POINT CLOUD DATA ENHANCEMENT BY MATCHING MULTISPECTRAL IMAGES

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ABSTRACT: Generally, remote sensing images were two-dimensional multispectral data. The images can be classified more efficiently and precisely via ground features with different characteristics differ in spectrum. As processing in LIDAR technology, point cloud data with three-dimensional coordinates contain rich information.

LIDAR usually acquires data using only single band, and lacks of multispectral information such as multispectral images. Therefore, this research acquires visible light and near infrared images, via close-range photogrammetry method, then, matching images automatically by free online services to generate visible light and near infrared point clouds with three-dimensional coordinates and color information. At last, one can use three-dimensional affine coordinate transformation to combine different sources of point clouds, and compare the results with LIDAR data, as an assessment for positioning precision.

The experiment shows, image matching by near infrared images, point cloud data can increase 27%, much more than only using visible images; image matching by color infrared composition (NIR+R+G), point cloud data can increase 21%, much more than only using visible light images. As the results shows, multispectral point cloud data are helpful to enhance point clouds data.

1. INTRODUCTION

Passive remote sensing systems record electromagnetic energy reflected or emitted from the surface as two-dimensional multispectral images. The general used bands are blue (0.45~0.52μm), green (0.52~0.60μm), red (0.63~0.69μm), Near Infrared (0.70~1.3μm), Middle Infrared (1.3~3μm) and thermal Infrared (3~14μm). Due to ground features have their own characteristic in different spectrum, while classifying through Multispectral Images, generally, higher divergence between bands, may lead to higher classification accuracy. Therefore, one can interpret ground features effectively by collecting multispectral images, for example, healthy vegetation reflects massive near infrared light, and water body absorbs near infrared light, so one can use near infrared light with other bands for recognizing vegetation and water body.

LIDAR is an active remote sensing system, which can acquire ground feature point cloud data through laser scanning technique, this allows remote sensing data development toward three-dimensional space. Point cloud data includes three dimensional coordinates, intensity and other abundance spatial information, which contains much more potential to interpret ground features than two-dimensional images does. In general, LIDAR scans ground features by single band laser light, for instance, green lasers at 0.532μm has water penetration ability, and vegetation has high sensitive to near infrared laser light region in 1.04μm to 1.06μm (Jensen, 2007). If one acquires ground feature point cloud data only through single band laser light, it is lack of multispectral information.

Consequently, this research uses close-range photogrammetry method to collect visible light and near infrared images, and chooses free online service -- Photosynth, which is provided by Microsoft, as automatically image matching technique to generate point cloud data. After exporting the point cloud data, one can use three-dimensional affine coordinate transformation to merge multispectral point cloud and high precision terrestrial LIDAR point cloud data, as a check for the accuracy and precision for multispectral point cloud data. Else, by comparing the results of multispectral point cloud data on assisting visible light ones, analyzing its difference and increment, as an assessment of adding near infrared images to increasing point cloud data.

2. THEORIES

Ground features has different reflection intensity in electromagnetic energy, therefore, by recording the reflection intensity in different spectrum, then plotting a spectral reflectance of ground features, it can assist understanding different ground features with its reflectance in each spectrum, and one can recognize ground feature through its spectral reflectance curve easily. Generally, collecting visible light image can only plot spectral reflectance from 0.4μm to 0.7μm; by collecting other band, e.g. near infrared light, the spectrum beyond visible light can be plotted, which can effectively interpret ground feature. Then, by matching multispectral images through free online service, such as Photosynth, one can get point cloud data from image collected in close range; via three-dimensional coordinate transformation, combining it with high accuracy terrestrial LIDAR point cloud data, therefore one can compare and analyze the benefit of multispectral images on increasing point cloud data.

The following sections will introduce the advantage in ground feature interpretation by adding near infrared, brief introduction of Photosynth and three-dimensional affine coordinate transformation used in combining different sources point clouds.

