3D MODELING OF THE MICHIGAN TECH HUSKY STATUE USING A CLOSE-RANGE PHOTOGRAMMETRIC APPROACH

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ABSTRACT

In fall of 2014 a three meter tall statue of a Husky was erected on the campus of Michigan Technological University. The Husky is Michigan Tech's mascot and a symbol of the snowy frozen north woods in which the campus is located. The statue was conceived and funded by the universities alumni association and by donors who paid to have bricks engraved around the statue. A team of graduate students in the Integrated Geospatial Technology program came up with the idea of using photogrammetry to model the statue in order to perform accurate measurements of area and volume. This initial idea was taken another step by the need for a course project in close-range photogrammetry and a desire by the alumni association to publish a 3D model of the statue online. This study tests two software packages that can be used to create a photogrammetric model of the statue. A final data set has yet to be collected; however initial attempts have been successful in creating a highly detailed digital model. With the weather clearing and the snow melting work will continue on this project.

Keywords: Close-Range Photogrammetry, MicMac, Photoscan, 3D Imaging, Structure from Motion

1. INTRODUCTION

Close-range Photogrammetry has been used for a number of applications including digital elevation modeling (Fonstad, 2013; Schneider, M., & Klein, R. 2008; Rijsdijk, 2014), architectural modeling (Remondino, 2011; Chiabrando et al., 2014; De Luca et al., 2011; Pierrot-Deseilligny et al., 2011), and modeling archaeological dig sites (Guidi et al., 2009; Lerma et al 2010; Ducke et al., 2011; Verhoeven et al., 2012a; Verhoeven et al.,2012b). In this paper we will compare the results generated from the same data set using two different photogrammetry programs, MicMac and Agisoft Photoscan. MicMac is an open sourced Linux based program while Agisoft is a window's based commercial software.

MicMac, as stated above, is an open source program that relies on a command line based Linux workflow. This program was developed by the French National Institute of Geographic and Forest Information (IGN). MicMac uses three primary steps to generate a 3D model from 2D imagery, The first step being Pastis (Program using Autopano SIFT for the Tie-points in the images) (Pierrot-Deseilligny & Paparoditis 2006), then Apero (Relatively operational Experimental Photogrammetric Aerotriangulation)(Pierrot-Deseilligny & Cléry, 2011) and finally MicMac (Multi Image Matches for Auto Correlation Methods). The algorithms used by the Pastis module, which calculates tie points between overlapping images, include, SIFT (Lowe, 2004; Lingua et al., 2009), SURF, and MSER. The Apero algorithm is used to calculate the internal and external calibrations of the images used in the Pastis operation. Lastly MicMac performs a dense image matching using the calibrations and tie points generated in the first two operations.

The other program used in this paper is Agisoft Photoscan; which is developed by Agisoft LLC in St. Petersburg Russia (www.agisoft.com). The algorithms used in Agisoft are somewhat mysterious due to the commercial propriety of the developers. This highly efficient program takes the steps necessary to create 3D products and bundles them into a very simple workflow and graphic user interface.

The object modeled for this project is the Husky statue recently installed on the campus of Michigan Technological University. The funding for the statue, affectionately called "Balto", was provided by the universities Alumni, Balto is a 3 meter tall bronze statue of Michigan Tech's mascot. The School of Technology was approached by the alumni association to test the validity of creating a model of the statue and displaying that model online so alumni and friends of the school would be able to view the recent addition to campus without needing to travel to Houghton. Another project idea proposed by the School of Technology was to create a Balto fact sheet. This sheet would contain size and volume information in a format relevant to many college age individuals. The primary objective being to find out how much beer could be held inside the statue.

