Manual Point Cloud Classification and Extraction for Hunter-Gatherer Feature Investigation: A Test Case From Two Low Arctic Paleo-Inuit Sites

Abstract: For archaeologists, the task of processing large terrestrial laser scanning (TLS)-derived point cloud data can be difficult, particularly when focusing on acquiring analytical and interpretive outcomes from the data. Using our TLS lidar data collected in 2013 from two compositionally different, low Arctic multi-component hunter-gatherer sites (LdFa-1 and LeDx-42), we demonstrate how a manual point cloud classification approach with open source software can be used to extract natural and archaeological features from a site's surface. Through a combination of spectral datasets typical to TLS (i.e., intensity and RGB values), archaeologists can enhance the visual and analytical representation of archaeological hunter-gatherer site surfaces. Our approach classifies low visibility Arctic site point clouds into independent segments, each representing a different surface material found on the site. With the segmented dataset, we extract only the surface boulders to create an alternate characterization of the site’s prominent features and their surroundings. Using surface point clouds from Paleo-Inuit sites allows us to demonstrate the value of this approach within hunter-gatherer research as our results illustrate an effective use of large TLS datasets for extracting and improving our analytical capabilities for low relief site features.

Keywords: terrestrial laser scanning; digital archaeology; hunter-gatherer archaeology; Paleo-Inuit; Southern Baffin Island; Nunavut; point cloud classification

1 Introduction

The application of three-dimensional (3D) terrestrial laser scanning (TLS) in archaeological research has benefited from the fast-paced technological developments increasing both the resolution and scale of data, along with changing modern field survey methodologies (i.e., static, mobile, and/or drone scanners). As the application of TLS and collection of point cloud datasets continues to increase (e.g., Lerma et al. 2010; Huimin et al. 2012; Dawson et al. 2013; Romero and Bray 2014; Larsen et al. in press), critical attention is...
shifting towards the development of complementary analytical and interpretive processes (Huggett 2015: 80; Watterson 2015: 120). Even though techniques used for presenting point cloud datasets produce visually impressive results, they are entirely outpacing those used for data processing and analysis in archaeological research. While a small number of recent studies have successfully demonstrated the value of point cloud data processing and analysis on high relief archaeological sites and features (e.g., Schreiber et al. 2012: 16-17; Romero and Bray 2014: 30-34; Larsen et al. in press: 6-7), along with smaller-targeted prehistoric rock-art sites (Rüther et al. 2009: 1853-1854; Güth 2012: 3110-3113), the investigation of the low relief features common to prehistoric hunter-gatherer sites using TLS-derived datasets has remained limited, with the exception of Hakonen et al.’s (2015: 232-233) recent study of Finish stone cairn sites. As such, we present a simple open-source manual point cloud classification approach for convenient surface feature extraction from two low Arctic multi-component site datasets: LdFa-1 and LeDx-42 (Figure 1). These point clouds were acquired in 2013 using a Leica C10 ScanStation terrestrial light and detection ranging (lidar) laser scanner.

Complex automated TLS point cloud classification systems have been developed by engineers, geoscientists, and environmental scientists to analyse specific elements in large point clouds of both urban and rural landscapes (e.g., Brodu and Lague 2012; Niemeyer et al. 2012; Buckley et al. 2013 etc.). The CANUPO classification system developed by Brodu and Lague (2012: 13-15), for example, uses a complex algorithm to define classes based on the geometry of objects in a point cloud at multiple scales. It is a useful and accessible tool for defining different materials in heterogeneous environments; however, we have found that for identifying low relief hunter-gatherer archaeological features in an Arctic environment, where only slight changes in the material makeup and colour are of primary importance, an alternative manual point cloud classification approach is beneficial for both quick in-field and more involved laboratory investigations. Depending on the type of laser scanner in use, the collected TLS data that can be used for this include X, Y, Z Cartesian coordinates, 8 or 16 bit RGB colour pixel data, and pseudo-infrared intensity values (Abbas et al. 2014: 116). This digital approach provides archaeologists with control over an analytical tool aimed at investigating the layout, orientation, and distribution of surface elements and their surrounding objects in a low Arctic environment.

