Paper: ASAT-16-167-IP

16th International Conference on
AEROSPACE SCIENCES & AVIATION TECHNOLOGY,
ASAT - 16 – May 26 - 28, 2015, E-Mail: asat@mtc.edu.eg
Military Technical College, Kobry Elkobbah, Cairo, Egypt
Tel : +(202) 24025292 – 24036138, Fax: +(202) 22621908

Automatic registration for long range laser data in the stop-and-go mode

H. Badawy, M. Elhabiby, N. El-Sheimy, B. Sheta
Geomatics Engineering Department, University of Calgary, AB, Canada
mmelhabi@ucalgary.ca

Abstract

In this work we are focusing of the registration of Long Range scans taken in the SAG mode, we find an automatic registration algorithm based on mapping 3D scans to 2D images. After mapping the scans to images, we use SURF matching algorithm for automatic matching points detection. Rough registration parameters can be estimated via Least Squares method based on the tie points in the two scans. To refine these registration parameters, the Iterative Closest Point (ICP) approach is used with the scans.

The overall method of automation of registration is efficient in terms of speed, and accuracy, especially with many scans.

Introduction

Terrestrial Laser Scanner is an important tool for 3D modeling applications, especially for 3D city modelling, for which it gives accurate modelling of objects' dimensions and their locations in reality. The accuracy in some devices is in orders of millimeters. The accuracy of the 3D modelling/mapping depends on the device and the mapping mode used. There are mainly two categories of Terrestrial Laser scanners, namely, Short Range and Long Range. Short range Laser scanner is an accurate type of scanners but has limited effective range (10 to 20 meters). On the other hand, long range laser scanners have operating ranges up to 1000m but with less accuracy. Mapping modes could be either fully static, fully dynamic or Stop-And-Go (SAG). For the fully dynamic mapping modes (also known as mobile mapping), a vehicle equipped with GPS/IMU system together with a short range laser scanner, in which the accuracy is now limited not only by the laser scanner but also with the GPS/IMU system. Moreover, the short range laser scanner is limited to a certain working range. A good replacement for the system is the use of SAG mode with a long range laser scanner. The system does not require IMU since the vehicle is not moving during the scan time. Moreover, using long range laser scanner guarantees mapping large areas with few number of scans. The small number of scans reduces scanning time, number of labors and the registration errors between scans. Although the number of scans is few with the long range scan, the process of registration of the scans is cumbersome, and it generates errors especially when it is performed manually.

The automation of the registration process has been always a hot topic among those of laser scanner data manipulations. Many authors made lots of efforts towards the automation of registration. Some of the work done by the authors is summarized here as a review before introducing the proposed algorithm. Bae and Lichti (Bae and Lichti 2008) proposed a method for unorganized PCs using geometric primitive ICP with RANSAC. Their idea was to utilize the change in the curvature and normal vector of the surface in the neighborhood of a point to automatically detect corresponding points. Other authors have integrated images obtained from the camera attached to the devices such as Terrestrial Laser Scanners (TLS).

Some of the efforts made using images were targeted towards the use of image processing techniques to extract features from images such as (Barnea and Filin 2008), (Martin Weinmann and Jutzi 2011), (Ma Weinmann et al. 2011), (Wang & Brenner, 2008) and (Yang, Cao, and McDonald 2011). In the work of (Barnea and Filin 2008) they performed a transformation from the (x, y, z) coordinates to (ρ, ϕ, θ) then used (ϕ, θ) to generate a panoramic range image with intensity as range. Then they used an operator called max-min operator to detect corner features in the images.(Forkuo and King 2004) and (Moussa, Abdel-Wahab, and Fritsch 2012) used the collinearity equation to back-project the 3D points in the point cloud to their 2D image points. (Ma Weinmann et al. 2011) used the Efficient Perspective-n-Point (EPnP) after using SIFT matching algorithm to have a 3D to 2D correspondence. The work done by (Al-Manasir and Fraser 2006) and (Mohammed et al. 2014) are common examples of the use of photogrammetry to estimate initial orientation between point clouds.

