INTEGRATION OF HIGH-RESOLUTION IMAGING AND TERRESTRIAL LASER SCANNER

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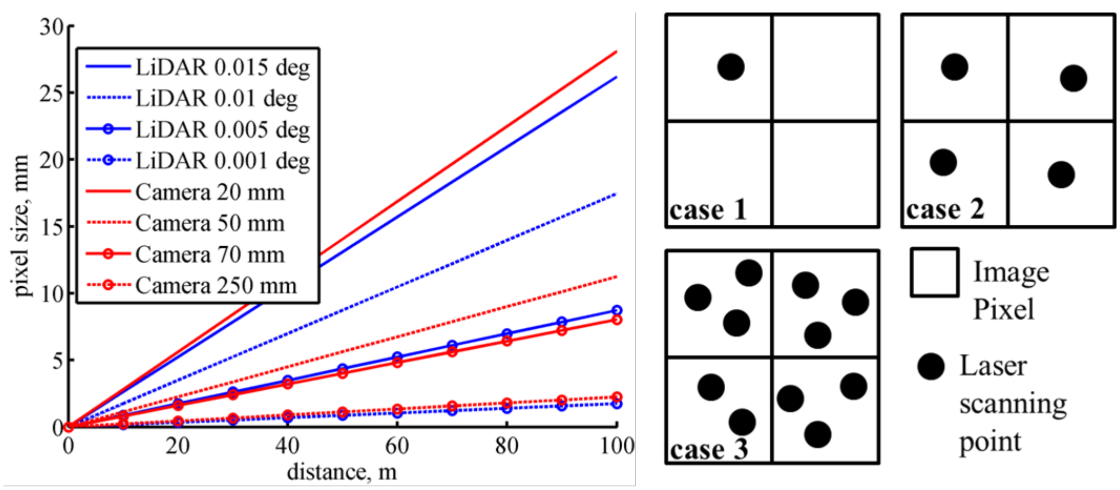
ABSTRACT

Point cloud data from laser scanner has a complementary property to imagery data such as surface information vs. texture information. Advance in technology has reached to the point where a camera mounted on top of a laser scanner can assign color directly from image pixels to 3D point clouds. Current terrestrial laser scanning system with camera on board uses digital image pixel (color) retrieval and Orthophoto generation, but the scanner camera is not fully utilized in terms of 3-dimensional measurement. For example, a target that is more than 100 meters from the system tends to experience a degraded image, spatial resolution-wise, while generating a sufficient number of points. It simply means image resolution is fixed while laser-scanning parameters are adjustable through scan rate, scan angle etc. The objective of this study is to incorporate a high-resolution imaging system to the laser scanning system so that color information is updated from high-resolution image.

Key Words: Digital Camera, Laser Scanning, Integration

INTRODUCTION

Terrestrial laser scanner has reached the level to which digital camera is tightly integrated so that color can be assigned to laser scanning point cloud from image pixel (Al-Manasir 2006). This provides visually enhanced point cloud model where intensity information of point become less distinct. Moreover, from image perspective, single image alone can possess 3-dimensional information without stereo setup. Most laser scanner system approaches this task through solving 'camera mounting matrix', explaining the relationship between scanner and camera's coordinate systems.



(A) (B)

Figure 1. (A) The resolution of laser scanning data and image. Image column is assumed to be 4200 pixel. (B) Image pixel and points distribution diagram – case 1, case 2 and case 3 indicate less points, same (or equivalent) points and more points per image pixel, respectively.

With different angular resolutions in laser scanner (0.015, 0.01, 0.005 and 0.001 degree) and lens focal lengths (20, 50, 70 and 250mm), simple calculation can reveal the relationship between spatial resolution of scanner and camera (Figure 1). The equations are followed below.

$$Pixel\ size = \frac{Distance}{Focal\ length} \times \frac{CCD\ size}{Image\ dimension}$$

$$Laser\ scanning\ point\ resolution = angular\ resolution(rad) \times Distance$$

For example, when 0.005 degree angular resolution of scanner and image with 70mm focal length are used (Case 2 in Figure 1-B), they tend to show similar spatial resolutions, regardless of the target distance. So does between 0.001 degree angular resolution and 250mm focal length image. While convenient to change scanner resolution by changing angular resolution, scanner camera that is used for color retrieval is usually position-fixed and calibrated. In this scenario, scanner resolution can be higher, equivalent or less than scanner image pixel size, depending on scanner angular resolution. In case there are multiple points in a pixel, colors of scanning point experience degradation from interpolation.

