Intensity Augmented ICP for Registration of Laser Scanner Point Clouds

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Abstract

While using Laser Scanner for map-making or developing 3D models of objects, it is important to scan the site or the object of interest from multiple viewpoints. These different scans are then integrated to generate a complete point cloud which is then used for developing the map or 3D model of the site. ICP (Iterative Closest Point) is a standard algorithm for registration of point clouds. However, in the absence of marked 3D features which are geometrically distinct in the points clouds, that are being combined, this method tend to fail sometime. This paper exploits the radiometric data that are always obtained along with the coordinates of point cloud and devises a novel approach for scan registration. Before using radiometric data in registration process these are normalized. The algorithm presented in this paper works in two stages- with Intensity Augmented ICP (IAICP) for coarse registration stage and conventional geometric ICP at the fine registration stage. The proposed approach is successfully applied to a test data resulting in an accurate estimation of the transformation parameters. A comparison of the conventional and intensity augmented registration approaches is also presented. The results indicate the supremacy of IAICP over the ICP, as the latter is found to fail in geometrically confusing cases while intensity augmented ICP works in these cases.

Introduction

The process of map making has changed in a significant manner since the availability of laser scanners. As laser scanners are capable of capturing billions of data points in a single hour, in comparison to about 60-80 data points in case of Total Station, the speed of data capture has increased multifold. Besides, the data captured are very comprehensive and make it possible to map or model fine details, which would otherwise go unnoticed in case of Total Station survey. There are several advantages of using laser scanner for mapping or 3D modeling and in view of these this is replacing Total Station based mapping to some extent in some applications.

While working with laser scanner it is required to capture multiple scans of the area to be mapped or the object to be modeled. The multiple scans have their own local coordinate systems. To view complete area of interest together all such scans are combined in a single point cloud. This single point cloud is then used for mapping or modeling the objects.

The conventional methods of integrating multiple scans are by first selecting few control points in the overlap area of the master and slave scans. With the rigid body transform using these control points the slave scan is brought on to the coordinate system of the master point cloud. This method is, however, affected by the observational errors in selecting the control points and also need the manual intervention as control points are selected by an observer. In order to avoid these limitations a common method for scan point cloud registration is ICP (Iterative Closest Point) algorithm [1]. The original method was based on establishing point to point correspondences by Euclidean distance evaluation. The ICP variant proposed by [2] analyzes the local surface approximations of the datasets. A method to incorporate the k-d tree data structure into point matching algorithm in order to speed up point correspondence computational times is described in [3]. The classical ICP is susceptible to non-overlapping regions since it does not consider the overall geometry but local geometries and may lead to incorrect results by converging to local minima [4]. As the ICP algorithm basically uses the geometric property of the scanned objects it tends to fail in situations where the objects do not possess marked geometric features, or where the geometric match still is possible even if the object is rotated e.g. wide land, a wall, a door etc. Most of the variants of ICP that were developed tend to focus on increasing the speed but not to solve this problem.

In view of the above the goal of this paper is to investigate the use of intensity information along with the geometric information of point clouds for their registration. This approach is based on the fact that despite the objects (overlap area between two scans) being bereft of any or sufficient number of distinctive geometric features there always is a possibility that there exist distinctive radiometric features which can be used for matching scans. The paper will show development of this new approach, called, intensity augmented ICP (IAICP), and present some results to show its utility.

Methodology

The proposed methodology has three basic steps. (1) Normalization of the LiDAR intensity data (2) Coarse registration of the LiDAR point clouds using intensity augmented method (3) Fine registration using geometric ICP algorithm. The flow chart of the proposed algorithm is given in Fig. 1.