The Algorithm

In the proposed automatic registration algorithm, a 2D image is created form the 3D point cloud generated from the TLS through a one-to-one direct mapping from (x, y, z) point cloud coordinates to (x_p, y_p) image coordinates. One of the coordinates will be excluded via flattening of the point cloud. Mainly, the $z-$ coordinate component is excluded to have a projected flattened plan view of the point cloud.

After the point cloud to image mapping; the SURF algorithm for matching features detection between images is applied to two created images from two point clouds, and the common features are selected. These features are used as tie points between the two point clouds. In order to get the 3D point information associated with these tie points, a reverse mapping from 2D images pixels of the features to the 3D point clouds coordinates is performed. Where we benefit from the fact that laser scanner is mapping surfaces, therefore each pair of coordinate components (x, y) is associated with only one unique third coordinate component z.

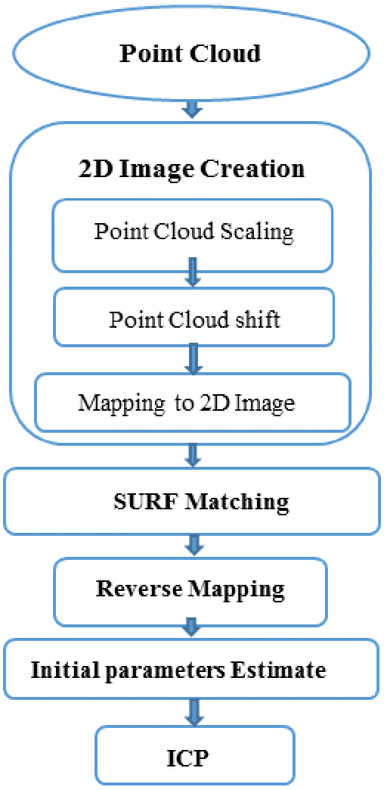

Figure 1: Automatic Registration Algorithm.

Now, after obtaining the 3D coordinates of the tie points in each scan, a simple Least Square (LS) estimation for the registration parameters is performed to obtain rough registration parameters of the two point clouds. To enhance those registration parameters the well-known standard Iterative Closest Point (ICP) algorithm is applied. This new automatic registration algorithm is illustrated in **Figure 1**, and each step is described here in detail.

Creation of 2D images from 3D point clouds

3D points are either of the form (x, y, z, R, G, B) or (x, y, z, I). Where the (R, G, B) stands for the Red, Green and Blue values of the colour associated with each point, and I stands for the intensity of the received laser beam. Sometimes both RGB and Intensity information are included associated with the point cloud.

The (x, y) coordinates will be mapped to the index of the image matrix and the value of the pixel in the image at that index will be the RGB or intensity value.

That is:

$$f(x_p, y_p) = RGB \tag{1}$$

Point Cloud Scale

Each index in the image matrix must have an integer value. However; the (x, y, z) coordinates in the point cloud are of decimal values. It is noticeable also that these coordinates are measured in meters. Therefore, the point cloud coordinates are multiplied by a scale factor and the result is rounded so that the mapped pixels are consistent with the 3D point cloud. The rounding error will be the same order of the point spacing. The scale factor value is chosen depending on the point density of the point cloud and the accuracy required. For example, if we consider a point with one of its component$= 1.149\,m$. If the scale factor is chosen to be $S = 10$, then the value of the component after rounding will be 11 in 2D image space. If this point is reverse mapped to 3D point space, it will be divided by the scale, $S = 10$, then the component retrieved will be $1.1m$. That means we $4.9cm$ were lost during the rounding process, which means that a scale factor of 10 will lead to inaccuracy of about *5cm*. Similarly, a scale factor of 100 will lead to a rounding error of 5 mm, and so on.

