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Effects of LIDAR point density on bare earth extraction and DEM creation

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ABSTRACT

Data density has a crucial impact on the accuracy of Digital Elevation Models (DEMs). In this study, DEMs were created from a high point-density LIDAR dataset using the bare earth extraction module in Quick Terrain Modeler. Lower point-density LIDAR collects were simulated by randomly selecting points from the original dataset at a series of decreasing percentages. The DEMs created from the lower resolution datasets are compared to the original DEM. Results show a decrease in DEM accuracy as the resolution of the LIDAR dataset is reduced. Some analysis is made of the types of errors encountered in the lower resolution DEMs. It is also noted that the percentage of points classified as bare earth decreases as the resolution of the LIDAR dataset is reduced.

Keywords: LIDAR point density, bare earth extraction, DEM accuracy

1. INTRODUCTION

As part of the ISPRS Working Group III, a study completed by George Sithole and George Vosselman looked at the performance of a variety of bare earth extraction algorithms. [1] One of the stated purposes of this study was "to determine the performance of filtering algorithms under varying point densities" in order to understand the trade-offs between cost efficiency and DEM accuracy. This balance between cost and resolution is still relevant today.

A portion of the data and ground truth information from the Sithole/Vosselman study was used to complete the analysis presented here. A second dataset collected over Sequoia National Park in August 2008 was used to perform a qualitative analysis of the effects of LIDAR point density. Ground truth data was not available for the Sequoia dataset.

2. THE LIDAR DATA

The data used in the Sithole/Vosselman study is available for download from http://www.itc.nl/isprswgIII-3/filtertest/index.html. This site also contains further information about the study design and results. The datasets were collected over the Vaihingen/Enz test field and Stuttgart city center. A subset of these datasets containing mostly vegetation features were used here. The area of each subset is between 0.5 and 1.0 km^2. See Figure 1.

According to the Sithole/Vosselman metadata, the average point spacing of the rural and forested sites was approximately 2.0 to 3.5 meters between points (0.18 points per square meter). [1] The Quick Terrain Modeler software has a statistics function that gives the average point spacing of the dataset, and this measure gave a slightly smaller value (1.5 to 1.6 meter spacing) on average for the rural/forest sites. The Quick Terrain Modeler measurement was used throughout to maintain consistency.

The Sequoia National Park dataset was collected by Airborne-1 Corporation in August of 2008. The average point spacing of the subset used for this study was 3.36 points per square meter. The area covered by this dataset is approximately 5.8 km^2. See Figure 2.

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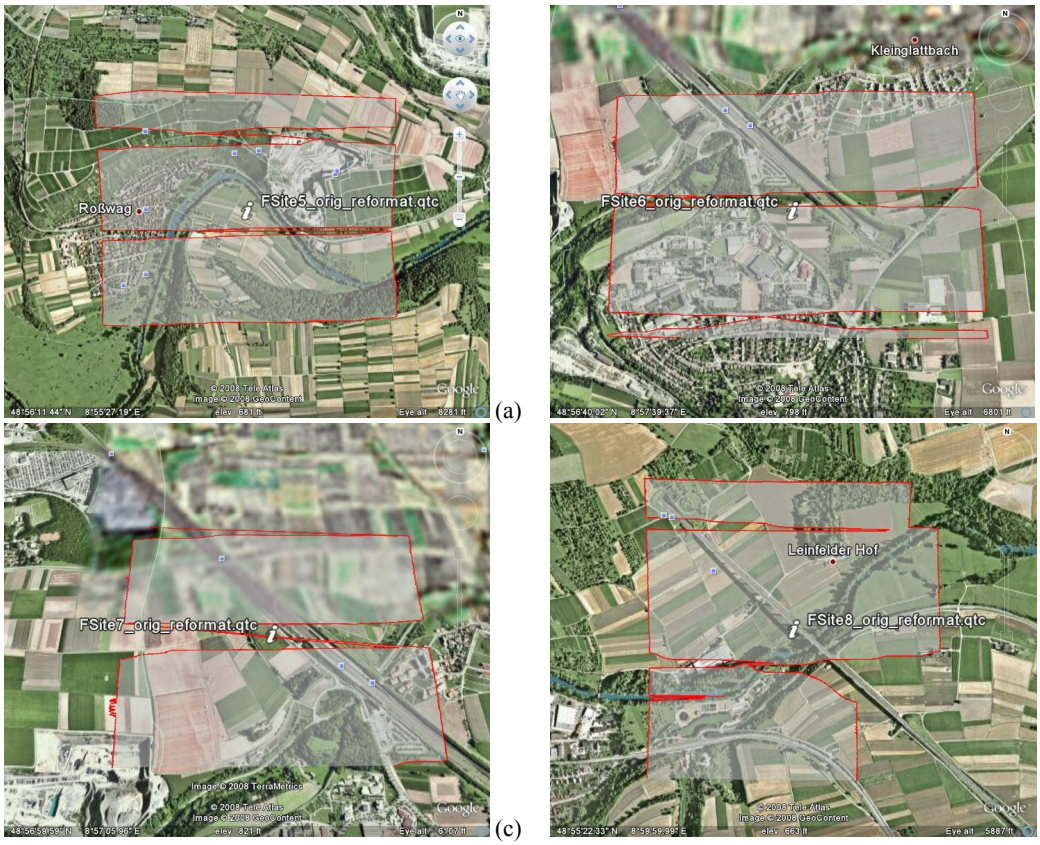