The use of close-range photogrammetry in 3D imaging is a relatively new technique. The concepts used in Structure from Motion (SfM) technology fall back to the roots to traditional photogrammetry and computer vision (Jebara, 1999). The ability to generate topographic maps from stereo imagery is one of the first steps made towards today’s technology. Computers do not see images as humans do, they only knows pixel positions and data values. The introduction of low-cost unmanned aerial vehicles (UAVs) in conjunction with miniaturization of cameras has created a new way for nearly anyone to create 3D models and landscapes. Low-cost methods of archeological surveying have been born from the recent advancements and availability of these tools. Rather than pay the high cost of fueling a plane to fly expensive LiDAR imagery one can deploy a camera autonomously at any time (Westboy, 2012). Recent studies have shown very promising results in regards to the levels of accuracy one can achieve with these methods. Software, camera and UAV technologies are allowing the rapid digital preservation of historical heritage sites around the world.

2. DATA ACQUISITION

Listed below are the relevant technical specifications of the camera used during the stages of image capture for this project. The Panasonic FZ1000 (Table 1) is a high-end SLR-bridge style superzoom fixed lens mirrorless camera. It uses a high-quality one-inch sensor manufactured by Sony and is matched to a Leica designed lens assembly. Panasonic and Leica have been collaborating on projects since August of 2000. The FZ1000 has a particularly impressive lens quality due to its optical system containing 15 elements in 11 groups, including 4 ED lenses and 5 aspherical lenses with 8 aspherical surfaces. This results in a high Modulation Transfer Function value and allows for sharp images with gently defocused backgrounds. Due to the sensor being smaller than the traditional full-frame 35mm size there is a benefit derived from the significant increase in depth-of-focus at equivalent lens aperture values.

Table 1. Panasonic FZ1000 camera parameters

Max resolution:	5472 x 3648	
Effective pixels:	20 megapixels	
Sensor size, type:	1″ (13.2 x 8.8 mm), CMOS	
Pixel pitch (µm):	2.4	
Maximum aperture:	F2.8 - F4.0	
Focal length (equiv.):	25–400 mm	
Focal length (native):	9.12-146 mm	
Focal length multiplier:	2.73	

The recommended technique to obtain photos for close-range photogrammetry and three-dimensional modeling using SfM technology involves capturing large amounts data. It is important to have a high degree of overlap between the images taken. Each of the subsequent photos after the first should contain a majority of the elements from the previous image. Depending on the intricacy of the targets design and texture it is necessary to have images overlap by at least 60%, in many cases much more is needed. All positions and angles in relation to the subject need to be considered for a high quality result (Remondino, 2006). The pattern in which the images are acquired is a key element to the success of final results. It is important to take photos from as many angles and distances as possible. Highly detailed portions of the subject may require more images than others to match points. One could imagine a spherical grid surrounding the subject, similar to the longitude and latitude graticules on a globe. It is good practice to take images in a set pattern around the subject as this aids the software algorithms while processing the images into point clouds (Kersten, 2004).

The Husky statue is over three meters tall and its surface details vary dramatically. To acquire a proper photo set special care was taken in planning the data collection. Because Balto is constructed from bronze, light levels were a consideration to prevent troublesome glare and lens flare. With this in mind the image acquisition was performed on an evenly overcast day. Acquiring the photo set around solar noon is advisable to ensure the light diffused through the cloud cover is coming from above the statue (Chiuso, 2002). Due to the large size of the subject it was found that use of an extendable monopod was advantageous when attempting to take photos from the higher and lower height levels. The FZ1000 has a fully-articulating LCD screen which allows a good view of the frame to be taken at any angle. Utilizing the remote trigger function on the camera with a wireless remote let us take photos without ever having to touch the camera. This not only sped up the whole process, but also limited potential movement caused by regularly having to move the camera back and forth to push buttons in order to set the timer, focus, and shutter. Figure 1 shows a sampling of images in the dataset.

Figure 1. Eight consecutive images acquired around the statue

3. DATA PROCESSING

3.1 MicMac

MicMac was developed by the MATIS laboratory (IGN France) that since 2007 has been an open source product that can be used for extracting point clouds from images in different contexts (satellite, aerial and close-range applications). The main difference of MicMac from other open source software developed within the Computer Vision community like Bundler-PMVS (Furukawa and Ponce, 2010) or Samantha (Gherardi et al, 2011) is the introduction of photogrammetric rigidity in the equations (according to a traditional bundle block adjustment approach). Moreover MicMac uses several camera calibration models (starting from radial standard up to polynomial) and is better suited to modeling Balto.