Point Cloud Shift

The origin of the point cloud is normally the origin of the laser scanner. Which means that the point cloud have coordinates shifted from the origin (in which the laser scanner is placed). When mapping these points to the image, usually they we will be located at one of the corners of the image and the rest of the image will be white pixels. In order to overcome this problem the point cloud is shifted such that its origin is at the origin of image. First the centroids of the point cloud are computed as in (Vosselman, Maas, and Eds.) 2010):

$$\begin{aligned} x_m &= \frac{1}{n_x}\sum_{i=1}^{n_x} x_i \\ y_m &= \frac{1}{n_y}\sum_{i=1}^{n_y} y_i \\ z_m &= \frac{1}{n_z}\sum_{i=1}^{n_z} z_i \end{aligned} \qquad (2)$$

Then the coordinates are shifted:

$$\begin{aligned} x_i' &= x_i - x_m \\ y_i' &= y_i - y_m \\ z_i' &= z_i - z_m \end{aligned} \qquad (3)$$

Point Cloud to Image Mapping

The algorithm used to map the 3D point $P_i(x_i, y_i, z_i)$ in the point cloud into a pixel in the 2D image with a scale S can be summarized with the following equations:

$$Q_i(x, y, z) = P_i(x, y, z).S \qquad (4)$$

$$\alpha = -z_i' + \frac{r}{2} \tag{5}$$

$$\beta = x_i' + \frac{c}{2} \tag{6}$$

$$f(\alpha, \beta) = RGB_{P_i} \tag{7}$$

where Q_i is the scaled 3D point,(α, β) are the pixel coordinates, r is the number of rows in the image, and c is the number of columns. Equation (7) can be used with intensity values instead of RGB colour.

The reverse mapping from image pixels to 3D points is straight forward from the above equations. The only thing is that we will get a 2D point from these equations. A simple search in the point cloud will retain the third coordinate of the 3D point. If multiple third coordinate values arise from this search (which will be very close), one can take the average of these values

The one-to-one direct mapping is very simple in formulation and does not require organizing the point cloud. Also, the algorithm does not require a large overlapped area, opposite to algorithms using photogrammetric methods such as collinearity and coplanarity equations.

Rough Registration Estimation

The equation which describes the orientation of one scan with respect to another is:

$$\begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix} = \boldsymbol{R}(\omega, \phi, \kappa) \begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \end{pmatrix} + \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

Where (X_1, Y_1, Z_1) is the coordinates of points in the first scan, and (X_2, Y_2, Z_2) is the coordinates of points in the second scan, $\boldsymbol{R}(\omega, \phi, \kappa)$ is the rotation matrix in terms of the Euler angles (ω, ϕ, κ). The Euler angles and the translation vector $(x, y, z)^T$ are the registration parameters to be estimated.

The estimation of these parameters is done using the Least Squares estimation method. At least three non-collinear tie points must be selected in the two scans in order to have the Least Squares equation.

The tie points are selected automatically using the point cloud to image mapping algorithm. The accuracy of these selected points will affect the accuracy of the estimation of the registration parameters. In general, the registration parameters will not be accurate. Hence, the ICP approach is used to enhance the registration parameters. The ICP algorithm is discussed in detail in (Vosselman and Maas 2010).

Results and Discussion

Test Data

The test data were collected with a long range laser scanner in the downtown area of the city of Calgary, AB, Canada. The data were collected over an area of $(176m \times 200m)$. Two scans were taken as a sample to show that long range scans can cover a wide working area for mapping. The test area is shown in Figure 2 taken from Google Maps.

Figure 2: Test area in the city of Calgary.

The two scans were taken from opposite directions. The two scans are shown in . The blue points refer to the point cloud taken as a reference, and the red points refer to the point cloud to be registered.

