

# USING STEREO IMAGES TO DENSIFY LIDAR DATA POINTS AT WHERE NEEDED

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## **ABSTRACT:**

For many applications, dense Lidar data is often needed. For instance, for telecommunication antenna network design, 1 meter spacing Lidar data would be needed for downtown area of a big city. However, it is expensive to collect high density Lidar data. Many systems can easily collect 2-3 meter spacing data with one flight line, but for 1 meter spacing data, multiple flight lines including cross flight lines have to be flown to meet the spacing requirement. In this paper, a novel approach is presented to tackle the problem. The approach generates 3D points through image matching techniques to densify Lidar points at where denser points are needed. For example, when denser building points are needed, the approach will first identify all the buildings and then generates 3D points for the buildings. The generated 3D points plus the existing Lidar points will make a denser coverage for the buildings. The 3D points can be generated at any specified reasonable spacing. The paper first introduces the motivation and need to develop such an approach, and then describes the concept of the approach and the system design. After those are the experimental results and conclusions.

## **1. INTRODUCTION**

For many applications, dense Lidar data is often needed. For instance, in telecommunication antenna network design, 1 meter spacing Lidar data would be needed for downtown area of a big city. However, it is expensive to collect high density Lidar data. Many systems can easily collect 2-3 meter spacing data with one flight line, but for 1 meter spacing data, multiple flight lines including cross flight lines have to be flown to meet the spacing requirement. So, the need of minimizing the cost of Lidar data acquisition motivate people to explore the possibility of using other alternative(s) to meet the point density requirement. In this paper, a novel approach of using stereo images to densify the Lidar data points is presented.

Quite often, when Lidar data is collected, stereo imagery covering the same area that the Lidar data covers is acquired as well. We all know that 3D terrain data can be extracted from a stereo pair of images (left and right images normally with 60% overlap) either manually or automatically. When it is done manually, breaklines and mass points are digitized from a stereo pair of images on a softcopy photogrammetry system. When it is done automatically, image matching technique(s) are used to find conjugate points on the stereo pair of images and then 3D points are formed by the space intersection process (Moffitt and Mikhail, 1980) for the conjugate points. Here, conjugate points always come in pair; one in the left image and the other one in the right image and a pair of conjugate points represent the same point on the ground. If a mass of conjugate points generated by the automated image matching process is dense enough, then the conjugate points become an additional terrain data source and can be used as complement to the existing Lidar data points. When the two data sources are merged together, the needed point spacing can be met.

Image matching techniques have been used for more than a decade to generate Digital Elevation Models (DEMs) (Grün et al., 1995). Image matching works quite effectively and

efficiently for areas where terrain is flat or rolling and ground surface has rich texture, i.e., the surface texture is not uniform like sand beach. However, image matching faces difficulties at where terrain changes abruptly, e.g., steep mountains and high-rise buildings in cities. The concept of using image matching to generate DEMs is to find 2D conjugate points in a stereo pair of images through image matching technique and then generate 3D ground points by the space intersection process for the 2D conjugate points. One of the parameters in the image matching is the Search Window that determines the searching range of a conjugate point. The size of the search window is critical to the success of the image matching process. A too big search window often leads to a wrong match. On the contrary, a too small search window easily leads to no match. The search window should be a function of the terrain elevation change: the bigger the elevation changes, the bigger the search window should be. But, when there is no terrain information available at all for an area, the selection of the search window size can only be based on any available general knowledge of the terrain in the area, and therefore the image matching results are certainly not as reliable as one wants. However, when there exists available terrain information such as from an existing Lidar data, the existing Lidar data can make a huge positive difference on the results of the image matching. The existing Lidar data can provide accurate and reliable elevation information about the terrain, which allows an accurate determination of the searching location and a relatively small search window, which, in turn, keeps the image matching time to a minimum.

This paper presents an approach developed at EarthData that uses stereo images to generate 3D points through image matching with terrain information from an existing Lidar data set and then add the generated 3D points to the existing Lidar data set to meet the Lidar data point density requirement. For many applications, dense Lidar points are only needed for buildings, again for example, the telecommunication antenna network design. Therefore, this approach was designed to not densify the entire area of a Lidar data coverage; instead, it only densifies the buildings. Doing so also keeps the data amount to a minimum.

In the Section 2, the paper introduces the general concept of the approach and some basic considerations in the approach. This section also shows a Lidar Point Densification System (LPDS) developed based on the approach. Then in the Section 3, the paper presents the experimental data and results and gives an analysis of the results. In the last section, the paper discusses the feasibility of the approach, the potential applications of the densified Lidar data, and gives direction of future works at the end.