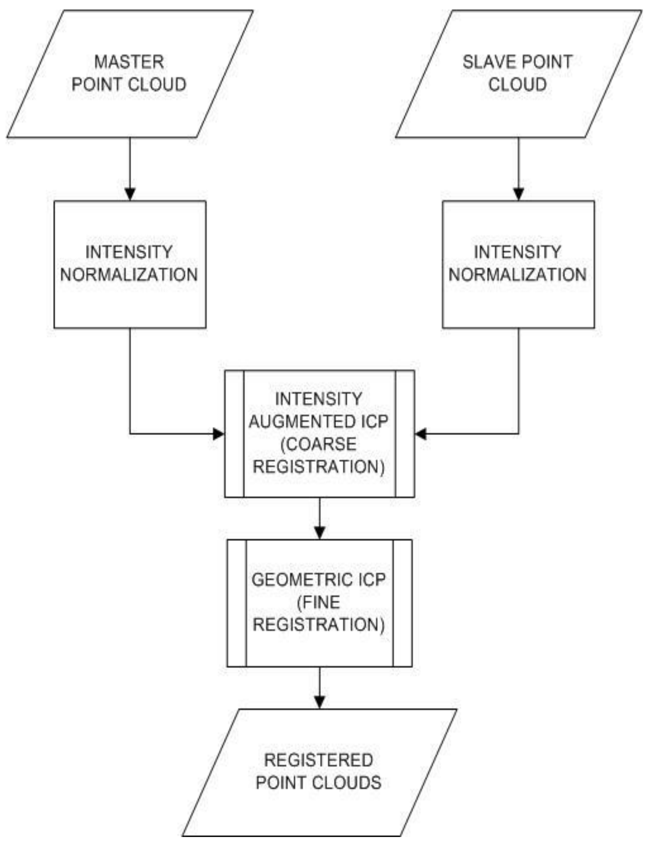

Fig. 1. Flow chart of the proposed algorithm.

A. Resources employed

ILRIS 3D terrestrial laser scanner from Optech. Inc. Canada was used in this study for collecting laser scans of the test objects. This scanner collects data in a 40 by 40 degree window, while this window can be rotated with the help of a PanTilt device to cover entire 360 degree in horizontal and 180 degree in vertical. The initial data generated by ILRIS3D were processed using the accompanying parser software to yield coordinates (x, y, z) and the intensity value for each point captured. The intensity directly provided by the instrument is called raw intensity. The 8 bit intensity data is derived from the raw intensity after applying some corrections and truncating these values to 8 bit format for improving the visual quality of the point cloud and is unavailable to the end user. In this paper terminology ‘raw intensity’ refers to the 16 bit intensity data provided by the TLS.

All algorithms developed and employed in this paper were realized through a code written in MATLAB. The mathematical background and code is beyond the scope of this paper and are not being presented.

B. Normalization of LiDAR intensity

The steps for normalization of LiDAR intensity are shown in Fig. 2. Outlier elimination step removes the isolated data points, i.e., those with less than 10 nearest neighbors. A simple k-nearest neighbor ball

