMVS is accessible from the VisualSFM toolbar, but the appropriate binaries need to be installed by the user for it to work.

The dense point cloud that is created after using the CMVS tool is exported as a Polygon File Format (.ply) file that is then opened in MeshLab (ver. 2016.12, Cignoni et al. 2016). Two more steps occur within MeshLab. The first is to compute surface normals (vectors perpendicular to the tangent plane) for the model. The second step is to run a Screened Poisson Surface Reconstruction on the result. At this point, the resulting mesh can be cropped and cleaned up as needed, and exported in whatever 3D file format is preferred.

Cleanup and any necessary modifications can be done in MeshLab or in any number of open-source or paid 3D modeling programs. For this test run, I elected to use Blender (ver. 2.75, Blender Foundation) to extrude the resulting model to a suitable thickness and place it upon a flat platform for printing. While the results were not perfect, they were adequate for a test print. This model was imported into Cura Lulzbot Edition (ver. 21.04, derived from Bramm

The petroglyph model, printed and painted.

2013), and printed on a Lulzbot TAZ 6 3D printer at a 0.2mm layer height using Verbatim PLA. After printing, the model was hand-painted using acrylic paint.

This test run has demonstrated that SfM is an appropriate method for documenting and replicating the endangered petroglyphs of the Machias Bay region, with an extremely low financial expense requirement (camera batteries, processing time, PLA filament). Importantly, it is a largely non-intrusive method for documenting the petroglyphs. Casting and molding is damaging to the rock surface, as it causes erosional damage over time. Similarly, previous efforts to record the petroglyphs using a NextEngine laser scanner had the potential to be damaging to the rock face as they required a considerable amount of equipment on the bedrock outcrops (scanner, computer, generator, counterweights, etc.). The SfM method only requires that a single individual visit the site with a camera, stepping barefoot onto the ledge so as to prevent the tracking of gravel and other abrasives onto the surface.

Beyond the digital documentation of the morphology of the petroglyphs, 3D printing is an appealing alternative to casting and molding for a number of reasons, including the ability to increase or decrease the size of the resulting model. Additionally, latex molds will wear microscopically every time a cast is made from them, meaning that each replication of the

original object is slightly altered from the previous version. 3D printing technology ensures that each model will be the same as those made before it, assuming no change in parameters, hardware, or filament type.

The long-term goal of this project will be to digitally preserve all of the Machias Bay petroglyphs using SfM methods and the open-source software suite described in this paper. Resulting data will be used to create a permanent archive of the petroglyphs' morphology, with models produced for education and outreach purposes. Additionally, a tablet-based application and/or website may be created to address the problem of access to the petroglyphs, allowing interested persons to "visit" the sites, learning about and interacting with them, without any risk to the petroglyphs or ledges themselves.