The first step of using MicMac according to the traditional steps of the photogrammetric data processing pipeline consists of the automatic tie point extraction. After the tie point extraction the bundle adjustment (relative orientation) and the camera interior parameters are computed, then a dense image matching for surface reconstruction is realized and finally the orthoimages could be generated. In the first step when tie points (TPs) are computed from all pairs of images; the TPs computation uses a modified version of the SIFT++ implementation (Vedaldi, 2007; Vedaldi 2011) of SIFT algorithm (Lowe, D.G., 2004) that is able to work with large images (Pierrot-Deseilligny, M., Cléry, I., 2011). SIFT generally gives excellent results when the images are taken with correct acquisition geometry and an overlap of about 80%. Even with the challenges of Balto's reflective surface, complex shape, and areas of shadow, the reliability of the algorithm was confirmed by our test. A multi-scale and multi-resolution approach was followed for image acquisition starting from a large circle around Balto (6 meters from the statue) up to a very close range approach (~1 meters). The approximate acquisition step of each pose was 5°.

After the bundle block computation (relative or absolute), the main step of the pipeline is the multi-image matching. The software is based on a multi-scale, multi-resolution, pyramidal approach, with the employment of an energy minimization function that uses a pyramidal processing. In the workflow, each pyramid level guides the matching at the next, higher resolution level in order to improve the quality of the matching. Several parameters could be managed in the software at each step: the optimization algorithm, the regularization parameters, the dilatation parameters, the subset of images, the post filtering on depth method, the size of the correlation window and the regularization resolution. Once the computation is performed the 3D point cloud is derived with the extraction of the depth value from the depth image (the result of the dense matching) and at each point a colored (RGB) value is assigned (derived from the oriented original images). Finally, thanks to the big amount of 3D information derived from the point cloud the 3D models, the orthophotos and other products could be achieved. In the second week of April 2015 some new tools became available (under development) that allow MicMac to realize the mesh (*TiPunch*) and texture it (*Tequila*).

The first step of the MicMac workflow (TPs extraction) is typically the most time consuming, in order to speed up this process a multiscale approach was used. First of all the points were extracted from 500 pixels of each image (MicMac resamples the image at the desired resolution), afterwards using only image pairs that have more than 10 common points (this setting is assigned using a specific command: *NbMinPoint*) the new TPs computation was performed using 3000 pixels. The following Figure 2 shows an image set with the extracted TPs.

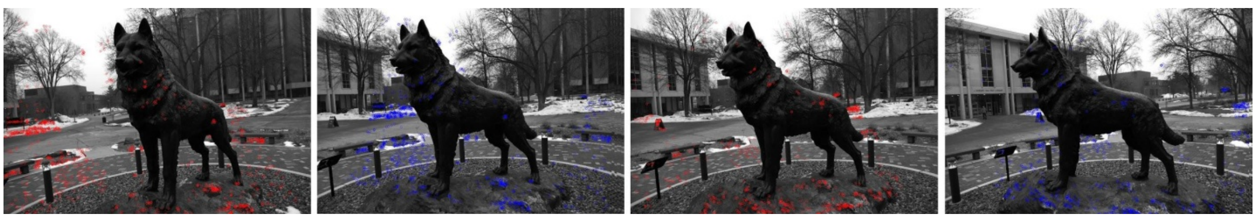

Figure 2. Extracted TPs for two pairs of images (the second and third image are the same)

Visible in Figure 2 only a few points were computed, this is clearly attributable to the characteristics of the statue itself (reflective surface and shadow). Using this result, the next relative orientation and interior calibration were performed using the next step. First of all, only a subset of the data-set was employed for the camera calibration: in this case 15 images were used for camera calibration and the first relative orientation. For the interior calibration the Radial Standard model was used. This model calculates the focal length, the principal point position and the radial distortion parameters K_1, K_2, K_3 (Brown 1971) of the images. The parameters of this calibration were then applied to all of the other images in order to define their final relative orientation. In Figure 3 some views of the final sparse cloud are shown (132 oriented poses).