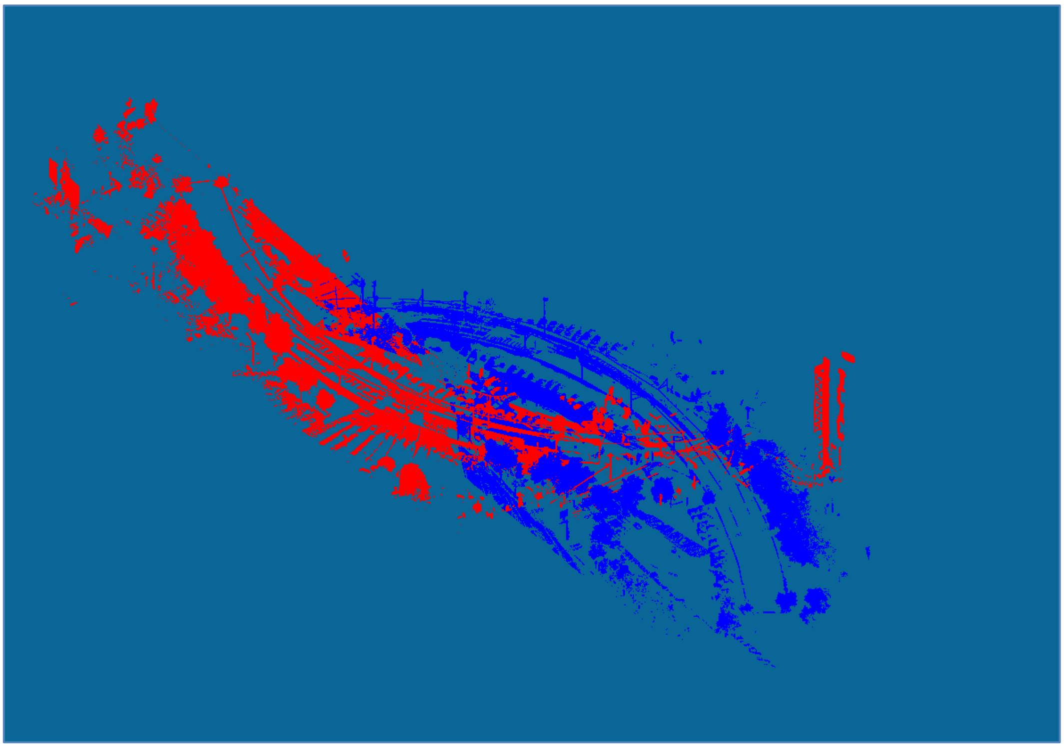

Figure 3: The two scans taken in the test area with long range laser scanner. Blue points are the reference point cloud, and red points are the point cloud to be registered.

The images are created from both scans, and the SURF algorithm was applied on the two images. The matching points from both images are shown in **Figure 4**.

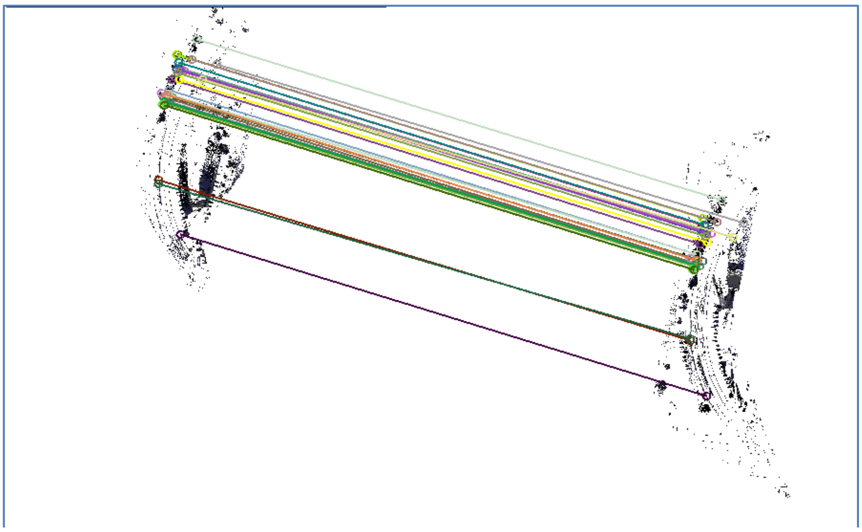

Figure 4: the SURF matching results in two scans.

These points were reverse mapped to get the corresponding 3D points. These 3D tie points are used to obtain a Least Square solution for the registration parameters. The registration from the Least Square solution is rough registration. This is clearly illustrated in **Figure 5** where the two points cloud are roughly registered. It's noticeable that the red point cloud is aligned with blue point cloud at the center, then it diverges from the blue scan as we move away from the center.