2.1 Near Infrared Light

Near infrared (NIR) light is close to red light in spectrum, its wavelength is in region from 0.7μm to 1.3μm, healthy vegetation and water body has special reflective characteristic in NIR band, so it is beneficial to recognize them from other ground features. As the spectral reflectance plot of vegetation and water body shown in Figure 1, one can find out the high reflectance of vegetation in NIR is at approximately 40%; the reason is that the chlorophyll of healthy vegetation absorbs red light but reflects massive NIR light. On the other hand, the high reflectance in water body is at blue and green band, but the reflectance in NIR band is approximately 0%; the reason is that water is a bad reflector, so it only reflects a few blue and green light, but the electromagnetic energy of other band is absorbed. Therefore, vegetation appears brighter and water body appears darker in NIR images, by this characteristic, it can be interpreted easily. If one combines green and red band from visible light, and NIR band, then, a color infrared composition of G, R, NIR images can enhance vegetation and water body.

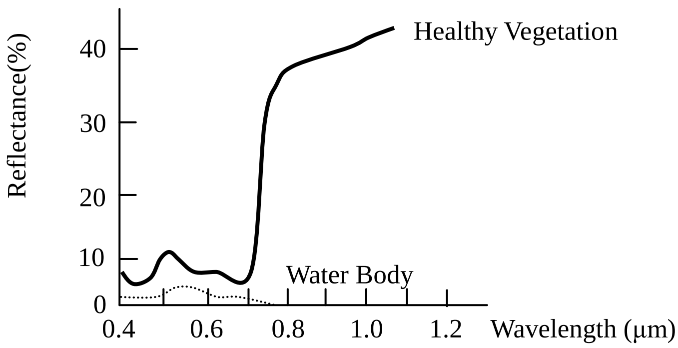


Figure 1. Spectral Reflectance of Vegetation and Water Body (Jensen, 2007)

2.2 Photosynth

Photosynth was established by University of Washington and Microsoft Live Labs, as an online virtual reality application, it has been released to the public on August, 2008. Users can upload their images taken in different view angles and distances with overlapping areas to its website, through image matching technology provided by Photosynth, it can stitch panoramas and generate point clouds of photographed area. The image matching algorithm is Scale-Invariant Feature Transform (SIFT), published by David Lowe on 1999 (Lowe, 1999); this computer vision based algorithm detects key points in local images, then compute the invariant key points in different scale space, by describing the invariant image translation, scaling and rotation factors, it can generate point clouds with three-dimensional coordinates and color information (Chen and Huang, 2010). If one using homogeneous images, then less point clouds will be generated; but one using heterogeneous images, then more point clouds may be generated.

2.3 Three Dimensional Affine Coordinate Transformation

Three-dimensional conformal coordinate transformation is generally used, when combining different three-dimensional coordinate systems, as shown in Eq. (1), which contains 1 scaling factor s, 3 rotation factors (ω, φ, and κ in three matrixes, M_x, M_y, *and* M_z) and 3 translation factors (T_x, T_y, T_z), at least two horizontal and three vertical control points are required to compute seven parameters, thus it is so called seven parameter transformation.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = s \begin{bmatrix} m_{11} & m_{21} & m_{31} \\ m_{12} & m_{22} & m_{32} \\ m_{13} & m_{23} & m_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} \tag{1}$$

In three-dimensional conformal coordinate transformation, there are only one scaling factor *s* for xyz axes, since it is suitable for stable coordinate systems; in case of point clouds generated from Photosynth, which contains image matching by different view angles and distances may produce different scaling on xyz axes, it can be avoided by using three-dimensional affine coordinate transformation, as shown in Eq. (2).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} \begin{bmatrix} m_{11} & m_{21} & m_{31} \\ m_{12} & m_{22} & m_{32} \\ m_{13} & m_{23} & m_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} \tag{2}$$

By comparing Eqs. (1) and (2), the later one has added 3 scaling factors on xyz axes, which contains 3 scaling factors (s_x, s_y, s_z), 3 rotation factors (M_x, M_y, M_z) and 3 translation factors (T_x, T_y, T_z), at least three three-dimensional control points are required to compute nine parameters, thus it is so called nine parameter transformation.

3. METHOD

The research area, instrument used, and procedure are described as follows.