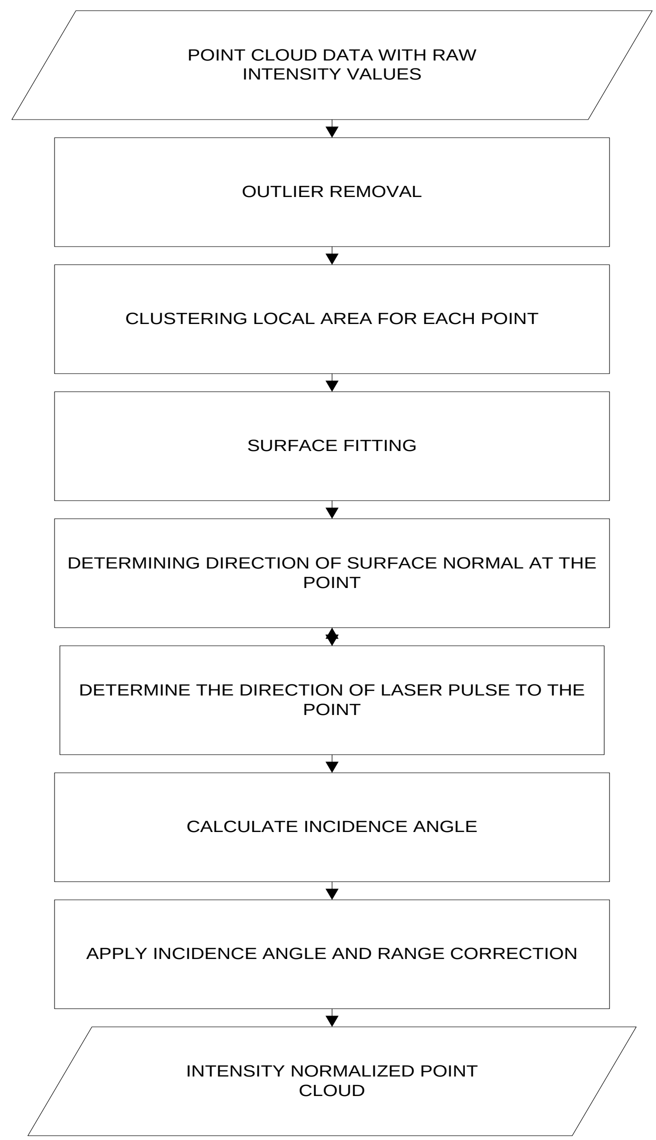

Fig. 2. Flow chart for Intensity Normalization Algorithm.

search is employed for clustering the data. Each data point is selected at a time and its neighboring data points lying at a radius are selected. The radial distance for nearest neighbor ball search depends on scan density. To apply the incident angle correction at each data point, the direction of the incident ray vector and the normal at each data point needs to be calculated. For individual clusters formed at each data point, a second order polynomial surface is fit and the direction of the normal at that data point is determined. The incident angle is calculated by taking the inverse cosine of the ratio of dot products of direction of normal and direction of laser pulse at a particular point, where the latter is known in terms of coordinate of the point where normal is being computed. The normalized intensity is then computed using:

$$I_{norm} = I_{raw}\left(\frac{R_{act}}{R_{ref}}\right)^2 \left(\frac{1}{\cos(i)}\right) \quad (1)$$

Where, I_{raw} and I_{norm} are raw and normalized intensities, R_{act} and R_{ref} are actual and reference ranges and i is the incident angle.

C. Coarse registration by intensity augmented ICP

The description of ICP algorithm is beyond the scope of this paper and can be seen in the cited references. The intensity augmented ICP implemented in this paper differs from the classical ICP as in addition to coordinates the intensity information is also included in the correspondence matching search space. Before including the intensity information, the intensity normalization process explained above is performed. This enables the determination of correspondences in a more abstract way by using (x, y, z, Intensity) vectors rather than using pure geometric information using (x, y, z).

Hence the algorithm searches both intensity and spatial spaces at the same time for correspondences. For a point cloud from a terrestrial laser scanner the spatial coordinates and the intensity values cannot be directly utilized without scaling. For scaling intensity data, the z-score statistical standardization technique is used. The basic algorithm flow chart is shown in Fig. 3.