Fig. 1. Outlines of Sithole/Vosselman subsets overlaid on imagery using Google Earth. (a) FSite5, (b) FSite6, (c) FSite7, and (d) FSite8.

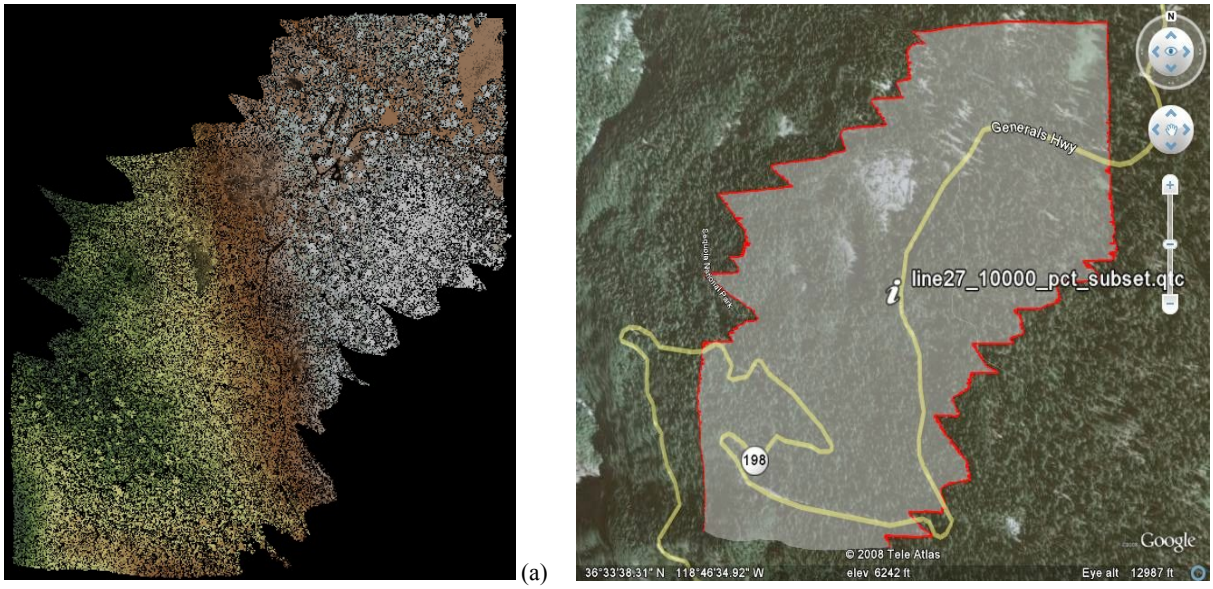

Fig. 2. (a) Sequoia National Park dataset as displayed by Quick Terrain Modeler, with coloration according to point elevation. (b) Outline of Sequoia National Park data overlaid on imagery using Google Earth.