## 2. THE APPROACH

An approach has been developed at EarthData to generate 3D points through image matching techniques to densify Lidar points at where denser points are needed. The approach is designed to densify only buildings for practical reasons mentioned in the Introduction section. The concept of the approach is described as follows. When denser building points are needed for an existing Lidar data, the approach is to firstly identify all the buildings by a semi-automated building extraction process (Wang, 2000). Then, it generates 2D conjugate points through image matching with the help of the building Lidar data. As explained above, the existing Lidar data allows the searching of a conjugate point to be done at an accurate searching location and with a minimum search window, which therefore leads to a minimum image matching time. After the image matching process, the generated 2D conjugate points are converted to 3D points by the space intersection process. Then, the generated 3D building points and the existing Lidar points are merged to make a denser coverage for the buildings. The 3D points can be generated at any reasonably specified spacing. In order to produce reasonable results, the approach has certain assumptions on the input Lidar data and imagery: the input Lidar data should have 2-3 meter or better point spacing and have at least 20cm elevation accuracy. If the Lidar point spacing is too coarse, it may not be able to provide an accurate searching location for the conjugate points. Additionally, the input imagery used in the image matching process must have a ground pixel resolution that is equal or better than the specified output point spacing for the densified data, i.e., if 1 meter point spacing is wanted for the output 3D points, then the ground pixel resolution of the stereo images used in the matching process has to be 1 meter or finer.

Based on the approach, the LPDS was developed. The drawing in Figure 1 shows the processes and data flow of the LPDS. The first process of LPDS is Building Extraction. The algorithms for this process were developed several years ago. The process is semi-automated; it mainly requires an operator to delete those non-building features that are detected as buildings. This process generates Lidar building points. Each building has its own set of Lidar points. The second process is the generation of conjugate points through image matching. The image matching technique used in the LPDS is Cross-Correlation. This process produces a mass of 2D conjugate points for each and every building. Then the 2D conjugate points are converted to 3D points in the third process that is the space intersection. The output of the third process is the 3D building points. The last process of the LPDS is to merge the 3D building points with the existing Lidar building points to form the densified Lidar points, or also called in this paper the densified building points.

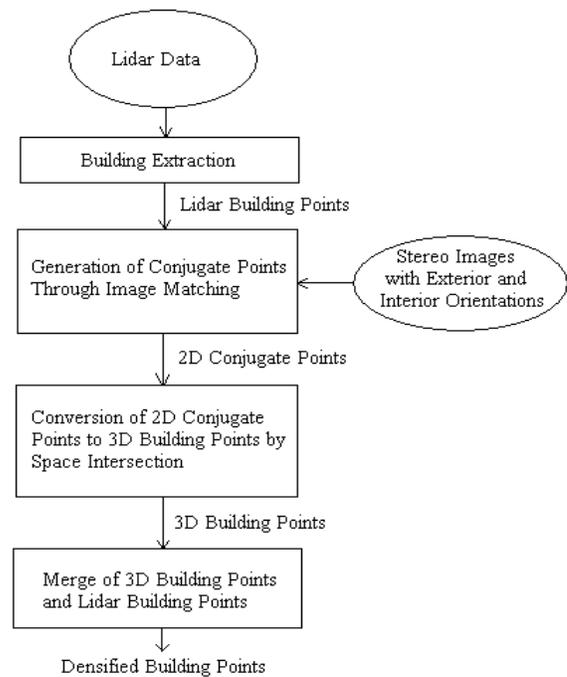


Figure 1. The processes and data flow of the LPDS.

## 3. THE EXPERIMENTS AND RESULTS

### 3.1 The Experimental Data

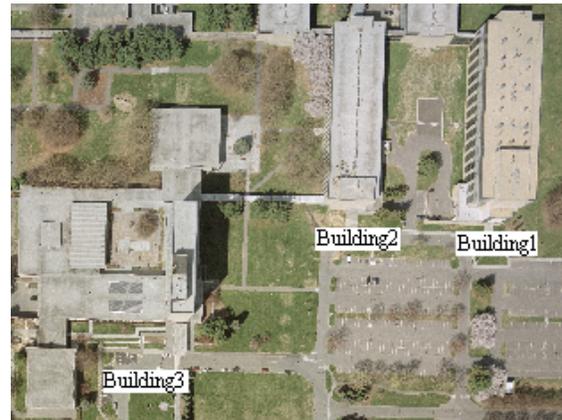


Figure 2. The experimental area and buildings.