This first stage of the project was achieved using a relative orientation approach; the oriented model was scaled according to a measured distance between the two front dewclaws of Balto in order to give an approximate dimension to the final point cloud. An accurate Total Station survey will be used in order correctly scale and reference the statue in the final model. Using the relative orientation parameters and scale factor, the image matching was performed as a last step. In this case the *GeomImage* command of MicMac was employed. Using this command the user selects a set of master images for the correlation procedure; then for each candidate 3D point a patch in the master image is identified and projected to all the neighboring images, and a global similarity is derived. Finally using the multi-scale approach the point clouds are calculated (Figure 4).

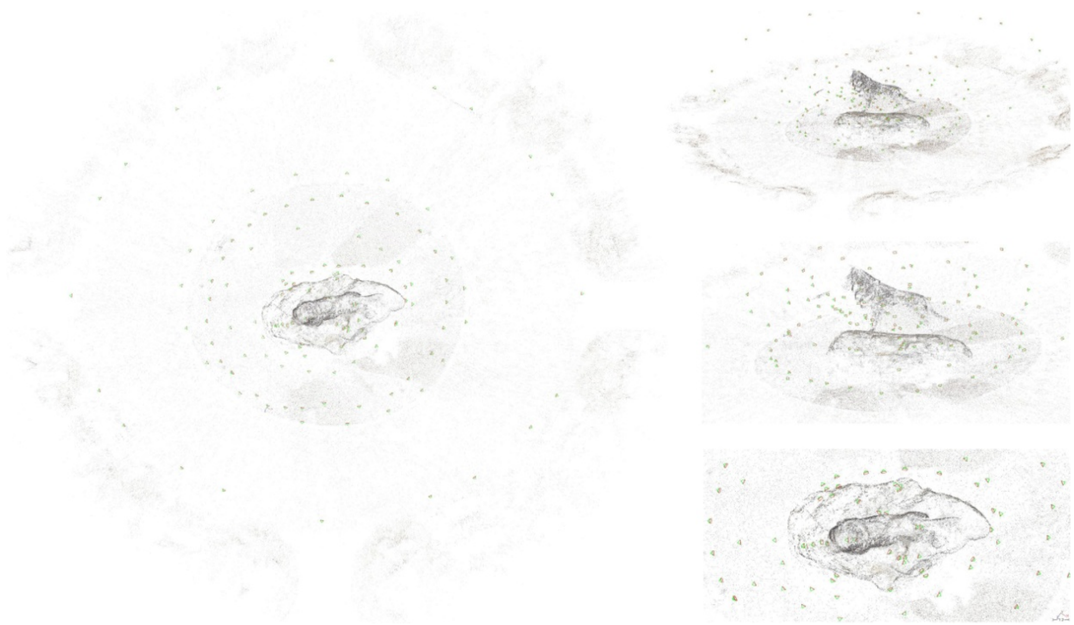

Figure 3. Some views of the obtained sparse point cloud (132 oriented images).

Figure 4. The multi resolution MicMac matching approach

After the matching process that was performed using 20 master images the point clouds could be assembled separately or merged directly in MicMac. In our case in order to check the results the point clouds were inserted in Meshlab (Cignoni et al., 2008; Callieri et al., 2011); a well-known open source software that is able to manage and process point clouds for editing and modeling purposes. The results of the computation in MicMac using 20 master images is a final point cloud with 17,547,573 colored points that could be employed for 3D modeling generation, section extraction etc (Figure 5).