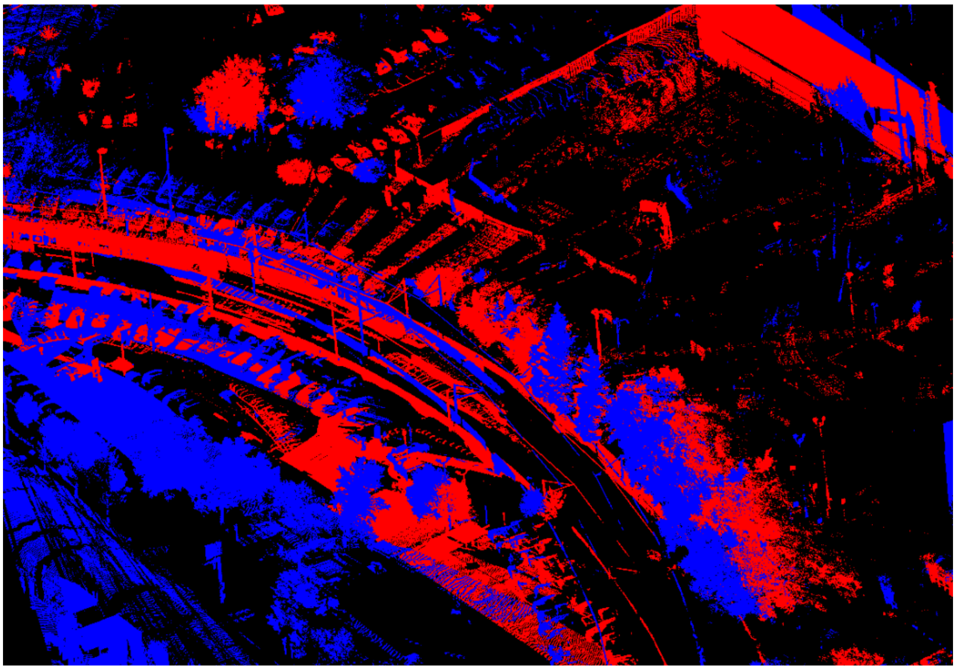

Figure 5: The two point clouds registered (roughly) using the automatic point cloud to image mappings algorithm.

The ICP approach was applied on the red scan to refine the registration to the reference scan (the blue point cloud).

The result of the ICP registration refinement is in **Figure 6**, **Figure 7** and **Figure 8**, where in Figure 6 and Figure 7 show a full view for the two scans, where in ***Figure 8*** a close up zoom views are drawn to show visually the efficiency of the algorithm.

Numerical assessment is listed in Table 0-1, where the error was taken with respect to the ICP result as a reference. The error in the x-coordinate and the angle κ were shown to have large error values. The reason is that we work on a large and wide area and moving away from the center of the point cloud will increase the error of registration.