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3. METHODS

The bare earth extraction algorithm in Quick Terrain Modeler is specifically designed to work over forested areas. For this reason, four (of eight available) Sithole/Vosselman subsets collected over rural landscapes and forested areas were chosen for the analysis. A 5.8 km^2 subset of the Sequoia National Park dataset was also chosen. For each of the datasets, 13 lower resolution point clouds were created by randomly selecting points from the original dataset at a series of resolutions (90%, 66%, 50%, 30%, 10%, 5%, 3%, 1%, 0.5%, 0.3%, 0.05%, 0.03%, and 0.01%).

Quick Terrain Modeler is a powerful analytical tool developed at the Johns Hopkins University's Applied Physics Laboratory for working with 3-D data, including "LIDAR, SAR, multibeam sonar, DEM, and other data."[2] The software enables the user to import many different types of data, building models, many visualization and editing tools, and a suite of analysis tools.

The bare earth extraction module of Quick Terrain Modeler can classify each point in the original point cloud as either belonging to 'cloud' or 'surface'. The module can also create a gridded surface file. Both of these outputs were used to analyze the effects of reducing the point-cloud resolution.

There are several parameters that can be adjusted in the Quick Terrain Modeler software to give a better bare earth extraction result if the user knows something about the dataset and the desired product. To maintain consistency, and to focus mainly on the effects of reducing the resolution of the point cloud, the only parameter that was adjusted as the DEMs were created was the 'scale' of the surface model. The 'scale' refers to the average spacing between points to create the gridded surface file.[2] This value was set to match the average spacing of the point cloud as measured by the Quick Terrain Modeler statistics function.

4. RESULTS

The percentage of points classified as bare earth was determined for each of the datasets. As shown in Figure 3, the percentage of points classified as bare earth decreases as the overall number of points in the data cloud is reduced. Since the phenomenon occurs for all the datasets analyzed, we are confident that this is a function of the type of bare earth extraction algorithm being used.

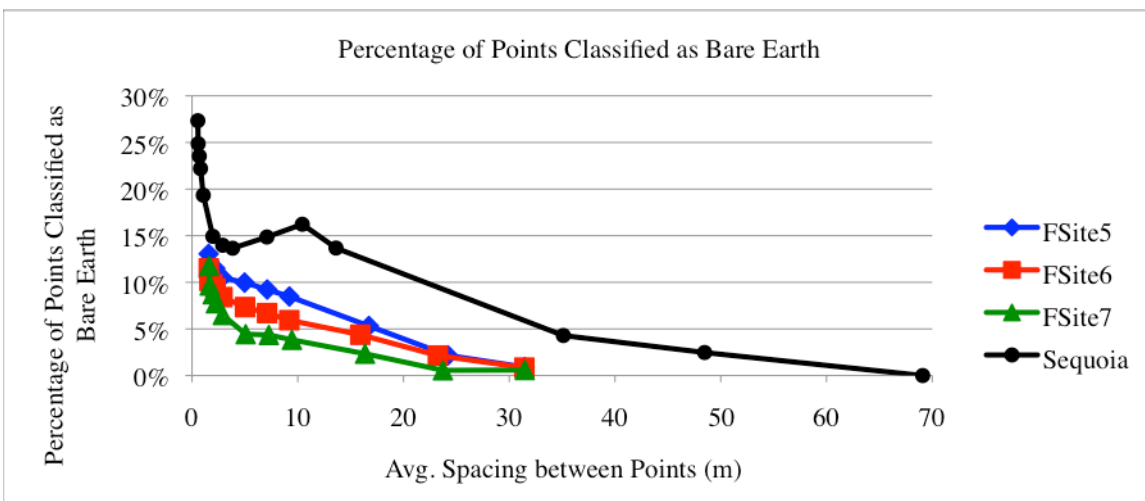

Fig. 3. The percentage of points classified as bare earth using the Sithole/Vosselman data (FSite5, FSite6 and FSite7), and the Sequoia National Park data.