Figure 1: Archaeological sites LdFa-1 and LeDx-42 situated on a Google Earth landsat image with southern Baffin Island inset. Sites are located near lakes Mingo and Amadjuak, southern Baffin Island, NU.
Low Arctic sites in North America (i.e., those lying south of the Parry Channel) present some unique challenges in terms of surface survey because wetlands, hummocky terrain, and thick vegetation obstruct archaeological surface remains, while annual freeze-thaw cycles can act to displace or destroy them entirely (Milne 2003: 67-68). Additionally, in sites occupied for millennia, the low relief surface structures were sometimes cannibalized for building materials by subsequent groups camping in the same locations, leaving the original surface features in disarray (Bielawski 1988; Milne 2003). Our manual point cloud classification approach uses a ground point classifier from LAStools to first separate ground points from non-ground points. Commonly functioning as a bare-earth process in airborne lidar processing, we use this tool to separate our TLS dataset into two data groups: low-lying features (e.g., grass, snow) and taller surface features (e.g., boulders, tall grasses, etc.). Then, using a combination of two spectral data value ranges – intensity and red/green/blue (RGB) pixel data – we isolate the location of each material on the surface within the point clouds. The results are then used to map individual surface materials, fingerprint each by their spectral value ranges, extract them from their original point clouds, and finally demonstrate how this approach improves the analytical capacity – in and out of the field – of large 3D digital datasets representing low relief surface structures in Arctic hunter-gatherer contexts.

2 Study Sites and Methods

2.1 LdFa-1 and LeDx-42

LdFa-1 is a large, multi-component site with evidence of Pre-Dorset (2250-800 BC), Dorset (800 BC-1200 AD) and Thule/Inuit (1200-1500 AD) cultural occupations, located in the interior of southern Baffin Island. The site is situated at the base of the Mingo Lake esker (Milne 2005; Milne 2008; Milne 2013; Park 2008) and was first recorded in 1991 by Stenton with subsequent investigations by Milne (2005, 2008, 2013) and Park (2008). Stone tent rings – boulder rock formations used to hold down the edges of ancient skin tents – represent an important surface feature for locating and investigating Arctic archaeological sites. There are at least 33 visible tent ring features at LdFa-1 (Park 2008). Other visible surface remains include stone caches used for meat storage, and widespread scatters of lithic artifacts and faunal remains. Archaeogeophysical surveying has been conducted in a section of the site to locate potential sub-surface remains and with the eventual aim to investigate the combined surface and sub-surface spatial datasets (Landry et al. 2015). TLS data were acquired at LdFa-1 in 2013, during our first field tests of the instrument in the Arctic. The point cloud registration at LdFa-1 derives from three station scanning positions around the site. For the purpose of this paper, only a small section of the point cloud measuring approximately 30 m x 10 m was selected given the level of detail and accuracy of the point cloud registration.

LeDx-42 is a smaller archaeological site both in terms of its areal extent and its total number of surface features. It too is multi-component, having been occupied by the Pre-Dorset and Dorset (Milne et al. 2012, Milne 2013) – who together are referred to archaeologically as Paleo-Inuit (see Friesen 2015). LeDx-42 is located on a bedrock outcrop that looks out over the Mingo River. The landscape surrounding the site is characterized as flat, hummocky tundra. Unlike LdFa-1, LeDx-42 has no visible tent ring features yet the site was identified originally because of the extensive scatters of lithic tools and debitage, and fragmented faunal remains (Milne 2005). Widespread test excavations at the site yielded dozens of diagnostic Pre-Dorset and Dorset stone tools, and delicate organic remains including bone needles (Milne 2005; Milne et al. 2013). This site was also scanned during the 2013 field season. Two lidar stations were used to register the central portion of this site. Our novice use of the equipment is demonstrated in the data by the lack of overlap on the station platforms, resulting in circular shaped gaps in the data. The point cloud included in this study derives from an area measuring 45 m x 25 m.