In theory, a camera doesn't have to be on or inside of laser scanner as long as 'mounting matrix' or camera exterior orientation parameter is known. In this research, a method to incorporate another digital camera in color retrieval is presented. Once camera position and orientation is known, the color of scanning points is assigned from new image that has better spatial resolution than scanner camera.

EXPERIMENTS

Experimental Data

This experiment uses Riegl Z210II terrestrial laser scanner with Nikon D300s scanner camera on top of the scanner. Scanner camera is calibrated by 'reflector column' method that computes 'mounting matrix' and intrinsic camera parameter as well. Total 10 retro-reflective targets were used for calibration. For this experiment, segment of the room were scanned in arbitrary local Cartesian coordinate with 24 KHz laser rate and 0.01 degree angular resolution. This makes scanner position an origin (0, 0, 0). Total 7,658,806 point cloud were generated and exported to XYZRGB ASCII format. There are two cameras – one in the scanner and another digital camera. To avoid the confusion between cameras, when referred, the camera on the scanner is called 'scanner camera' and the other as 'digital camera'

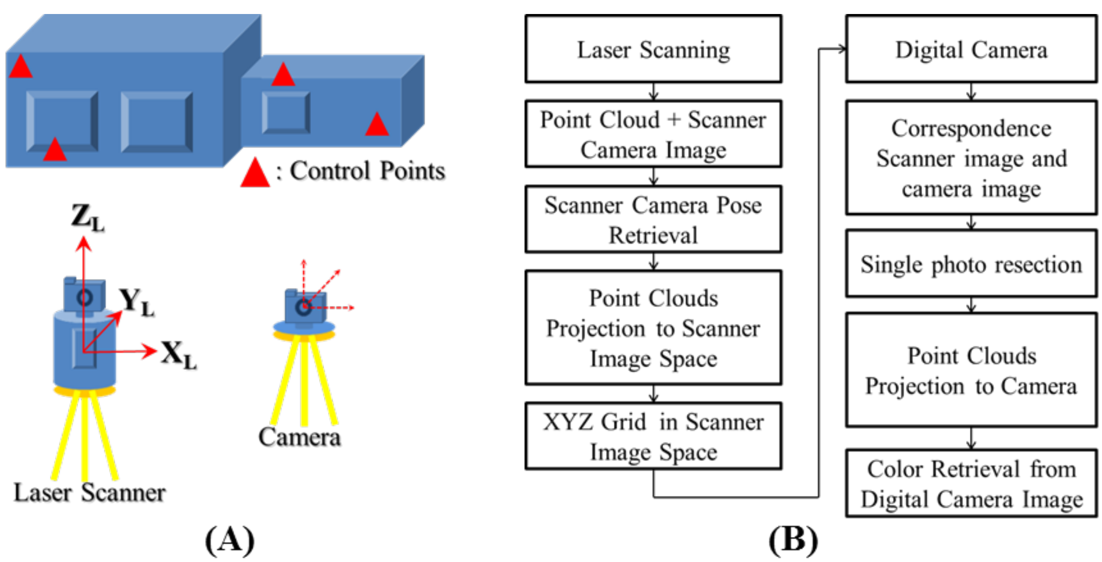


Figure 2. Deployment of sensors (Left) and Workflow of proposed method

Scanner camera (Nikon D300s) has 4299x2848 image dimension with 20mm focal length lens and Digital camera (Nikon D7100) has 2992x2000 image dimension with 18-300 mm zoom lens. CCD sizes of these cameras are 23.6x15.8mm and 23.5x15.6mm respectively.

Figure 3. (A) 3D point cloud of test site- screenshot of RiSCAN PRO. (B) Subset of point cloud of three objects in 3D. (C) Scanner camera image (D) digital camera image (E) Subset of scanner image (F) Subset of digital camera image.