The DEMs created for the Sequoia National Park dataset are shown below in Figure 4. Similar files were created for each of the Sithole/Vosselman subsets as well.

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DEMs created from Sequoia National Park LIDAR data
- Percentage of original dataset
- Number of points classified as bare earth / Number of points in data cloud
- Average spacing between points in data cloud

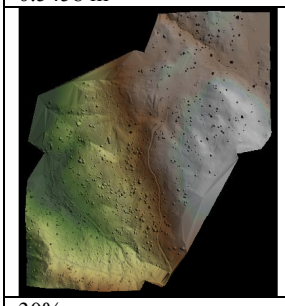
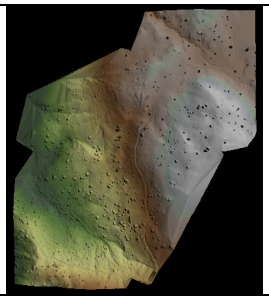
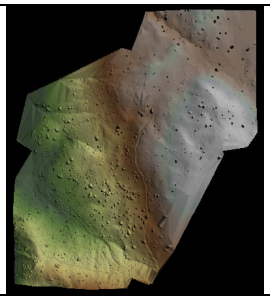
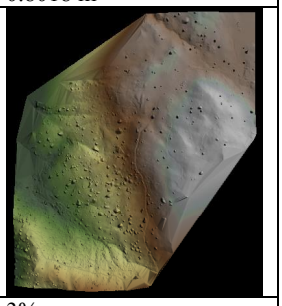
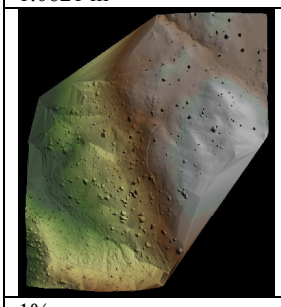
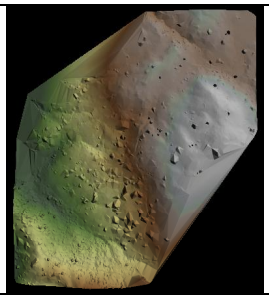
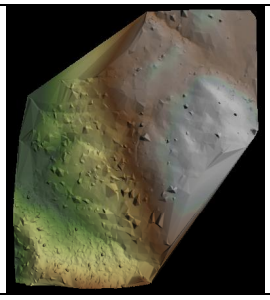
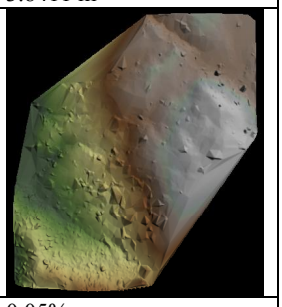
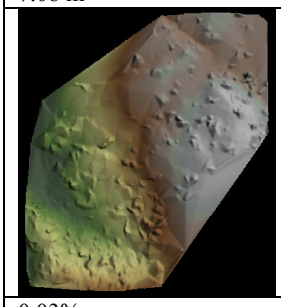
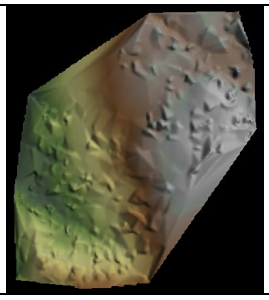
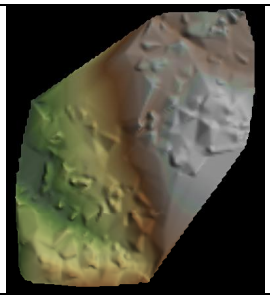
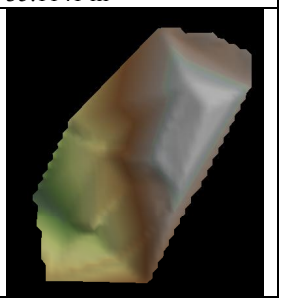
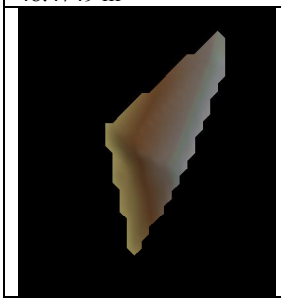
100% 834,037 / 3,051,400 0.5458 m	90% 681,935 / 2,742,629 0.5782 m	66% 474,583 / 2,016,401 0.6865 m	50% 338,477 / 1,524,477 0.8018 m
			