Figure 5. Three views of the final point cloud of Balto achieved using MicMac

The final point cloud needs to be processed in order to realize a mesh or other products. In MicMac the tools for meshing first appeared in version rev. 911, then were removed and reappear in the latest release rev. 5348. In this latest version the commands are available for the user to generate a mesh and texture it as well. The employed algorithm is based on the well-known Poisson algorithm (Kazhdan et al., 2006; Bolito et al., 2009); the textured approach computes a UV texture image from a ply file, a set of images and their orientations. The tool works by choosing which image is best for each triangle of the mesh and can be done using two different criteria: best angle between triangle normal and image viewing direction or best stretching of triangle projection in image. Since this tool was just released only a first test was performed (Figure 6). Moreover at this stage in order to obtain a final 3D model the open source software Meshlab was employed. In the following Figure 7 some views of the generated mesh are shown.

Figure 6. Two views of the Balto shaded mesh and texture realized in MicMac

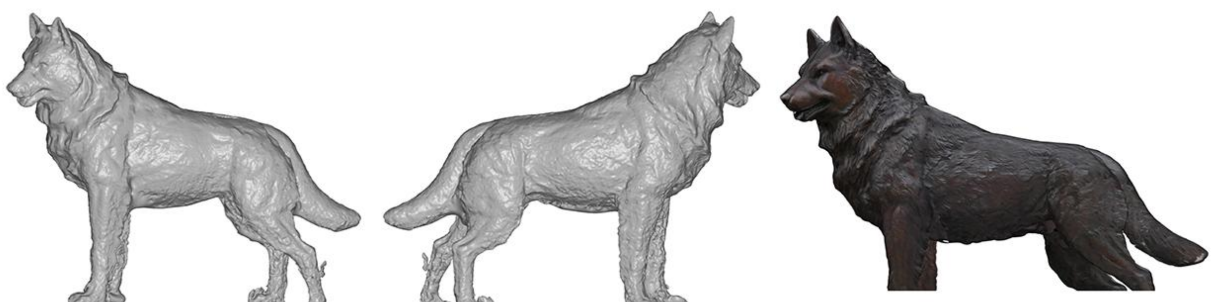

Figure 7. Two views of the Balto shaded mesh and a textured mesh realized in meshlab

Some small problems were observed using MicMac to process the Balto data set. The calibration and relative orientation were performed in different steps: first, only a small set of images were oriented then, all the other images were oriented. At this stage several attempts were made to define the final orientation (some acquired images needed to be discarded). According to the previous approach of MicMac the orientation was computed step by step; the new command *C3DC* allows the user to automatically orient all of the images was tested but not used since the first orientation failed. The matching was performed as well in different steps (again with the "old approach") in order to obtain the maximum detail in all parts of the statue (20 subsets were processed and the connected point clouds were realized). Finally the point cloud merging required a lot of editing, especially on the border of the statue (where the matching delivered a blunder or wrong points, Figure 8).

Figure 8. Blunder or wrong points in the achieved point clouds (red circle)

After removing the false points with a complete manual editing it is possible to state that the final point cloud is totally comparable with the one realized by Photoscan; all the afore mentioned aspects are closely related to the open approach of MicMac where each step is controlled by the user and the automation is reduced.

3.2. AGISOFT PHOTOSCAN

Agisoft Photoscan (www.agisoft.com) provides a very simple workflow for photogrammetric applications. As mentioned previously the mechanics of the software are proprietary, therefore it is impossible to discuss the algorithms used. However Agisoft is a very useful tool for all manner of photogrammetric applications from close-range structural and object modeling to DEM generation from aerial images. In order to use Agisoft it is necessary to obtain a license, the cost of which makes it accessible for commercial use instead of personal or private use.