3.1 Research Area

For testing the effect of adding NIR images in image matching, this research chooses rich vegetation growth area as research object, expecting to separate vegetation from manmade structures through NIR band, also, matching visible light images to generate point clouds. The research area is shown in Figure 2, the white arrow represents north.

3.2 Instrument

By using FUJIFILM FinePix J10 digital camera with NIR detection ability to collect images, then stabilized the camera on a tripod to photographed visible light images, afterwards, by adding a 0.72μm NIR filter, which allows spectrum wavelength larger than 0.72μm to pass, photographed NIR images in the same view angle. After adding NIR filter, the illumination becomes lower; therefore, longer exposure time had been set to acquire clear NIR images, the detailed camera settings are listed in Table 1.

Figure 2.Vertical View of Research Area

Table 1. Camera Settings

Image Category	Visible Light	Near Infrared
Focal Length	6 mm	6 mm
Shutter Speed	1 / 199 sec.	1 sec.
Aperture	F / 2.8	F / 2.8
Exposure Time	1 / 400 to 1 / 200 sec.	1.0 to 1.7 sec.

Then, by using Leica HDS 3000 terrestrial LIDAR to acquire high accuracy point cloud data, which can be used as in situ checkpoint. The research object were scanned in the density of 1 cm × 1cm at distance 100 m, the maximum scanning field of view of the LIDAR is 360° at horizontal and 270° at vertical, with ±6 mm accuracy in position, ±4 mm accuracy in distance and ±60 mrad accuracy in angle, and green laser light was used when acquiring data. (Leica Geosystems, 2006)

3.3 Procedure

The research procedure is as follows. After research area selection, first, by stabling the digital camera on a tripod in the middle of the research area, then, photographed surrounding images of the research are in visible light and NIR light from the same view angle, afterward, scanned the same area by terrestrial LIDAR for acquiring in situ data.

Second, by combining images with different band combinations through digital image processing, one can split blue, green and red band from visible light and NIR images, then, set the red band from NIR image as near infrared band, which creates a color infrared (IR) composition with band green, red, NIR as channel blue, green and red. The three image category in this research as follows visible light, NIR and color IR. As shown in Figure 3.

Third, by uploading the three category images to Photosynth website to generate point clouds, then, downloading the .ply file with SynthExport software in ASCII format, next, importing the xyz coordinates from .ply file to a shapefile in ArcScene through Arc toolbox; also, importing LIDAR data into ArcScene, by choosing at least three pairs of feature points as control points for three-dimensional affine coordinate transformation manually, afterward, set the unit weight standard deviation of the coordinate transformation as an criteria. If the unit weight standard deviation is conformed to the criteria, then, one can combine the multispectral point cloud data to the LIDAR coordinate system; else, the feature point should be chosen and the transformation parameters being computed again, until the unit weight standard deviation is conformed to the criteria.

At last, checkpoints were chosen manually, by computing its xyz direction error, positioning error and root mean squared error (RMSE), the accuracy of multispectral point clouds can be checked, and the beneficial of matching multispectral images to increase point cloud data can be analyzed.

a. Visible Light	b. NIR	c. Color IR

Figure 3. Images of Different Band Combinations

4. RESULTS ANALYSIS

The point clouds generated by three combination images are differed in coordinate systems, therefore, control points should be selected and transformed into the LIDAR coordinate system, then, the positioning error could be checked to comprehend the accuracy of Photosynth point clouds, finally, the ratio of multispectral point clouds assisting visible light ones can be computed. Figure 4 shows the spatial distribution of the 10 control points selected in the research area.

Figure 4. Spatial Distribution of Control Points

The following sections will introduce the visible light, NIR and color IR point cloud data generated by image matching, its unit weight standard deviation of coordinate transformation and the precision of checkpoints. The results of multispectral images in increasing point cloud data are also discussed.