30% 177,283 / 916,570 1.0621 m	10% 45,469 / 304,561 1.9687 m	5% 21,382 / 153,002 2.8959 m	3% 12,552 / 91,889 3.8411 m
			
1% 4,506 / 30,326 7.08 m	0.5% 2,473 / 15,241 10.4278 m	0.3% 1,243 / 9,087 13.616 m	0.05% 66 / 1,537 35.1141 m
			
0.03% 23 / 931 48.4749 m	0.01% 0 / 308 69.0988 m		
	No points were classified as ‘ground’.		

Fig. 4. DEMs created from Sequoia National Park LIDAR data

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5. ANALYSIS

A qualitative assessment of the DEMs created shows the level of detail in the DEMs dropping off as the resolution of the dataset decreases. This is expected, and there are no glaring errors due to the decreasing resolution. When the resolution of the dataset is decreased so that the average point spacing between points exceeds 60 meters, the Quick Terrain Modeler bare earth extraction algorithm does not find any bare earth points, and all points are classified as 'cloud'.

A quantitative assessment was completed for areas with corresponding reference data, which includes subsets of the Sithole/Vosselman datasets. The reference data consists of lists of points from the original dataset that are known to be bare earth surface points. These points were generated by manually filtering the data, making use of landscape information and aerial imagery where available.[1] The reference data covers only small portions of the original datasets, and were chosen to highlight some of the areas expected to be difficult for bare earth extraction. These sites include data gaps, steep slopes, bridges, and buildings.

The reference files for FSite5 (samples 5.1, 5.2 and 5.3) contain 74,697 points, and cover an area totaling 0.09 km^2. Sample 6.1 contains 35,060 points originally from FSite6, and covers an area of approximately 0.05 km^2. Sample 7.1 has 50,705 points originally from FSite7, and covers a spatial area of 0.02 km^2. There was no reference data available for FSite8. Likewise, there was no reference data available for the Sequoia National Park data.

Truth tables were created for each of the DEMs to tabulate the accuracy of the bare earth extraction. The errors occurring in each DEM can be classified in two ways, as defined in the Sithole/Vosselman study.[1] A Type I error refers to the case where a bare earth point is classified as a cloud point. A Type II error occurs when a cloud point is classified as a bare earth point.

Graphical representations of the information available in each of the truth tables are displayed below. Accuracy is measured by dividing the total number of correctly classified points by the total number of points in the reference files.