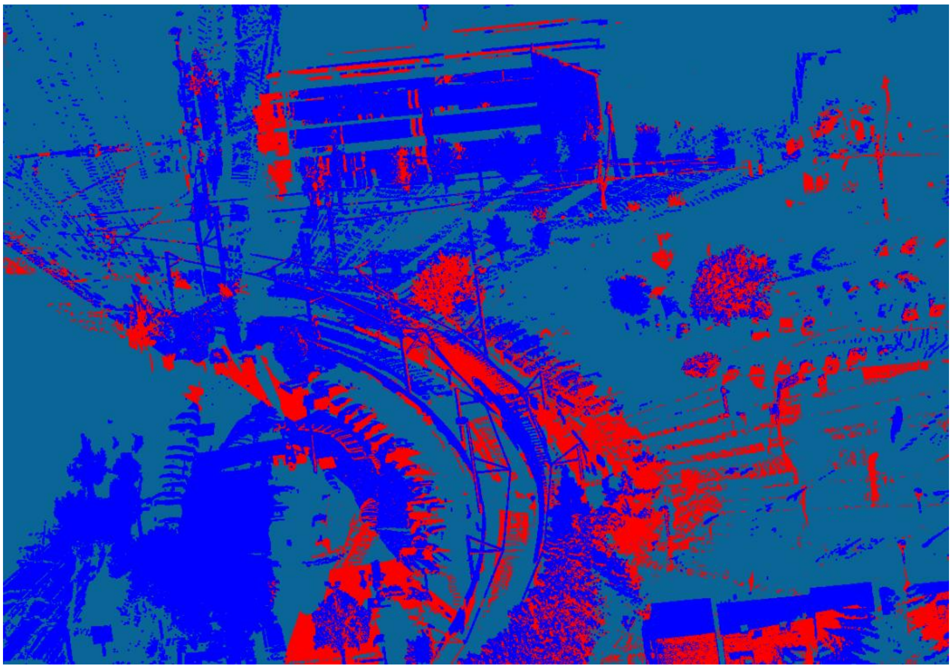

Figure 6: Refinement of the registration process using the ICP approcah (Scene 1).

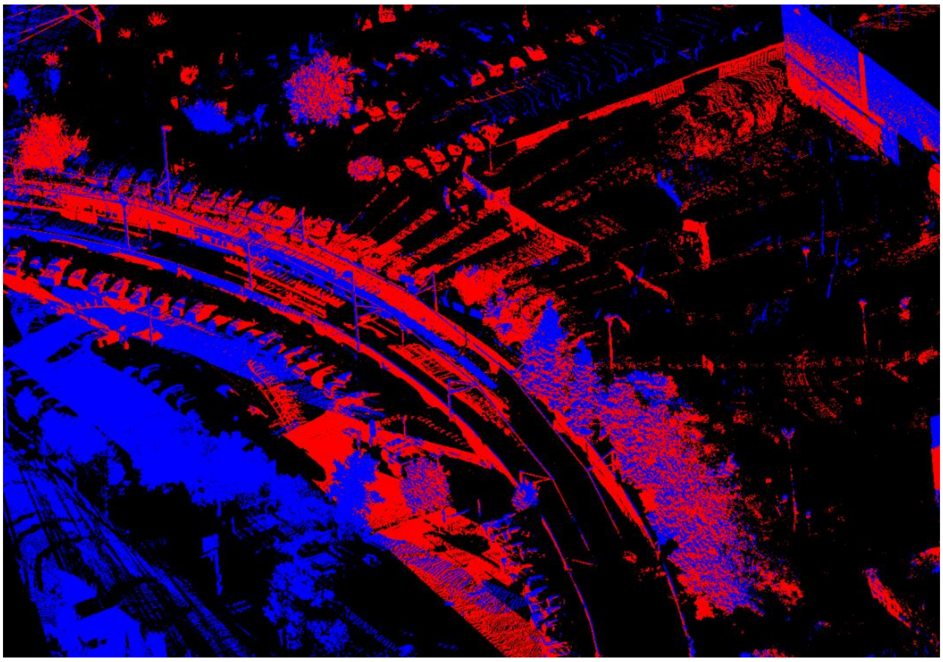

Figure 7: Refinement of the registration process using the ICP approcah (Scene 2).

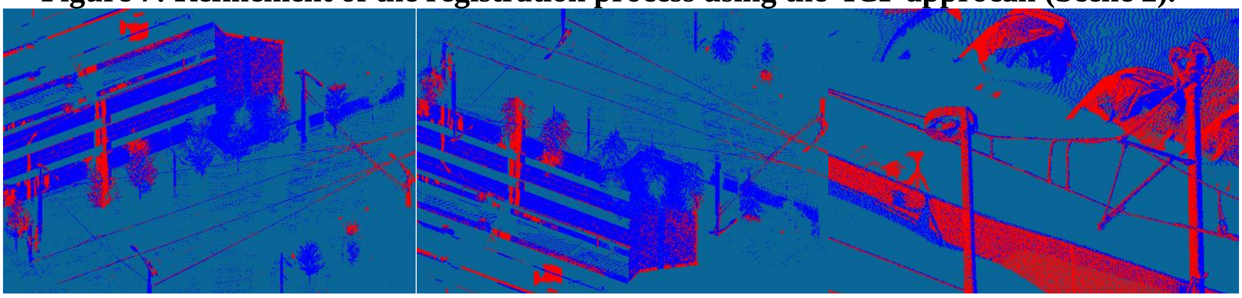

Figure 8: Close-up view of the final registration using the automatic registration and the ICP approach.