The experimental data was a Lidar data with 0.5 meter spacing with an average 15 cm vertical accuracy. Then, this original 0.5 meter spacing Lidar data was thinned to generate a Lidar data set of 3 meter spacing and the generated Lidar data set was used in the experiments. Having the original 0.5 meter spacing Lidar data available allows a quality check and analysis on the densified building points. The imagery used in the experiments had a range of ground pixel resolution from 0.1 to 0.5 meter. The experimental area covered three

buildings with heights above the ground from 8 levels to 19 levels (assuming averagely 3 meter per level). Building1 was about 34 meters high with a major structure on top of it. Building2 was about 25 meters high with a major structure on top of it as well. And, Building3 was a complex with the highest point at 57 meters. Figure 2 shows the area and the three buildings used in the experiments.

### 3.2 The Experiments and Results

The experiments were conducted by using LPDS to generate 3D points to densify the Lidar data sets of the three buildings. The TIN models of the existing Lidar data sets with 3 meter spacing are in Figure 3, 6, and 9 respectively. And, the outputs of LPDS are shown in Figure 4, 7, and 10, respectively. These results were generated by using the imagery of 0.1 meter ground pixel resolution. Other pixel resolutions were tested as well, however, the ones shown in this paper represent the best results. At the beginning the experiments, images with 0.5 meter ground pixel resolution were used and thought to be sufficient meeting the 1 meter accuracy requirement. But, the experimental results proved that 0.5 meter resolution was just too coarse. The 3D points generated for the flat building tops had variation in elevation much larger than 1 meter. As already mentioned above, the best results came out of the images with the finest ground pixel resolution that was 0.1 meter. Of course, the finer the pixel resolution, the longer the image matching takes. For comparison and quality check purposes, the TIN models of the original 1 meter spacing Lidar data were generated as well for the three buildings and those TIN models are shown in Figure 5, 8, and 11 respectively.

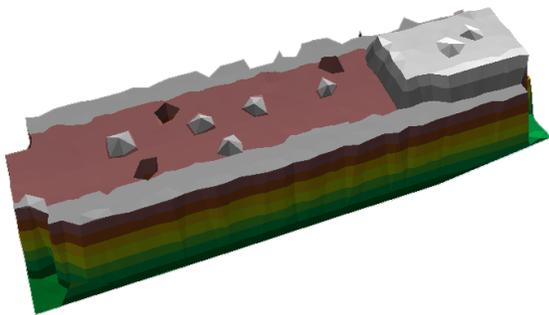


Figure 3. A TIN model of Building1 generated from Lidar data with 3 meter point spacing.

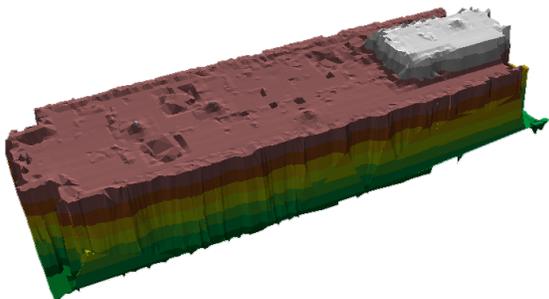


Figure 4. A TIN model of Building1 generated with the densified building points at 1 meter point spacing.

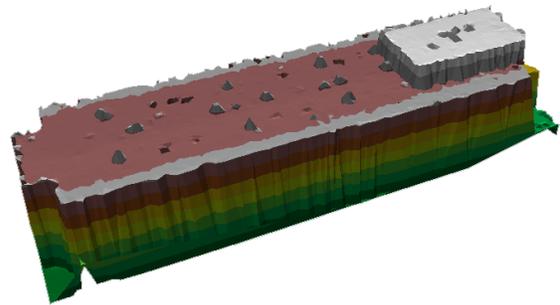


Figure 5. A TIN model of Building1 generated with the original Lidar points at 1 meter point spacing for comparison.

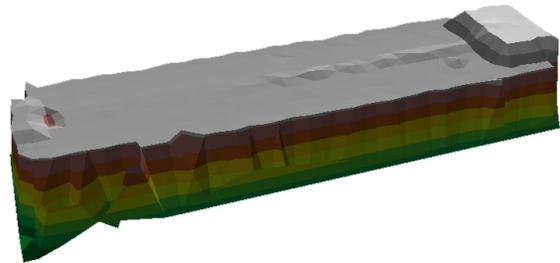


Figure 6. A TIN model of Building2 generated from Lidar data with 3 meter point spacing.