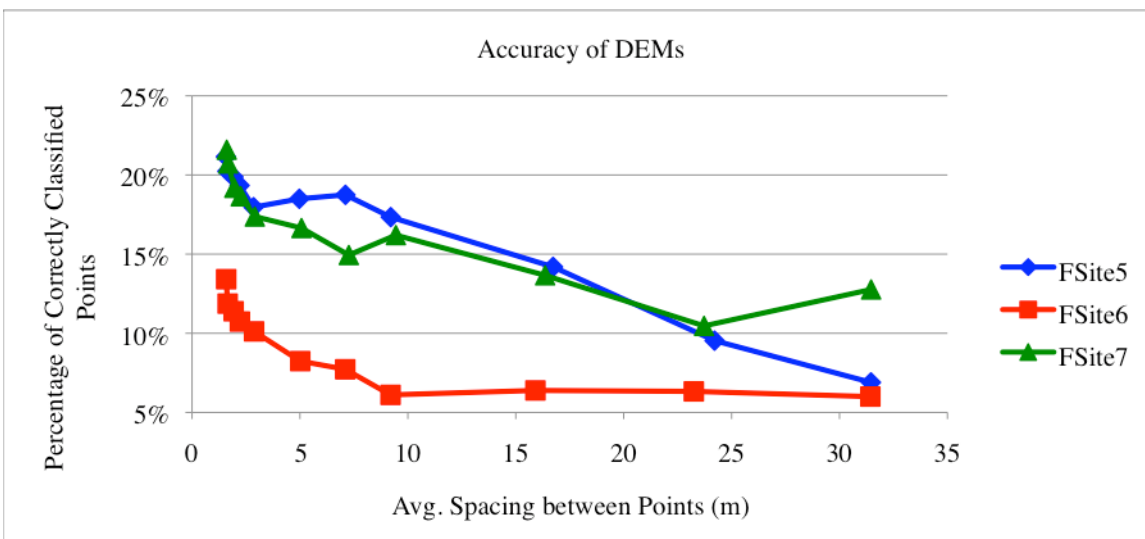

Fig. 5. The accuracy of the DEM results decreases as the resolution of the point cloud is reduced.

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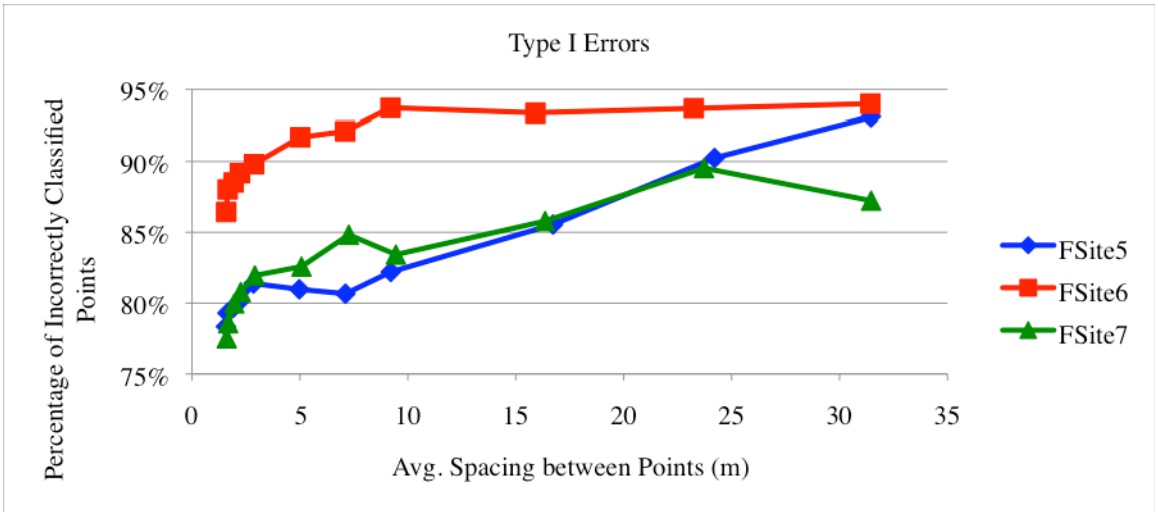

Fig. 6. Percentage of points classified incorrectly as Type I errors (points incorrectly classified as 'cloud').

As seen in Figure 3, the percentage of points classified as bare earth decreases as the overall number of points in the cloud is reduced. This could explain why the number of Type I errors (missed 'ground' points) increases as the resolution of the dataset is reduced.