Table 0-1: The registration parameters (using only the automatic registration algorithm) and their errors.

$x(m)$	$y(m)$	$z\ (m)$	ω (°)	ϕ (°)	κ (°)
0.257	-37.185	-0.94	-0.67	1.8	-178.6
$\Delta x(m)$	$\Delta y(m)$	$\Delta z\ (m)$	$\Delta\omega$ (°)	$\Delta\phi$ (°)	$\Delta\kappa$ (°)
8.757	0.606	0.296	-1.045	-2.04	-7.59

Conclusion

In this paper we have shown that direct 3d to 2d image mapping is an easy and efficient method of estimation of coarse registration parameters between point clouds. We used SURF algorithm which is also fast image matching algorithm to determine the matching points between the two point clouds. Applying standard ICP enhanced the registration as expected. The mapping method is direct one-to-one mapping which works with both RGB and intensity information. The error of coarse registration was computed with respect to the ICP registration as a reference and it was shown that the error increases with moving away from the center of the point cloud.

References

Al-Manasir, Khalil, and Clive S. Fraser. 2006. “Registration of Terrestrial Laser Scanner Data Using Imagery.” *The Photogrammetric Record* 21 (115): 255–68.

Bae, Kwang-Ho, and Derek D. Lichti. 2008. “A Method for Automated Registration of Unorganised Point Clouds.” *Theme Issue: Terrestrial Laser Scanning* 63 (1): 36–54. doi:10.1016/j.isprsjprs.2007.05.012.

Barnea, Shahar, and Sagi Filin. 2008. “Keypoint Based Autonomous Registration of Terrestrial Laser Point-Clouds.” *ISPRS Journal of Photogrammetry and Remote Sensing* 63 (1): 19–35.

Forkuo, Eric K., and Bruce King. 2004. “Automatic Fusion of Photogrammetric Imagery and Laser Scanner Point Clouds.” *International Archives of Photogrammetry and Remote Sensing* 35: 921–26.

Mohammed, H., N. M. Alsubaie, M. Elhabiby, and N. El-sheimy. 2014. “Registration of Time of Flight Terrestrial Laser Scanner Data for Stop-and-Go Mode.” *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* XL-1 (November): 287–91. doi:10.5194/isprsarchives-XL-1-287-2014.

Moussa, Wassim, Mohammed Abdel-Wahab, and Dieter Fritsch. 2012. “Automatic Fusion of Digital Images and Laser Scanner Data for Heritage Preservation.” In *Progress in Cultural Heritage Preservation*, 76–85. Springer.

Vosselman, George, and Hans-Gerd Maas. 2010. *Airborne and Terrestrial Laser Scanning*. Whittles.

Vosselman, George, Hans-Gerd Maas, and (Eds.). 2010. *Airborne and Terrestrial Laser Scanning*. Whittles.

Weinmann, Martin, and Boris Jutzi. 2011. “Fully Automatic Image-Based Registration of Unorganized TLS Data.” *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci* 38: 1–6.

Weinmann, Ma, Mi Weinmann, Stefan Hinz, and Boris Jutzi. 2011. “Fast and Automatic Image-Based Registration of TLS Data.” *ISPRS Journal of Photogrammetry and Remote Sensing* 66 (6): S62–70.

Yang, Michael Ying, Yanpeng Cao, and John McDonald. 2011. “Fusion of Camera Images and Laser Scans for Wide Baseline 3D Scene Alignment in Urban Environments.” *Advances in LIDAR Data Processing and Applications* 66 (6, Supplement): S52–61. doi:10.1016/j.isprsjprs.2011.09.004.