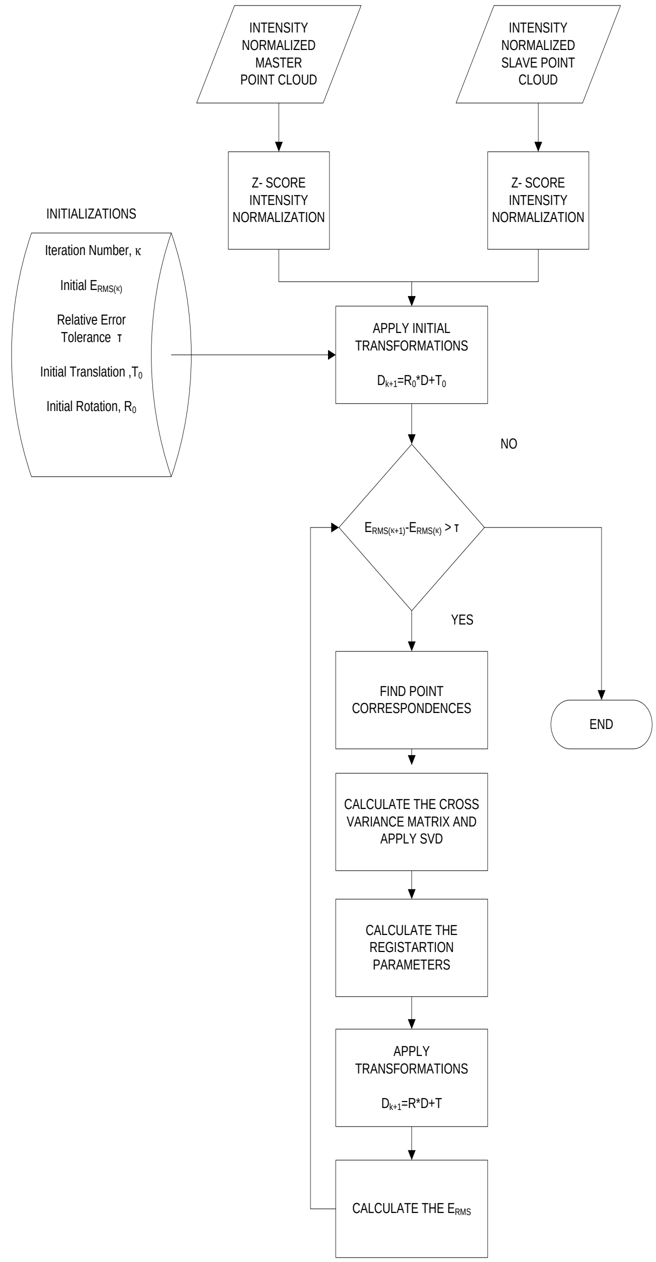

Fig. 3. Course registration process-Phase I

D. Fine registration using geometric ICP

The IAICP is followed by the geometric ICP in order to guarantee proper registration. Here the more accurate point to plane minimization technique is used. The point to plane variant of ICP improves performance by taking advantage of the surface normal information. The point to plane algorithm minimizes the error along the surface normal.

This minimization scheme involves two processes, viz. calculating the surface normals for the Master point cloud and then minimizing the angle between the normals of Slave and Master cloud. The approximate surface normals are computed using Principal component analysis. For computing the surface normals, four nearest neighbors are selected for each point, the Eigen vector corresponding to the smallest Eigen value represents the surface normal at that point. The flowchart for fine registration is shown in Fig. 4. The output of ICP iteration is 3D transformation parameters for registration. Plane minimization is computationally complex and time consuming, but as the coarse registration has already been achieved, the convergence is faster.