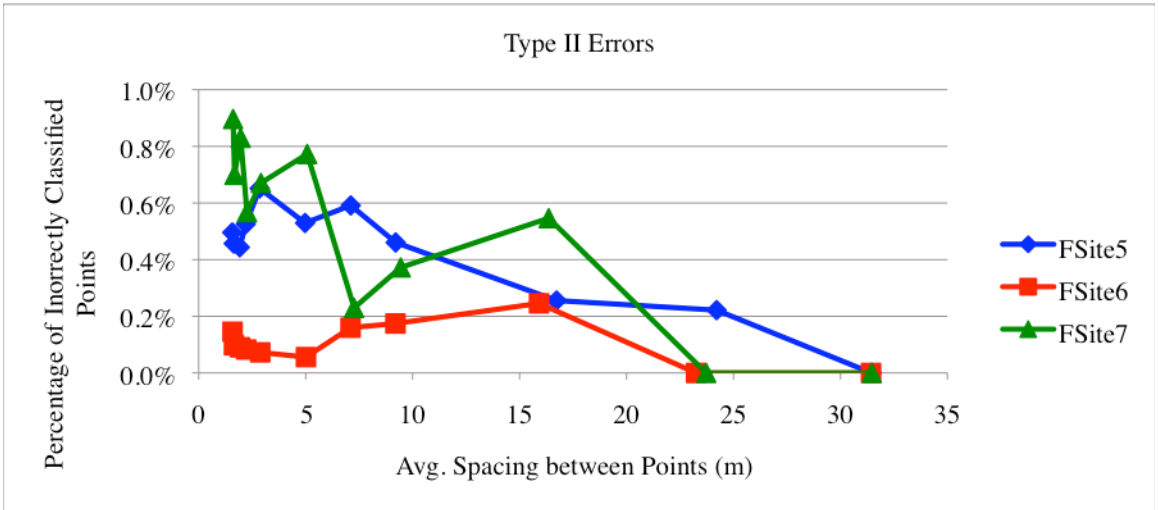

Fig. 7. Percentage of points classified incorrectly as Type II errors (points incorrectly classifed as 'ground').

An attempt was made to determine the source of the Type I and Type II errors. Unfortunately, because of the very large percentages of points incorrectly classified as 'cloud' (Type I errors), it was hard to determine the source of these errors. These points are displayed in green in the figures below. There were fewer Type II errors (points being incorrectly classified as ground); these points are shown in red. From looking at these images, it seems that the bare earth algorithm might classify LIDAR points occurring on steep slopes or structures incorrectly as 'ground'.

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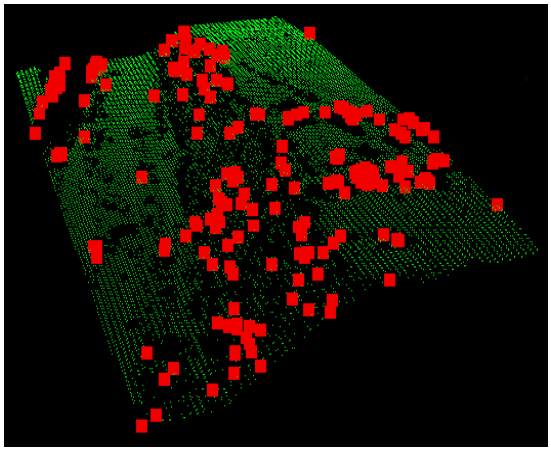
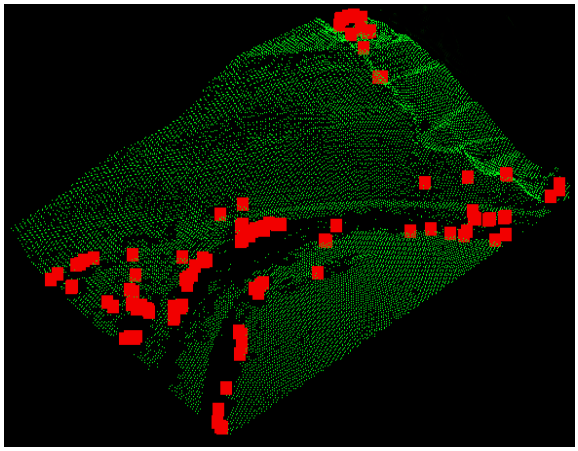
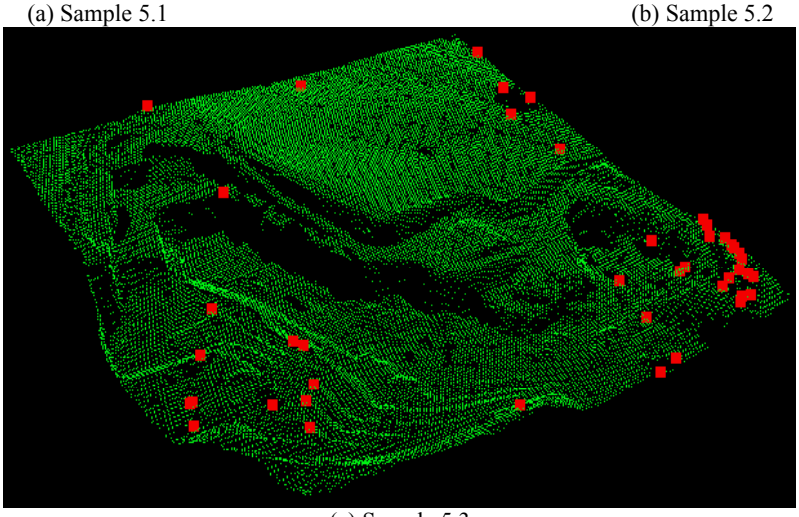