The first step for processing a data set in Agisoft is to acquire the data. As mentioned above the data set used contained 142 images with at least 80% overlap. Each image was taken in a circular fashion around the statue of Balto approximately every 5 degrees. Once this dataset is loaded into the program an alignment of the photos is performed. Unlike MicMac it is not necessary to resample the images for alignment. This alignment finds matching pixels in each image and performs the exterior orientation of the images and creates a sparse point cloud (Figure 9). Agisoft uses the exif data attached to the image files in order to perform the interior orientation of the images, it is also possible to use the companion program Agisoft Lens to calibrate (principal point, K_1, K_2, K_3 etc.) the camera used for the image acquisition.

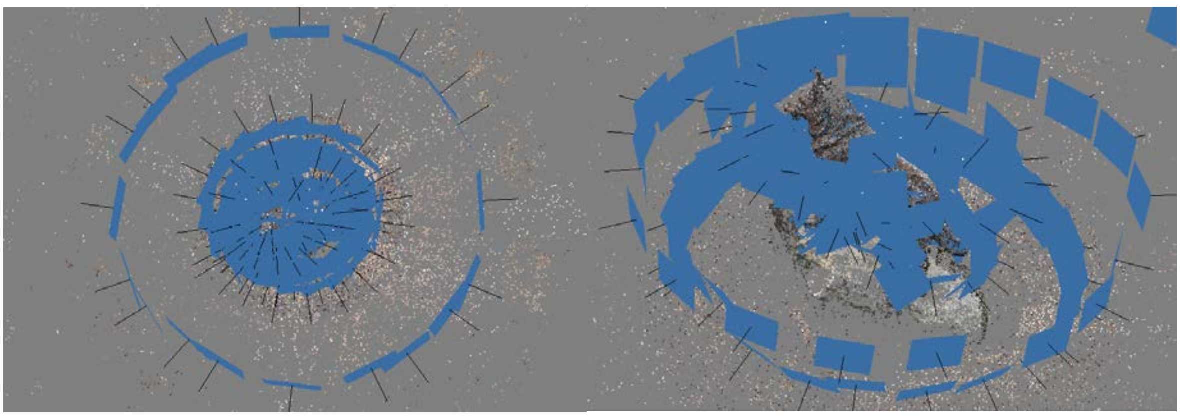

Figure 9. These images show the sparse point cloud and computed camera orientations

Once the images are aligned it is then necessary to import the Ground Control Points (GCPs), if available. These points can be imported from a text file and a reference system for the project can be set (Local, State Plane, WGS84, etc.). The GCPs are then labeled and positioned in each image (automatically with some supervision) and an absolute orientation of the sparse point cloud can be computed (in this part of the project the GCPs were not used, the model was scaled with a measured distance).

The next step in processing is the development of the dense point cloud. This is the most time consuming step of the whole process. It is here that all of the prior calculations are used to create a dense 3D point cloud. A number of options are available for the dense cloud generation, critically resolution. The resolutions range from medium to ultra-high. On most desktops it is possible to process dense clouds at medium resolution ($1/16^{th}$ of pixels in each image or every 4 pixels on each side) in a reasonable amount of time. Long processing times occur when high (1/4 of pixels in each image every other pixel on each side) or ultra-high (raw images) resolutions are selected. The amount of time needed to complete this step is of course dependent on the processing power of the computer being used. If super high detail and accurate geometry are desired in the model it will be necessary to process the data set at higher resolutions.

For the purposes of this particular project it was then necessary to build a mesh of the dense achieved point cloud (Figure 10). This simply requires the selection of the “Build Mesh” option in the workflow menu of Agisoft.

This command brings up options for the surface type and surface count. An arbitrary surface type was used for this project because it is more appropriate for purposes of close-range photogrammetry.

Figure 10. Dense cloud images. Left is result of needing more images. Right is whole scene.

The other option (Height Field) is useful for planar surfaces or aerial photos. The 3D model generated using the dense point cloud consists of 292,522 faces (Figure 11). The texture mapping is the result of a 12 count 4096 pixel size processing option. The next section discusses the results of the data processing in Agisoft and MicMac.