Figure 3 shows acquired laser scanning data (Figure 3-A), image from scanner camera (Figure 3-C) and image from digital camera (Figure 3-D). Scanner covers only vertical 75-100 degree and horizontal 0-30 degree that is a segment of scanner image. Figure 3-C and 3-D show the different image coverage due to different focal length, 20mm and 76mm respectively. Figure 3-E and 3-F are enlarged subsets of image to illustrate different spatial resolution. Figure 3-B is 3D point cloud representation of the same object as seen Figure 3-E. It is clear that color information of point cloud depends on scanner image quality. For instance, Figure 3-B shows similar representation of scanner image in Figure 3-E.

When 0.01 angular resolution of scanner (Blue dashed line in Figure 1-A) and 20mm scanner camera (Red solid line in Figure 1-A) are compared in terms of spatial resolution, roughly 2.7 points share the same pixel in image and this is case 3 in Figure 1-B. Digital camera (76mm focal length), on the other hand, shows opposite case. That is less than one point in a pixel. (0.47 points in a pixel)

Data Processing

Data processing consists of three main parts. In the first part, scanner/camera pose is extracted from a scanning project file by combining mounting matrix and image scanning matrix which is equivalent to exterior orientation in photogrammetry (Riegl et al 2003). Then, all cloud points are back-projected to scanner image space by collinearity equation and three grids are generated in image space, namely X Grid, Y Grid and Z Grid. These grids represent XYZ coordinate of scanned area (Figure 4)

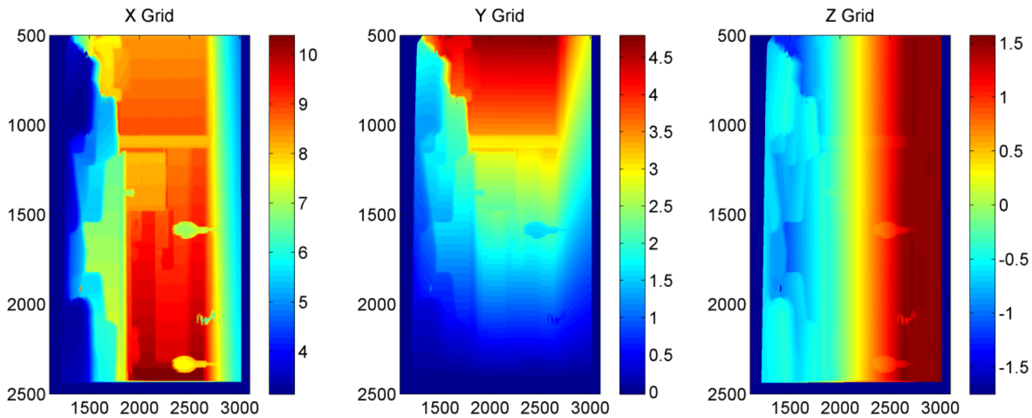


Figure 4. X, Y and Z grid. The dimension is equivalent to scanner image

The second part is to compute digital camera pose estimate. Here, 13 matching points are manually measured in scanner camera image and digital camera image with proper distribution. 3-diemntional information of matched points is extracted from XYZ grid computed above by bilinear interpolation. Then to compute focal length in single photo resection process (Mikhail and Bethel 2001, Stamos and Allen 2001, Haralick et al 1994), focal length parameter is linearized in a design matrix.

Last step is to back-project point cloud to digital camera image space with above computed camera pose parameter and focal length. Bilinear interpolation used to update color image information from digital camera image.

RESULTS AND DISCUSSION

Due to difficulty in comparing 3D point clouds, original point clouds and updated point clouds are projected to image space and gridded in Red, Green and Blue bands and merged for color representation to check the improvement. The improvement in spatial resolution is visible when Figure 5-B and 5-C are compared and the amount that is showed between Figure 5-B and 5-C is similar to difference between scanner image (Figure 3-E) and digital image (Figure 3-F). Another test subsets, Figure 4-E and Figure 4-F show a similar pattern.

