STRUCTURE FROM MOTION PHOTOGRAMMETRY AND MICRO X-RAY COMPUTED TOMOGRAPHY 3-D RECONSTRUCTION DATA FUSION FOR NON-DESTRUCTIVE CONSERVATION DOCUMENTATION OF LUNAR SAMPLES. K.R. Beaulieu[1], E.H. Blumenfeld[1], D.A. Liddle[1], E.R. Oshel[1], C.A. Evans[2], R.A. Zeigler[2], K. Righter[2], R.D. Hanna[3], R.A. Ketcham[3]. [1]JETS, NASA Johnson Space Center (kevin.r.beaulieu@nasa.gov), [2]NASA Johnson Space Center, Houston TX 77058, [3]UTCT Facility, Jackson School of Geosciences, University of Texas at Austin, Austin TX, 78712.

Introduction: Our team is developing a modern, cross-disciplinary approach to documentation and preservation of astromaterials, specifically lunar and meteorite samples stored at the Johnson Space Center (JSC) Lunar Sample Laboratory Facility [1]. Apollo Lunar Sample 60639, collected as part of rake sample 60610 during the 3rd Extra-Vehicular Activity of the Apollo 16 mission in 1972, served as the first NASA-preserved lunar sample to be examined by our team in the development of a novel approach to internal and external sample visualization. Apollo Sample 60639 is classified as a breccia with a glass-coated side and pristine mare basalt and anorthosite clasts [2].

Objective: The aim was to accurately register a 3-dimensional Micro X-Ray Computed Tomography (XCT)-derived internal composition data set and a Structure-From-Motion (SFM) Photogrammetry-derived high-fidelity, textured external polygonal model of Apollo Sample 60639. The developed process provided the means for accurate, comprehensive, non-destructive visualization of NASA's heritage lunar samples. The data products, to be ultimately served via an end-user web interface, will allow researchers and the public to interact with the unique heritage samples, providing a platform to "slice through" a photo-realistic rendering of a sample to analyze both its external visual and internal composition simultaneously.

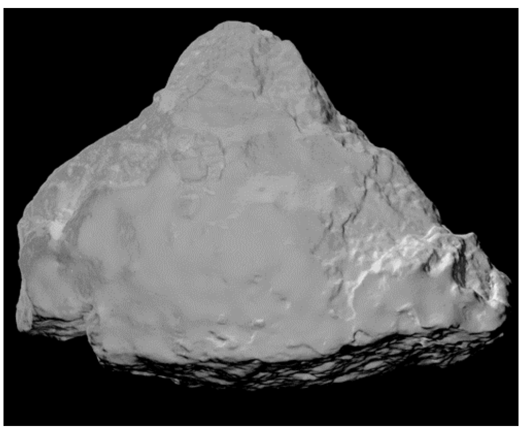
Data & Methods: Our cross-disciplinary team at JSC collected High-Resolution Precision Photography (HRPP) at 15-degree intervals of Apollo Sample 60639 at a resolution of 60 microns using a Nikon D700 digital camera. 194 of the HRPP images (4256 x 2832) were processed using off-the-shelf 3-D SFM software Agisoft PhotoScan [1]. A high-resolution textured polygonal model of Apollo Sample 60639, in a Wavefront OBJ file format with an associated Material Template Library surface shading file, was output from PhotoScan. The textured polygonal model served as a high-fidelity representation of the lunar rock sample structure and its external texture.

XCT data was collected by the Natural History Museum of London, and a total of 1,999 reconstructed image slices of pixel dimensions 1822 (horizontal) by 1349 (vertical) were generated. Volumetric element (voxel) scale data was documented to be 0.043 millimeters. Processing of the reconstructed image slices was performed using FEI Avizo software.