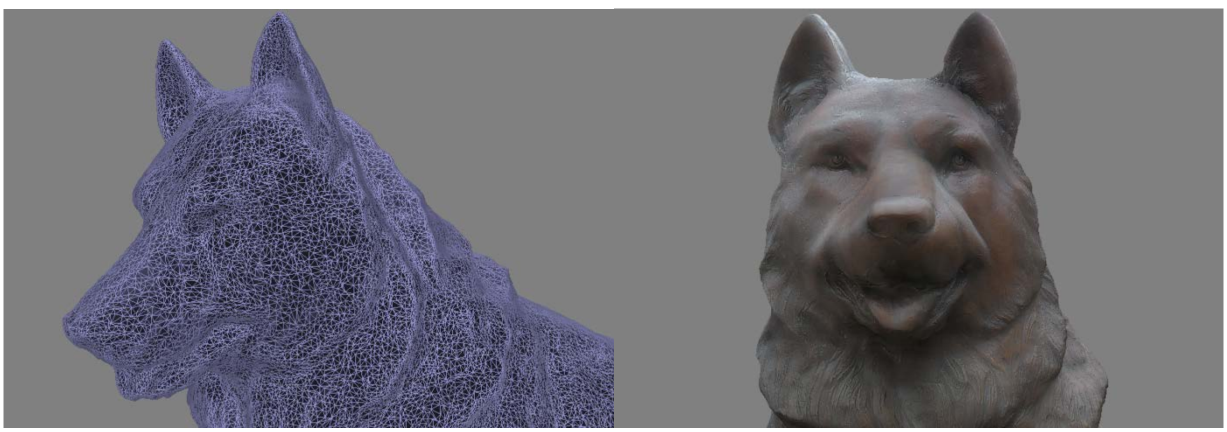

Figure 11. Left image shows the 3D mesh and the right is the mesh textured with imagery.

4. COMPARISONS

In order to compare the two data sets it is necessary to first discuss the differences in processing. It is clearly known that Agisoft Photoscan is flexible, simple and very efficient software and in this case all the good characteristics of the software were confirmed. After the data acquisition the images were inserted and processed without any problem starting from the TPs extraction up to the textured mesh realization. The workflow was followed using the high settings (extraction of a point for every other pixel in the dense matching process) and the final results were delivered after 240 hours of totally automatic process (no masks were set-up in order to help the limit the computation, therefore the whole scene was processed locally on a desktop computer with 8GB of RAM and a CORE i7 processor). As a result a dense cloud of 32.5 million points was generated, from this 1,463,112 points on the statue were extracted and a complete mesh was achieved.

Comparatively, using MicMac as reported above requires a great deal of interaction between the tool and the operator. After the automatic TPs extraction the most important step in MicMac is the image orientation. Due to the difficulties presented by the material and shape of Balto 15 images were selected to perform the interior and relative orientation. The reason images needed to be specified is that MicMac is unable to automatically reject a poor quality or unusable image. This makes MicMac better suited to carrying out a controlled processing. The parameters generated from the original 15 images are then used to find the orientation of the remainder of the images. Therefore the matching that was performed by Photoscan in one step takes two steps in MicMac. A new command in MicMac, *C3CD*, automatically creates point clouds and meshes from a realized 3D mask. Since this new command was only just added the masking operation in the case of Balto was carried out manually in order to following the traditional approach and to prevent the program from processing unwanted points and speed up the next matching step (20 masks were realized starting from 20 master images) (Figure12). With the masks in place the next step was performed using only a subset of the total oriented images (selected manually as well). All of this manual operation allows the algorithm to deliver a dense cloud in 10 minutes with a point extracted from each pixel (instead of every other pixel in Agisoft). The 20 realized point clouds were assembled in a final cloud of 17,547,573 points.

With the above information in mind it is possible to state that the matching computation using MicMac is much faster than it is in Photoscan, but since repeated manual operations are needed to process the data, an expert user is needed to deploy MicMac. Therefore MicMac is more labor intensive but less computationally expensive, even more so because its Linux base is commonly found on supercomputers.