The Arctic tundra characterising these sites is made up of a combination of thick low-lying and medium-height vegetation including grasses, small Arctic flowers, and areas of high vegetation and shrubbery. The natural surface can exhibit large patches of gravel, snow, melt ponds, exposed stone outcrops, and small and large stone boulders. LdFa-1 and LeDx-42 represent two archaeological sites with compositionally
different surfaces, illustrating a small portion of the heterogeneity exhibited among Arctic archaeological landscapes across this region. Their differences are highlighted by their density of surface boulders, vegetation growth, nearby water, snow cover, and even lichen growth that can obscure materials found on the surface making the identification of colour ranges as part of our approach more difficult.

### 2.2 Parameter Values

Intensity and RGB pixel data are used to create the classification parameters in this process. Unaccompanied, neither value provides enough detailed information about each surface material to accurately identify it within the point cloud. Intensity has been defined by Song et al. (2002: 259) as the ratio of strength of reflected light from a material to that of the emitted light of the laser. In theory, reflective materials should have a known value to represent this ratio; however, several natural factors influence the reflectance value of every material, including the surface roughness, the angle of incidence, the transit length, and the aggregate laser optics and receiver characteristics, among others (Reyes et al. 2009: 16). These factors are problematic in almost all natural environments as the materials in question are not uniform and, therefore, cause a greater range of intensity value fluctuations across a completed point cloud. The process to correct and normalize intensity data continues to be a highly active area of technical research (see Humair et al. 2015) that we do not intend to discuss in this paper. For the purposes of our simplified procedure and tests, we decided to account for fluctuations by using a wide intensity range for each material and combining it with a complementary RGB range to refine the classification outcome.

The second parameter value used in this test is 8-bit RGB pixel data. These values represent the colour combination in red, green, and blue, of each individual pixel that make up the digital image within the point cloud. By using RGB values we identify a range of colour classes most likely to fall within the material in question (e.g., Snow: R=205-255, G=250-255 B=225-255). Using RGB values alone has its limitations as changes in the daily sky conditions can cause shadowing and shifts in the spectral colours captured by the scanner’s digital camera. However, using visible colours to match materials is beneficial for refining a heterogeneous surface, including some of those found in these low Arctic environments. A combination of the intensity and RGB datasets is a simple and effective way to create a range of values for each surface material at these sites to define a classification outcome.

### 2.3 Processing Sequence

This processing sequence is modeled after several urban and rural area classification systems (Brodu and Lague 2012; Bandyopadhyay et al. 2013; Penasa et al. 2014). Our lidar site scans were originally stored as .PTS format files exported from Cyclone software. They were combined using a static target-based system (Abbas et al. 2014: 117), registering millions of points and 360-degree digital images to create a full 3D representation of the two separate sites. The following procedures were conducted using open-source software available for educational purposes, with a focus on non-technical, user-friendly methods.

In LAStools – a well-designed, active, and frequently updated software created by Martin Isenburg (2015) with a simple operating graphical user interface (GUI) – we were able to convert, manipulate, and filter the large point cloud datasets. The software has a two part license (part one OPEN source, part two CLOSED source), but remains ‘freely’ available to use for educational purposes, which is integral for our applications in this study. Almost all processing was conducted using its automated GUI tools. Manual script amendments are also made using this software to filter changes in the parameter values at each archaeological site. This software is designed to conveniently convert the large point cloud data file formats into the more openly accessible and compact .LAS/.LAZ formats. The conversion process is conducted in the software’s txt2las.exe GUI and included the translation of the intensity data to 16 bit and a rescaling of the X, Y, Z coordinates to 0.001 m. The manually edited script for this step is shown here:

```
txt2las -v -i “input.txt” –skip 1 –parse xyziRGB –translate_intensity 2048 –rescale 0.001 0.001 0.001 –odir “output”.olas
```
Following this step, the quantity of points in the dataset is reduced to 1.5 million using a random point remover while duplicate points caused by combining multiple scans were removed from the point cloud files to increase the efficiency during the processing stages within this software.