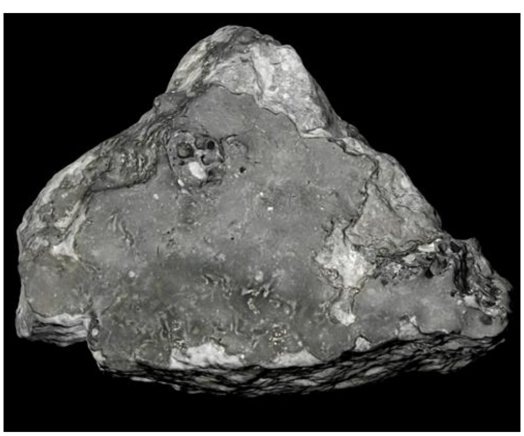
Initially, both internal and external compositional data sets resided in non-coincident coordinate systems. Registration of both data sets, an accurate "fusion" of both external and internal data sets for simultaneous visualization, required transformation of one dataset into the other dataset coordinate system. The process entailed calculation of the six degrees of freedom (6DoF) transformation from the SFM-derived model's coordinate system into the XCT coordinate system. The coordinate system of the XCT data was defined by the reconstructed image slice pixels in the horizontal direction (x), pixels in the vertical direction (y), and the number of slices multiplied by the voxel resolution (z). As the first step towards computing the 6DoF transformation, XCT image slices were processed and an isosurface model, an empty "shell" representation of the sample, was generated within FEI Avizo. Segmentation via intensity thresholding of the XCT image slices was required as part of a process to remove the signature of the plastic bag that housed the lunar sample from the signature of the lunar sample. The lunar sample could not be removed from the plastic bag prior to XCT data collection, a required protocol to ensure preservation of the sample outside of the controlled environment of the Lunar Sample Laboratory Facility at the Johnson Space Center. Once the signature of the plastic bag was removed from each slice in the image stack, an accurate isosurface 3-D model of the rock was computed and exported from Avizo.

The inability to accurately apply scaling was problematic in the creation of the SFM-derived textured polygonal model within PhotoScan. As a result, in absence of an automated method to match the scaling of the SFM PhotoScan model to that of the XCT-derived isosurface model, manual scale adjustments were required to the SFM model in Autodesk 3ds Max. A scaled SFM polygonal model, again in OBJ format, was exported from 3ds Max. Our team's recent improved and updated sample photography and SFM processing methods address accurate model scaling.

The registration of SFM-derived polygonal and XCT-derived isosurface models were performed in InnovMetric PolyWorks®. Within PolyWorks®, a one-point pair fit alignment, followed by a best fit automatic alignment, yielded very good registration results. This process derived and applied the 6DoF transformation of the scaled SFM-derived polygonal model, "fusing" the data to the XCT-derived isosurface model. Correlation of the registered data is analyzed in PolyWorks®. The transformed SFM-derived polygonal model was then exported, in OBJ format, from PolyWorks®. Orthographic XZ plane renders of the textured Apollo Sample 60639 SFM-derived model, now residing in the coordinate system of the reconstructed XCT image stack data, were generated in Autodesk 3ds Max. Within Avizo, XCT image slices can be generated in the same XZ plane.



Orthographic render of the XZ face of Apollo Sample 60639 XCT-derived isosurface model.



Orthographic render of the SFM-derived XZ face of Apollo Sample 60639 after registration to the XCT-derived isosurface model.

Through this data fusion process, we have designed a method to accurately visualize both external texture and internal composition data sets simultaneously.

Results & Discussion: Accurate data fusion of Apollo Sample 60639 XCT and SFM-derived data sets was successful. Comparing a total of 338,582 nearest neighbor data points, registration error of the XCT-derived isosurface model to the SFM-derived high-fidelity textured polygonal model was calculated within InnovMetric PolyWorks® to have a standard deviation of 1.206 millimeters. 78.6% of comparison data points were calculated to reside within one standard deviation. 100% of comparison data points were calculated to reside within four standard deviations (4.8mm). It is projected that the standard deviation registration error will be reduced to well below 1 millimeter after accurate scaling is applied to the SFM-derived polygonal model in the current acquisition of the HRPP.

Table Type	Data Color Map (Reference Surface)
Name	reference surfaces 6
Units	Millimeters
CSYS	world
Data Alignments	N point pairs (2)
Data	KatyModel.obj
Reference	DonModel.obj
Virtual Surface	
Effective Surface(s)	
Max Distance	4.000
Max Angle	45.000
Tol+	0.500
Tol-	-0.500
Direction	Shortest (Ignore)
#Points	338582
Dev Mean	-0.334
StdDev	1.206
Pts within +/-(1 * StdDev)	266281 (78.646%)
Pts within +/-(2 * StdDev)	308092 (90.995%)
Pts within +/-(3 * StdDev)	336085 (99.263%)
Pts within +/-(4 * StdDev)	338582 (100.000%)
Pts within +/-(5 * StdDev)	338582 (100.000%)
Pts within +/-(6 * StdDev)	338582 (100.000%)
Surface Out of Tol	24.264%

Data fusion registration error analysis results

The results allow for a comprehensive visualization of Apollo Sample 60639, to be served on NASA's Astromaterials Acquisition and Curation website: https://curator.jsc.nasa.gov.

References: [1] Blumenfeld E.H. et al. (2015) *LPSC,* Abstract #2740. [2] Meyer, C. (2008) NASA's Lunar Sample Compendium: 60639.