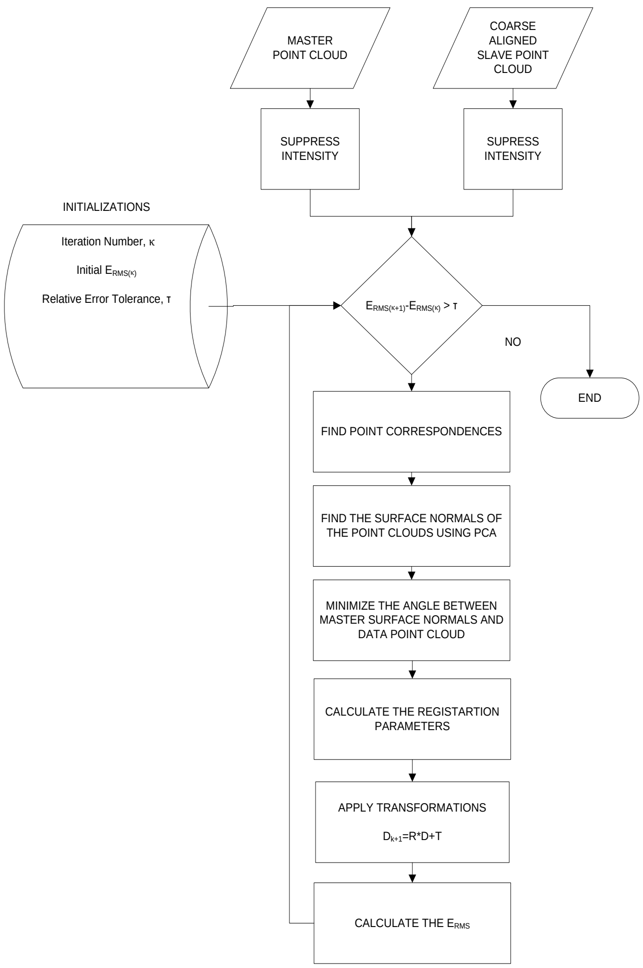

Fig. 4. Fine registration – Phase-II

Results and discussion

The results are aimed at proving the hypotheses that (i) intensity normalization method proposed is effective and (ii) intensity augmented ICP is an effective solution where classical ICP fails due to geometric confusion.

E. Intensity normalization results

Point clouds of same materials captured from different scan locations are used for analysis. Six sets of data were subjected to normalization technique explained above though result for only one is being presented here for want of space. The raw 16 bit intensity values

Table 1: Intensity Normalization Result

Material	Scan	Raw Mean	Raw SD	Norm. Mean	Norm. SD
Concrete Wall	1	418	192	104	48
	2	1385	505	147	53

obtained after parsing the scan data were used for normalization.

The intensity normalization results are tabulated in Table I. The normalization is performed for a reference range of 100 m while the average object range varied from 35 m to 50 m. The histograms of the raw and normalized data are represented in Fig. 5.

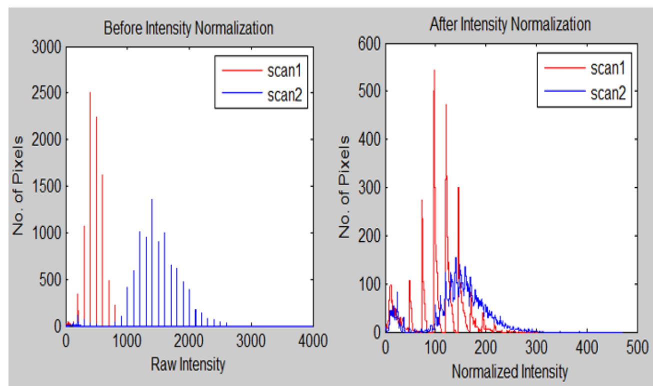

Fig. 5: Geometric ICP Vs. IAICP

The raw intensity values, after incidence angle and range correction, change to become comparable values for mean and standard deviation, as shown in the Table I. From the histogram also it can be inferred that after intensity normalization, intensities for the same material appear to have similar mean and standard deviation values and thus it can be effectively incorporated as one of the parameters for finding point to point correspondences in the ICP algorithm. In order to understand the efficacy of normalization process quantitatively, a statistical distance between the raw and normalized intensity distributions is calculated using the ratio of difference of the means and sums of the standard deviations for their distributions. This distance is 1.39 for raw data while 0.43 for normalized data, thus showing that the scans come nearer to each other after normalization.

F. IAICP Vs. ICP results

Four sites were chosen for studying this but for the want of space the results from only one site, which is a door with some notices pasted, are shown here. The registration was performed in 30 iterations and the RMS error value was computed. The RMSE value is the root of mean of square of the differences in the coordinates of master point and slave point after applying rotation and translation as suggested by registration process to the latter for all data points. This is computed at each iteration of the registration. Fig. 6 shows the result of only Geometric ICP and Intensity Augmented ICP, while Fig. 7 shows the convergence graph for this data. The RMSE for Geometric ICP was 3.26 cm while for IAICP it was 2.61 cm. Moreover, despite comparable RMSE it is important to note that in the case of Geometric ICP the slave scan was inverted thereby providing absolutely incorrect registration. This is due to the Geometric ICP converging at local minima. In case of IAICP the registration is correct, which is basically due to the use of intensity information in the coarse registration process. The convergence graph shows that IAICP converges faster.