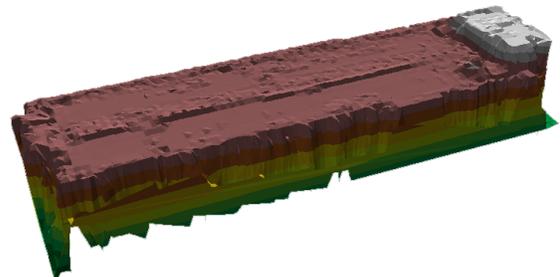


Figure 7. A TIN model of Building2 generated with the densified building points at 1 meter point spacing.

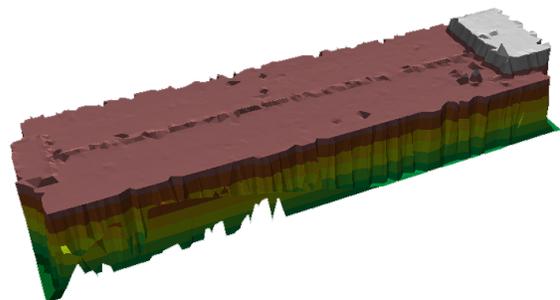


Figure 8. A TIN model of Building2 generated with the original Lidar points at 1 meter point spacing for comparison.

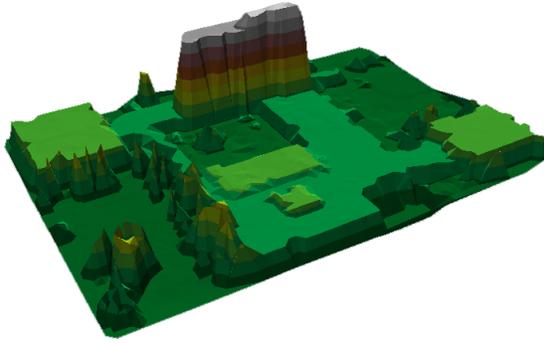


Figure 9. A TIN model of Building3 generated from Lidar data with 3 meter point spacing.

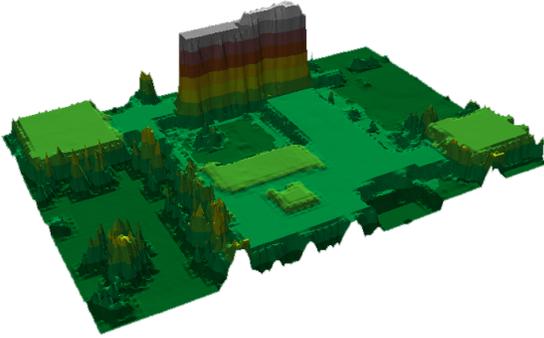


Figure 10 A TIN model of Building3 generated with the densified building points at 1 meter point spacing.

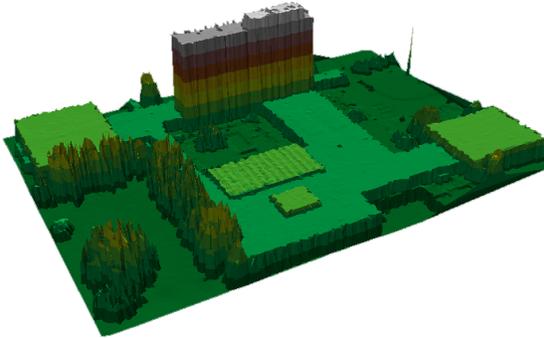


Figure 11 A TIN model of Building3 generated with the original Lidar points at 1 meter point spacing for comparison.

### 3.3 An Evaluation of the Experimental Results

From the experimental results shown in the above figures, we can observe several things. First, the densified building points generated more accurate building edges and therefore more accurate shapes. In figures 3, 6, and 9, all the three TIN models of the original 3 meter spacing Lidar data sets show jagged building edges. On the contrary, in figures 4, 7, and 10, the three TIN models generated from the densified building points show generally straight and continuous building edges. Second, Building3 is a building complex with multiple structures and heights. The densified building points not only generated more accurate building edges, but also added a lot of accurate details to the complex and even

to the trees next to the complex, which gave a more accurate representation of the building complex. Third, when comparing with the real 1 meter spacing Lidar data TIN models of the three buildings, we can see the TIN models generated by the densified building points lost almost all minor structures on the building tops, especially all medal chimneys. But, the loss of all chimneys didn't really make any surprise, because they were too thin to be matched. And the last, we can see that the building top surfaces generated from the densified building points in Figure 4 and Figure 7 were not as smooth as the building tops generated from the real 1 meter Lidar data in Figure 5 and Figure 8. Additionally, in spite of the building edges generated from the densified building points are more straight and continuous than the building edges generated from the 3 meter Lidar data points, they are still pretty rough. The roughness on the building tops and building edges shows the limitation of the image matching. Although the existing Lidar data made the image matching process in LPDS much easier in finding conjugate points and preserving the building shapes, the image matching process still faced certain problems. All classic difficulties faced by the image matching, except the selection of the search window in this experimental environment, were still there causing wrong matches or missing matches. Those classic difficulties include occlusions, fore-shortening problem, building leans, and poor textures.