From Figure 1-A, color points from scanner image is over-sampled with 2.7 point per pixel, while digital camera case is under-sampled with 0.47 points/pixel. It is ideal to match scanner resolution and image resolution however, small amount of over/under sample, in this case from 0.5 to 2, tends to be compensated by interpolation. Overall, updated point cloud shows improved image quality; however, side effect is observed in the left side of image, indicating errors in mounting matrix, camera pose estimation, and lens calibration parameter. Tests with equivalent scanner/image resolution will discover how much over/under sampling can be compensated by interpolation. There are also possibilities 1) to solve digital camera pose estimation by impropriating image matching techniques such as normalized correlation matching, Scale Invariant Feature Transform (SIFT) etc, and 2) to add more point cloud from multiple digital camera images.

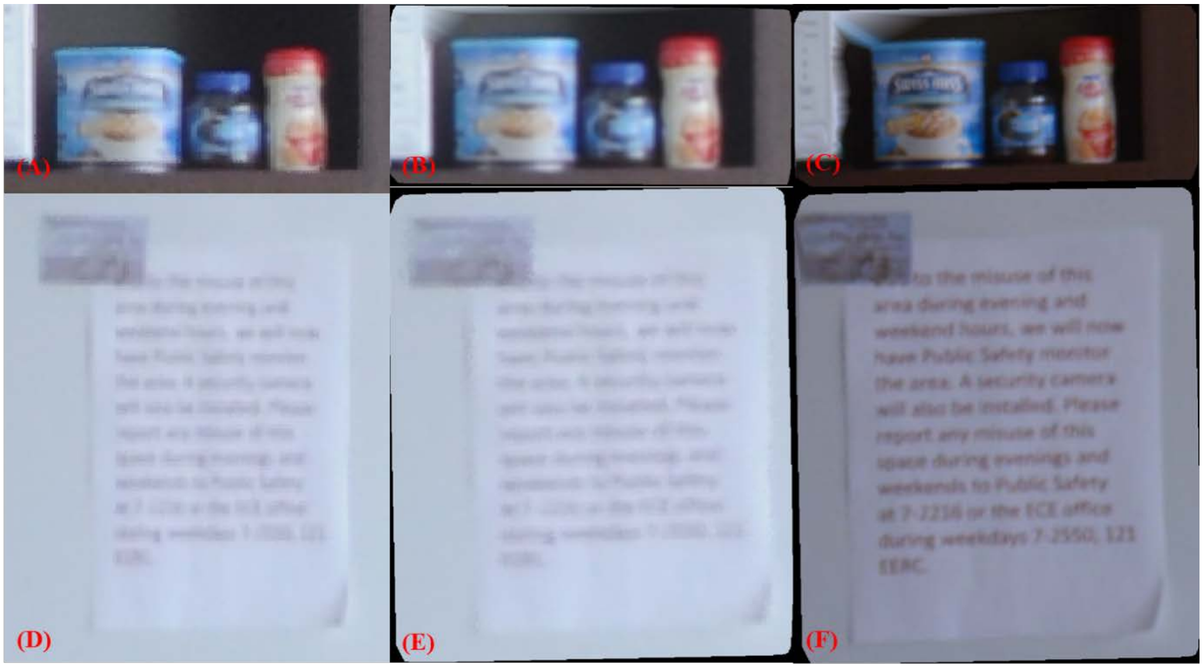


Figure 5. Original point cloud and updated point cloud. (A) and (D) are screenshots of RiSCAN PRO program (2D color representation). (B) and (E) are subset of image when point clouds are projected to scanner image and color gridded. (C) and (F) are projected to camera image and gridded with updated point cloud.

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REFERENCES

Al-Manasir, K. and Fraser, C., 2006. Registration of terrestrial laser scanner data using imagery. *The Photogrammetric Record* 21(115), 255–268.

Haralick, R. et al., 1994. Review and analysis of solutions of the three point perspective pose estimation problem. *IJCV* 13, pp. 331–356.

Mikhail, E.M., Bethel, J.S. and McGlone, J.C., 2001. *Introduction to Modern Photogrammetry*. John Wiley & Sons, New York. 479 pp.

Riegl J., Studnickan., Ullrich A., 2003. Merging and processing of laser scan data and high-resolution digital images acquired with a hybrid 3D laser sensor, Proceedings of CIPA XIX international Symposium, Commission V, WG5, Antalya,

Stamos, I., Allen, P.K., 2001. Automatic registration of 2-D with 3-D imagery in urban environments. *the 8th IEEE International Conference on Computer Vision*, vol. 2, pp. 731-736.