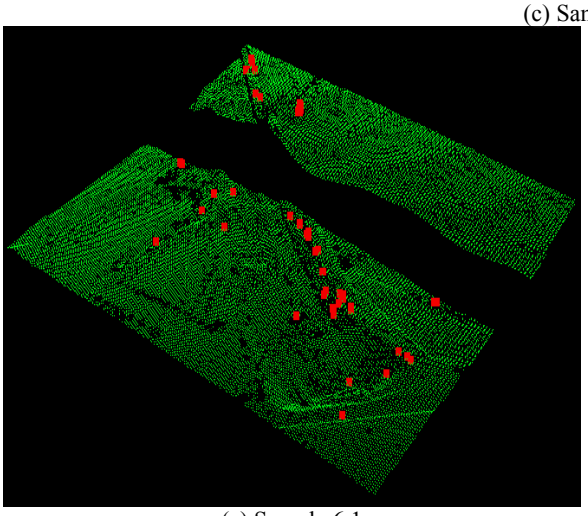
(a) Sample 5.1



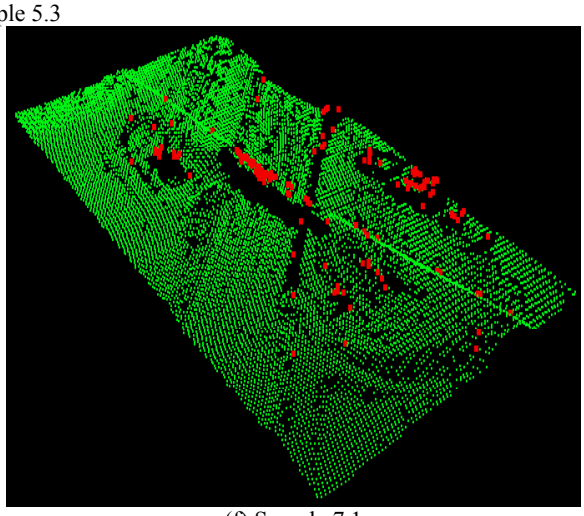
(b) Sample 5.2



(c) Sample 5.3



(e) Sample 6.1



(f) Sample 7.1

Fig. 8. 3-D renderings of incorrectly classified points. Green represents points that were incorrectly classified as 'cloud' (Type I errors), and red represents points that were incorrectly classified as 'ground' (Type II errors).

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6. FUTURE WORK

Other LIDAR software packages are available that provide a bare earth extraction capability. It would be useful to compare different algorithms and determine which effects are due to the bare earth extraction algorithm, and which are a function of reducing the density of the LIDAR dataset.

A more in-depth quantitative assessment can be completed with sufficient ground truth information for the Sequoia National Park dataset. With the higher resolution of this dataset, we would expect that the accuracy of the DEM classification result will improve. This would allow a more thorough investigation of the sources of Type I and Type II errors.

7. REFERENCES

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[2] Applied Imagery, 2008. *Quick Terrain Modeler User's Manual, Version 6*.
[3] Johns Hopkins University Applied Physics Laboratory, 2006. ILAP Bare Earth Extraction Plug-In Operator's Manual.
[4] Anderson, B., 2008. Assessing accuracy in varying LIDAR data point densities in digital elevation maps. Masters Thesis, Naval Postgraduate School, Monterey, California.

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