Next, the software suite is used to create a preliminary ground classification for objects that lay above the natural ground surface (>0.02 m at LdFa-1 and >0.05 m at LeDx-42) based on an automated point sampling algorithm in the software suite. Using the existing script in lasground_new.exe, we classify the “ground surface” and additionally classify all objects above them as “not ground.” Following the point separation between “ground” and “not ground,” we identify the parameter values for each separate material we wanted to classify. This is done using CloudCompare software (2015).

CloudCompare is another open-source program easily accessible to archaeologists learning to work with and process point cloud data. This software is used to manually sample data from the surface materials (e.g. stones, grass, water, outcrops etc.) we want to classify. Approximately 30 points are picked at random from each material. A range MAX/MIN of intensity and RGB is established and used to create the filtering parameters for each (Table 1). These parameters are then extracted out of the point cloud using the las2las.exe GUI in the LAStools software suite, and saved as individual files. The final script and amendments are shown below:

```
las2las -v -i "input.las" --drop_intensity_below ### --drop_intensity_above ### -keep_RGB_red ### ### -keep_RGB_green ### ### -keep_RGB_blue ### ### -olas
```

All subsequent processing is completed in CloudCompare, including a spatial outlier reduction process we use to clean and remove outlying points from the newly segmented files, and reduce noise and isolated points. This step is important for removing single data points from the cloud that fall within the same parameter range as for instance, stone boulders, yet do not specifically represent a common material type. The complete step-by-step process is outlined in Figure 2.

![Figure 2: Step-by-step classification sequence from original point cloud dataset to the individually classified elements, using open source LAStools and CloudCompare software.](image-url)
Table 1: Parameters and ranges used to fingerprint and define each surface material from LdFa-1 and LeDx-42. A combination of the four parameters can identify and isolate each material from the original point clouds.

<table>
<thead>
<tr>
<th></th>
<th>Water*</th>
<th>Snow</th>
<th>Gravel</th>
<th>Stone Boulders – Above Ground Points</th>
<th>Exposed Outcrop*</th>
<th>Low Vegetation – Above Ground Points</th>
<th>Medium Vegetation – Above Ground Points</th>
<th>High Vegetation – Above Ground Points</th>
</tr>
</thead>
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<tr>
<td>LdFa-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>500-700</td>
<td>878-978</td>
<td>1029-1462</td>
<td>716-943</td>
<td>714-920</td>
<td>737-920</td>
<td>503-699</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>69-95</td>
<td>250-255</td>
<td>177-255</td>
<td>155-255</td>
<td>69-95</td>
<td>75-130</td>
<td>80-188</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>71-120</td>
<td>250-255</td>
<td>170-255</td>
<td>155-255</td>
<td>55-130</td>
<td>55-130</td>
<td>55-130</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>65-120</td>
<td>225-255</td>
<td>166-215</td>
<td>120-255</td>
<td>31-100</td>
<td>31-100</td>
<td>31-100</td>
<td></td>
</tr>
<tr>
<td>LeDx-42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>878-978</td>
<td>819-1107</td>
<td>730-945</td>
<td>500-636</td>
<td>714-920</td>
<td>711-1015</td>
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<tr>
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<td>160-255</td>
<td>100-255</td>
<td>40-93</td>
<td>69-95</td>
<td>69-97</td>
<td>88-135</td>
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<tr>
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<td>250-255</td>
<td>167-255</td>
<td>95-255</td>
<td>56-142</td>
<td>55-130</td>
<td>44-132</td>
<td>53-134</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>225-255</td>
<td>190-220</td>
<td>70-252</td>
<td>40-106</td>
<td>31-100</td>
<td>29-109</td>
<td>40-106</td>
<td></td>
</tr>
</tbody>
</table>