Besides the TIN models generated to present the experimental results, boundaries for the all three buildings were digitized manually from the TIN models to examine the horizontal accuracy. Three boundaries were digitized for each building: the boundary generated by the 1 meter Lidar data (in Light Blue), the boundary generated by the 3 meter Lidar data (in Green), and the boundary generated by the densified Lidar points (in Red). If the Light Blue can represent the true building boundary location and shape, then the distances between a Light Blue boundary and a Green (or Red) boundary indicate the accuracy of the Green (or Red) boundary. In general, we can see in the all three drawings the Red boundaries were closer to the Light Blue boundaries than the Green ones did, which means the densified Lidar points were in better horizontal accuracy and completeness than the 3 meter Lidar data. However, apparently, there were places where the Red boundaries were away from the Light Blue boundaries by more than 1 meter. So, for some applications or certain accuracy requirements, additional editing would be needed or additional data has to be added to the densified data to meet the accuracy requirements.

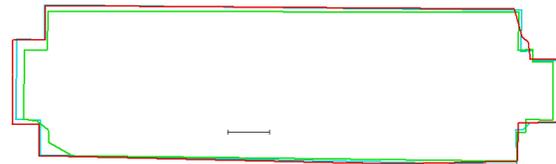


Figure 12. The boundaries of Building1: Light Blue one was generated by the real 1 meter Lidar data; Green one was generated by the 3 meter Lidar data; and Red one was generated by the densified 1 meter Lidar points. The bar in the middle of the drawing represents 10 meter distance.

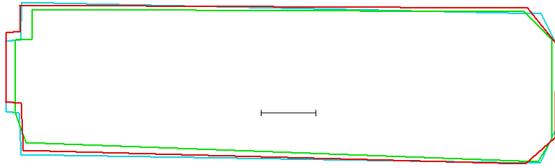


Figure 13. The boundaries of Building2: Light Blue one was generated by the real 1 meter Lidar data; Green one was generated by the 3 meter Lidar data; and Red one was generated by the densified 1 meter Lidar points. The bar in the middle of the drawing represents 10 meter distance.

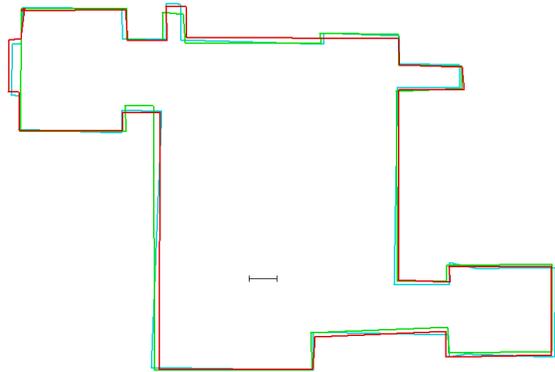


Figure 14. The boundaries of Building3: Light Blue one was generated by the real 1 meter Lidar data; Green one was generated by the 3 meter Lidar data; and Red one was generated by the densified 1 meter Lidar points. The bar in the middle of the drawing represents 10 meter distance.

#### 4. THE FEASIBILITY OF THE APPROACH, ITS POTENTIAL APPLICATIONS, AND FUTURE WORKS

The experimental results shown in the Section 3 demonstrate that the approach and the LPDS developed based on it are effective and efficient in using stereo images to generate 3D points with the help of an existing Lidar data. The generated 3D points are complement to the existing Lidar data and when the generated 3D points are added to the existing Lidar data, the existing Lidar data is densified to meet the needed data point spacing. The experimental results also show that the densified Lidar data points have high quality in terms of preserving building shapes and keeping the accuracy.

The high quality of the densified Lidar data allows it to be used in any applications where high quality Lidar data is needed. One particular application of using the densified Lidar data is for making True Orthophotos. It is well known that the quality requirement on the DEMs for making True Orthophotos is very high. Such DEMs have to have accurate building shapes, building elevations, and high point density. It is very expensive to collect such DEMs manually and extremely difficult, if not impossible, to generate them automatically from frame imagery. The availability of the densified Lidar data would provide the needed high quality and also reduce the cost of data acquisition.

While this paper is being prepared, more tests are going to be conducted. The goal for the further tests is to fine turn the

image matching parameters and make the LPDS a production level system.

#### 5. REFERENCES

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