4.1 Visible Light Point Cloud Data

Point clouds generated by visible light images distribute over the whole research area, there are only lack of data in the southwest side, 6 control points are used in the coordinate transformation, as point number 1, 4, 5, 6, 8, 9 in Figure 4, the maximum error is 0.046 m, and the unit weight standard deviation of coordinate transformation is ±0.030 m. Through the results of combination of visible light point cloud and LIDAR data, the northeast side is lack of control point, so the point cloud has an obvious offset, its maximum checkpoint positioning error is 0.341 m; also, the southwest side is short of data, the checkpoint A5 has a positioning error of 0.261 m, and the RMSE is

±0.089 m. The manually selected 15 checkpoints, spatial distribution and their accuracy are shown in Table 2.

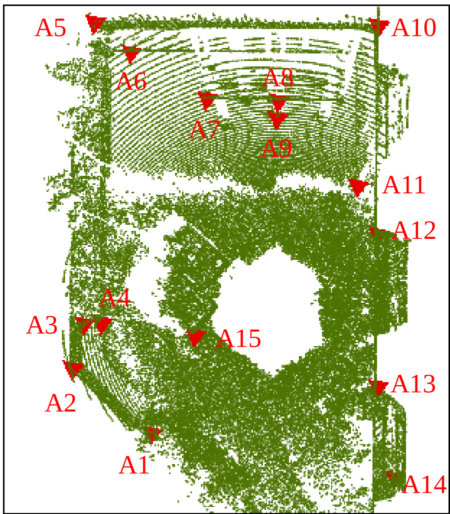
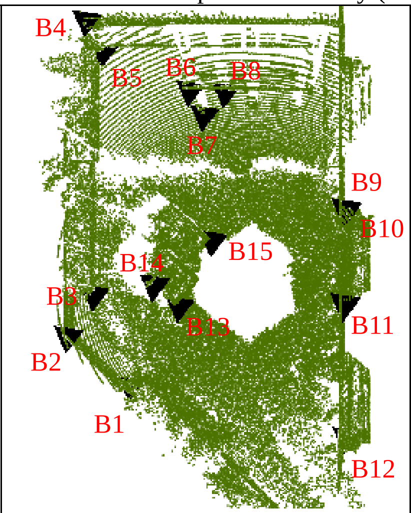
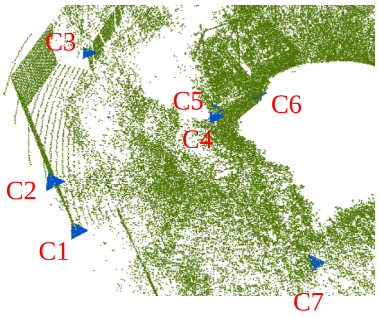
4.2 Near Infrared Point Cloud Data

Points cloud generated by NIR filtered images also distribute over the whole research area, there are lack of data in the northeast side, 5 control points are used in the coordinate transformation, as point number 1, 3, 4, 8, 9 in Figure 4, the maximum error is 0.034 m, and the unit weight standard deviation of coordinate transformation is ±0.026 m. Through the results of combination of NIR point cloud and LIDAR data, the northeast side has much point cloud data, but there are gross vegetation covering the wall, so its lack of interpretable feature points. Its maximum checkpoint positioning error is 0.386 m, and the RMSE is ±0.096 m. The manually selected 15 checkpoints, spatial distribution and their accuracy are shown in Table 2.

4.3 Color Infrared Point Cloud Data

Point cloud data generated by color IR images is lesser than former one, the spatial data distribute on center flower bed and southeast corner side, 7 control points are used in the coordinate transformation, as point number 1, 2, 6, 7, 8, 9, 10 in Figure 4, the maximum error is 0.123 m, and the unit weight standard deviation of coordinate transformation is ±0.069 m. Due to the lesser data, therefore, 7 interpretable checkpoints has been selected as shown in Table 2, the RMSE is ±0.077 m, and the maximum checkpoint positioning error is 0.334 m, other checkpoints such as C1 and C2, still remains obvious offset, and its positioning precision is 0.176 m and 0.223 m.