*Element appears in only 1 of the 2 study sites

3 Results

Using this classification approach, eight different material classes commonly found across Arctic hunter-gatherer sites have been successfully fingerprinted, and segmented from their original point cloud. These classifications, especially the stone boulders class, are used to map potential features in the site point clouds, and investigate them along with any associated objects in their nearby surroundings. LdFa-1 was successfully classified into: Water; Snow; Gravel; Stone Boulders; Low Vegetation; Medium Vegetation; and High Vegetation. LeDx-42 was successfully classified into: Snow; Gravel; Stone Boulders; Exposed Outcrop; Low Vegetation; Medium Vegetation; and High Vegetation. Figure 3 illustrates the site point clouds in their original forms and the finalized classification of surface materials. Each surface material in these files can be individually extracted, or alternatively, combined so that two or three layers can be represented at the same time while removing overlying objects or materials. At LdFa-1, water and snow were easily identified and classified in the point cloud. Gravel was primarily located near the edges of the point cloud dataset. The stone boulders segment was extracted from the point cloud and layered on top of a contour map of the surface area to illuminate any features. Figure 4 highlights some of the obvious stone features located on the surface of the site, while also providing a detailed map of all stone boulder placements and distributions of all shapes and sizes. The dense stone boulder area shown on the map was initially obstructed by a mix of medium and high vegetation and grasses on the site, while in other areas the boulders had begun to sink into the surrounding hummocky soils adjacent to the water.

LeDx-42 had less medium and high vegetation growth on the surface, but did exhibit exposed stone outcrops and numerous patches of gravel near the previous unit excavations. In comparison to LdFa-1, the visibility of stone features is low even when stone boulders were extracted and layered onto a contour map (Figure 5). The classification and extraction process was successful, yet due to lichen growth on the surfaces of the boulders, a slightly wider range of intensity and colour values was used. The file segment shows a wide distribution of surface boulders in this area of the site. While many of the stones are small in size (<0.30 m) and isolated from each other, some larger surface scatters are visible and may prove useful for further investigation. There was no water in this point cloud of LeDx-42, yet small patches of snow remained on the surface of the site.
Figure 3: Bottom: Original colour point clouds of LdFa-1 and LeDx-42. Top: Colour classified point clouds using our processing sequence. Colours correspond to the following materials: Blue – Water/Snow; Light Green – Low-vegetation; Dark Green – Medium-vegetation; Red – High-vegetation; Grey – Gravel; Orange – Exposed Outcrop; Yellow – Stone Boulders. Note that the scanner positioning in LeDx-42 caused the shadowed areas in the point clouds.

Figure 4: Top: Original point cloud sample from LdFa-1. Bottom: Extracted stone boulders from the point cloud and layered on top of a surface contour map. Arrows indicating the location of stone tent rings near the right side of the map. Scale is in meters.
Figure 5: Top: Original point cloud sample from LeDx-42. Gaps in the data represent the location of the laser scanner stations and are indicated by S1 and S2. The exposed stone outcrops on the surface are also outlined in orange. Bottom: Extracted stone boulders from point cloud and layered on top of surface contour map. Stone clusters are found radiating from the points of highest elevation near the left side of the map, away from the hummocky tundra seen on the right. Scale is in meters.

4 Discussion

This classification and extraction approach proved to be an effective means of using large digital point clouds to enhance our ability to map and investigate Arctic hunter-gatherer sites. Specifically, it demonstrates how discrete elements can be extracted from low relief hunter-gatherer sites with different surface compositions. This approach was designed to accomplish two goals: (1) to fingerprint specific materials found on diverse small scale archaeological surfaces in order to isolate them from their original 3D point clouds, and (2) to provide archaeologists with a new visual and spatial analytical tool that can be used for future feature investigation and interpretation of similar low visibility sites.

The low relief surface stone boulders at LdFa-1 were successfully extracted from the rest of the point cloud. Three prominent archaeological stone features are best highlighted within this new dataset while layered over top of a contour map and isolated from the mix of vegetation at the site. Extracting materials that make up the most common Arctic archaeological structures helps enhance the visual representation of these features at the site in order to measure, orient, and locate potential patterns in the surrounding debris. Using the distributions of materials in these extracted datasets can lead to the identification of subsequent areas of archaeological interest and also help in planning future fieldwork.