Figure 12. The achieved mask in MicMac (left) and the original image (right)

In order to compare the resulting dense point clouds the 3D models were scaled using the measured distance between the front dewclaws (0.366 m) and processed using CloudCompare (Girardeau-Montaut, 2011) in order to extract some measurements (Figure 13).

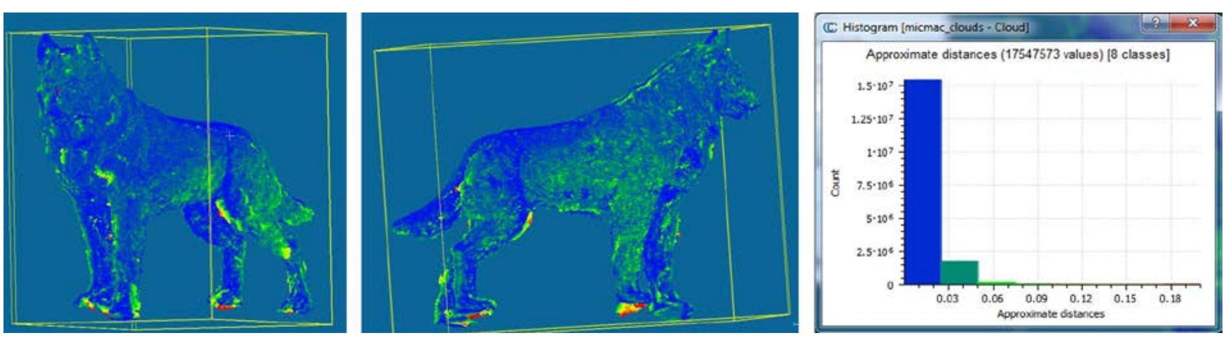

Figure 13. Comparison between the achieved point clouds (left and center), graph of the discrepancy between the computed points (right).

According to the achieved results the point clouds are very similar (the MicMac cloud is more dense) and the average discrepancy between the two clouds is approximately 5 mm (σ = 19.366 mm). Naturally this is only a relative comparison; a more thorough accuracy check will be performed once the Total Station survey is available. A check on the 3D model confirms more or less the same discrepancy obtained from the clouds (average distance close to 6 mm and σ = 23.460 mm).

5. CONCLUSION AND FUTURE WORK

This study has done an excellent job confirming that photogrammetry is still very much alive and well. In recent years other technologies, such as LiDAR, have attempted to exceed photogrammetry. With recent advances in software algorithms for processing photogrammetric data, the affordability of photogrammetric equipment and the ease of use of the programs used to process images photogrammetry is still a very relevant technology. Photogrammetry was once ruled by highly calibrated cameras and very specialized processing equipment; however both software suites presented in this paper make accurate 3D representations without the need for specialized equipment. MicMac works well for the skilled user who would like to be able to tweak the settings for data processing. The Linux interface is also useful for massive projects because it is relatively simple to find a computer with the muscle to process the large amounts of input data. The biggest positive MicMac has however is the fact that it is open source and constantly being improved. On the other hand Agisoft Photoscan provides users with an easy to navigate user interface. Being a commercial program also has its benefits, user support is available through Agisoft and all issues with the program can be resolved through frequent updates. Both products provide a quality result; depending on the needs and resources of the user both programs should be considered. We like MicMac because it allows for customized processing and it is open source.

This study has been a preliminary assessment of the use of photogrammetry for 3D modeling of Balto. Another data set will be collected shortly and processed using lessons learned from the processing of this first set. A total station survey has already been performed on the Husky plaza so the next data set will contain GCPs for accurate measurements and referencing of the model. Also to be tested with the next set of data are the new tools in MicMac: *C3DC*, *TiPunch*, *Liquor* and *Tequila*. We also plan to compare the final model from this new data with a LiDAR survey completed by some of the surveying students at Michigan Tech. We also seek to study a method for displaying the model online in sufficient detail to read the paver bricks with the names and messages of the donors who funded the statue and the plaza it sits in.

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