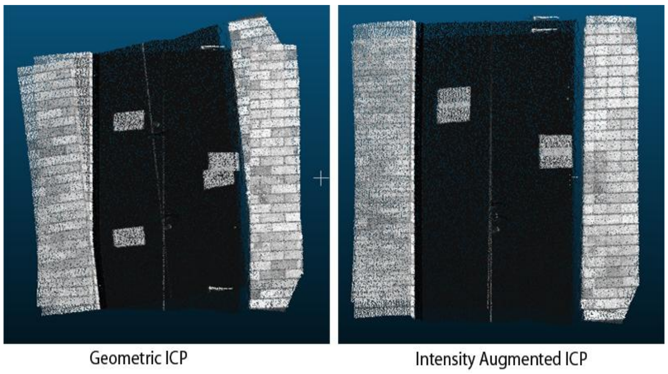

Fig. 6. Geometric ICP Vs. IAICP

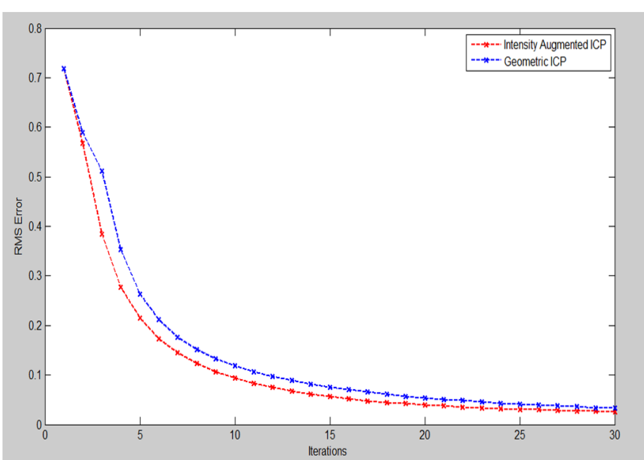

Fig. 7: Convergence graph – ICP Vs. IAICP

Conclusion

The automatic registration process in commercial software is generally not found correct as it leads to local minima. The procedure adopted in practice is to collect a good number of control points and use these through similarity transform to provide initial condition to ICP. In the present paper an Intensity Augmented ICP has been proposed, where first a coarse registration has been realized by using intensity along with geometric information through ICP. This process has potential to replace the manual selection of control points before proceeding to fine registration. In the present paper the fine registration has been achieved by Point to Plane ICP. While performing IAICP the intensity of both scans should be normalized, as proposed by the present approach.

The paper has shown with a data set that the intensity normalization approach suggested is effective and brings the intensities of multiple scans to same level, thereby facilitating their comparison. The paper further shows, with scan data of a site, that how simple ICP can fail in geometrically confusing circumstances, while IAICP has the potential to converge to the global minima, as the fourth dimension added in ICP process provides additional information to locate distinctive features in both scans. The proposed approach can be tested on more data and used in commercial software.

References

1. Besl, P. J., and McKay, N. D. , "A method for registration of 3D shapes", *IEEE Transactions of Pattern Analysis and Machine Intelligence*, Vol.14, 239-255, February,1992.

2. Chen, Y., and Medoni, G., "Object modeling by registration of multiple range images", *Image and vision Computing*, Vol.10(3), 145-155, 1992.

3. Masuda, T., Sakaue, K., and Yokoya, N., "Registration and integration of multiple range images for 3D model construction", *13th International Conference on Pattern Recognition*, Vol.10(3), 879-883, August, 1996.

4. Hebel, M., and Stilla, U., "Automatic Registration of laser point clouds of urban areas", *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVI(3/W49A)*, 13-18, 2007.