The results from LeDx-42 were equally successful in fingerprinting and extracting stone boulders from the original point cloud. No obvious stone features are identified in the new dataset, although in
combination with the collection of artifact deposits, the distribution of larger clusters of stone boulders may suggest the location of former, dismantled stone features on this known Paleo-Inuit site. In addition, the extracted point cloud data illustrate a tendency for stone clusters to occur near areas of highest elevation (see Figure 5), suggesting potential preference in occupation area situated away from the lower-lying hummocky terrain. Investigating the stone boulders in context with the surface outcrop exposure may also suggest a combined use of building materials (i.e., stone boulders and natural outcrop) at this site. However this does require further excavation in those adjacent areas.

The overall results demonstrate how a manual TLS point cloud classification approach can be a valuable tool in the analysis of low relief archaeological features on two Arctic hunter-gatherer sites. The manual classification process demonstrates the ability to fingerprint and extract specific materials on two compositionally different site surfaces. This digital approach is entirely processed in openly available software, making it a more accessible and flexible tool for non-specialists in the archaeological sciences. The resulting digital datasets provide us with a new starting point from which to record and interpret the distribution of both the natural and anthropogenic elements across the surface of a site. Using the segmented classifications provides a more objective and accurate way to record and compare archaeological surface features and other natural objects at sites like LdFa-1 and LeDx-42, and additionally creates a new dataset from which we can discuss the spatial organization of an Arctic hunter-gatherer site.

Using TLS analytical processes like this one allows researchers to accurately evaluate a site in real-time while still in the field. This has important implications for effective use of resources, namely time and money, when working in remote locations that are affected by unpredictable seasonal conditions like the interior of southern Baffin Island. Having the ability to identify important areas for investigation that were previously unknown or unclear due to surface obstructions allows researchers to shift site investigations to focus on those areas that are more likely to yield meaningful data. TLS analytical processes also provide researchers with the ability to continue a site analysis in a 3D digital space even if they do not have the funds to support returns to the physical site, which, again, is an important consideration when working in remote field locations like the Arctic.

During our tests of this approach, we encountered a few issues in our data that will be addressed in our future site investigations using this technology. Upon noticing some areas of overlapping classifications, this, and any other RGB and intensity-based approach, would benefit from a consistent data normalization process available for any type of terrestrial scanner. Additionally, better scanner positioning would have provided greater detail in shadowed areas on the site, benefiting both the intensity values and RGB colourization. Finally, even greater material classification accuracy could be achieved having used a higher quality digital camera, and image meshing procedures. Overall, given the methodological challenges of conducting this type of research in Arctic sites, this simple analytical process can provide a valuable addition to TLS research in the north.

5 Conclusions

Our results illustrate the potential of a manual TLS point cloud classification approach for extracting materials that make up Arctic hunter-gatherer archaeological features. We present a simple, but effective classification technique adopted from existing scripts, and available to any non-expert in the field of archaeology. Although simple in method, using manual classification processes provides an alternative to other existing, more robust procedures like CANUPO. Manual classification gives an archaeologist complete control to identify a combination of colours exhibited on often ambiguous and extremely low relief hunter-gatherer features on the surface of the low Arctic tundra, and makes it possible to locate and examine these potential features while still in the field. Using the extracted data to characterize the surface of the site in a unique way provides us with a new analytical tool for investigating and analysing low relief Arctic hunter-gatherer sites. TLS point clouds of LdFa-1 and LeDx-42 have been successfully segmented into several parts where both the natural and anthropogenic elements of the surface have been extracted in the resulting digital datasets. Using this classification approach, we were able to produce datasets composed of low
relief archaeological elements to allow for unique measurements, and larger scale analysis to take place. In providing a meaningful use for Arctic hunter-gatherer contexts, these results help us to move beyond the simple large-scale acquisition and visualization of 3D digital point clouds at archaeological sites. Our classification method provides a novel contribution to the field of digital archaeology as its focus shifts from data collection to data analysis and interpretation. Implementing this analytical approach in both a field and lab setting, demonstrates the value of large digital dataset procurement, processing, and analysis.

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