Table 2. Point Cloud Checkpoints Accuracy (Unit: m)

					
Maximum error	0.341 (A14)	Maximum error	0.386 (B12)	Maximum error	0.334 (C7)
RMSE	±0.089	RMSE	±0.096	RMSE	±0.077

4.4 Assessment of Multispectral Point Cloud Data Increment

By combining the multispectral point clouds with the LIDAR data, the accuracy can be assessed through checkpoints. One can set visible light point clouds as base data to compare the similarities and dissimilarities between NIR data and color IR data, by overlapping both former data on visible light data, one can interpret the data overlapped area and the data losing area manually; then, by selecting the data lost area, one can compute the numbers of all point cloud data in that cross-sectional area. The vertical view of combined data is shown in Figure 5, the point color red, green and blue individually represents visible light, NIR and color IR point cloud data.

After selecting the overlapping area data in Figure 5, it can be analyzed that NIR point cloud data (green) has more dissimilarity data than visible light data (red), this can be shown that point clouds generated by NIR images can additionally supply the southeast side lost data in visible light one; the overall point cloud data will increase 26.55%, if the NIR data being added to visible light data. On the other hand, point clouds generated by color IR images (blue) has high overlapping percentage with visible light data, although it cannot supply the lost data in visible light, but it can increase the data amount in east side corner and vegetation on the ground; the overall point cloud data can increased 20.87%; the results shows that multispectral point cloud is beneficial to increase data increment, the detailed information is shown in Table 3.

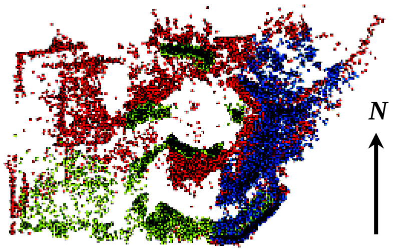


Figure 5. Vertical view of Combined Data

Table 3. Multispectral Point Cloud Data Information (Unit: Points)

Image Category	Visible Light	NIR	Color IR
Photosynth data	24850	20324	8975
Dissimilarity Points	--	8981	--
Same Area Increment Points	--	11343	6554
Data additionally supplied by NIR point clouds = 8981 / (8981+24850) = 26.55%			
Data increment by Color IR point clouds = 6554 / (6554+24850) = 20.87%			

5. SUMMARY

According to the results, overall accuracy, benefit of using multispectral images and the suggestions are described in following sections respectively.

5.1 Overall Accuracy

The point cloud data generated by multispectral images through coordinate transformation to LIDAR coordinate system, its checkpoint's RMSE in NIR data is ±9.6 cm, and the maximum checkpoint positioning error is 38.6 cm, it can be considered that although NIR images can generate mass point cloud data, but the recognizable feature point cannot cover the research area, causing the error in control point lacking area; the maximum checkpoint positioning error in visible light is 34.1 cm, which also produces in the same place.

Although the checkpoint's RMSE in color IR is ±7.7 cm, which is better than the checkpoint RMSE ±8.9 cm in visible light data, and checkpoint RMSE ±9.6 cm in NIR data, but its recognizable checkpoint is less than others, because of 46.6% vegetation point clouds in Color IR data, consequently, its actual accuracy should be lower than ±7.7 cm.

5.2 Benefit of Using Multispectral Images

This research uses multispectral images through image matching to generate point clouds, its purpose is to increase point cloud data by different reflectance in ground features. The result shows that NIR point clouds can additionally supply the data losing area of visible light data, because that area includes vegetation and manmade structures, which NIR images can generate different point clouds than visible light, and can compensate the lack of data area. On the other hand, color IR can generate less point cloud data than others, and it mostly appeared in vegetation area, because of its band combination contains two visible light bands (green and red), one can infer that band combination with higher divergence has better benefit in supplying lost data and increasing data increment.

5.3 Suggestions

(1) Due to the lack of point cloud data in partial research area, the control points cannot cover the whole area, causing the maximum 38.6 cm checkpoint positioning error. To reduce the error, one can take images with higher overlapping or different view angles, in the meanwhile, be caution of the aperture and exposure time while taking NIR images.

(2) This research only uses Photosynth three-dimensional coordinates to analyze the supplement and increment of multispectral data, further studies can focus on the accuracy and commission of point cloud data, also, by adding color information from Photosynth to assist ground feature interpretation.

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