Evaluation of intensity augmented ICP for terrestrial LiDAR data registration

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Need for LiDAR data registration

- Complete 3D reconstruction
- One scan is not sufficient to obtain a full scene converge
- Transformation of all point clouds to a single coordinate system

Motivation

- Process of LiDAR data collection
- LiDAR point cloud registration process in commercial software

Literatures on TLS data registration

- Point to point correspondence based ICP (Besl and McKay, 1992)
- Point to plane approximations based ICP (Chen and Medoni, 1992)
- Godin et al. (1994) – using range and intensity images
- Hefford and Samson (2009) – for 2D Laser scanners
- Weinmann et al. (2011) – using feature extraction
- Altuntas (2011) – using SIFT

Literatures on TLS data registration

- A method to incorporate the k-d tree data structure into point matching algorithm, to minimize computational time, is described in (Masuda et al., 1996).
- Hebel and Stilla (2007) propose a method for automatic registration of Laser Point Clouds from an airborne LiDAR for urban areas by incorporating the intensity of the reflected laser pulse and normal vectors of the fitted plane to attain faster convergence and higher robustness.
- The two -staged registration process presented by Weinmann et al. (2011) utilizes geometric and radiometric information, in the form of intensity images, derived from the TLS data for estimating the transformation parameters between two unregistered point clouds.
- Johnson and Kang (1997) used traditional ICP algorithm and modified it to use the color information provided by the scanner for creating virtual 3D environment.

Literature on Normalization

- (Fang et al., 2015); (Höfle, 2014); (Teo and Yu, 2015) propose different methods to Normalize the LiDAR intensity values

Past work

- Sasidharan (2012)
- Detailed evaluation of the intensity normalization method used in this paper with different data samples is discussed in (Sasidharan, 2016).
- Lohani and Sasidharan (2013) – Preliminary report

Objectives

- Minimize human intervention in data collection
- Propose a robust algorithm for automatic LiDAR data registration
- Algorithm must be less complex and easy to implement

Process Flow

Unregistered Point Clouds

Intensity Normalization

Coarse Registration

Fine Registration

Terminologies

- Iterative Closest Point Algorithm

- Intensity Normalization

- Intensity Augmented ICP

Iterative Closest Point (ICP) Algorithm

- Classical solution for all types of 3D registration problems
- Proposed by Besl and McKay, (1992) and Chen and Medoni (1992)

ICP Steps

ICP - Initialization

- Initialization of Rotation Matrix and Translation Matrix
- Master and Slave point clouds separated by large distance
- Tendency of ICP to converge to local minimum

Finding Point Correspondences

- Point to point correspondence between Slave and Master clouds based on Euclidian distance
- Any point search algorithm can be used
- Kd -Tree data structure for efficient searching (Masuda et al., 1996)

Point Matching

- Point to point distance minimization (Besl and McKay, 1992)
- Point to plane minimization (Chen and Medoni, 1992)

Point to Point distance minimization

Point to Plane distance minimization

Elimination of outliers

- Wrongly matched points
 - Presence of noise
 - No 100 % overlap
- Outlier elimination
 - Based on Euclidean distance

Registration Parameter Estimation

- At least 40-60 % overlap for ICP to converge
- Calculate the covariance matrix between matched point clouds after subtracting the centroids
- Singular Value Decomposition of the Covariance Matrix

SVD Theorem

- According to SVD theorem, any rectangular matrix A of size $N \times P$ can be decomposed as:

$$A_{N \times P} = U_{N \times N} S_{N \times P} V^T_{P \times P}$$

- Where U and V are orthogonal

$$U^T U = I_{N \times N}$$

$$V^T V = I_{P \times P}$$

Estimating Transformation Parameters using SVD

- Proposed by Arun et al., 1987

$$\sum_{MD} = \frac{1}{N} \sum_{i=1}^N (M_i - \mu_M)(D_i - \mu_D)^T$$

$$R(\omega, \varphi, \kappa) = VSU^T$$

$$T(x, y, z) = \square_D - R(\omega, \varphi, \kappa) \square_M$$

M = Master cloud

D = Slave cloud

R = Rotation Matrix

T = Translation matrix

$\square_M$ = Centroid of
Master

$\square_D$ = Centroid of Slave

Applying Transformation and Calculating RMS Error

$$D_{K+1} = R(\omega, \varphi, \kappa) * D_K + T(x, y, z)$$

M = Master cloud

D = Slave cloud

R = Rotation Matrix

T = Translation matrix

$\bar{M}$ = Centroid of Master

$\bar{D}$ = Centroid of Slave

K = Iteration Number

N = No. of
correspondences

$$E_{RMS} = \sqrt{\frac{1}{N} \sum_i^N ||M_i - (RD_i + T)||^2}$$

Intensity Normalization

- Intensity information collected is subjected to errors due to :
 - Range difference
 - Incidence angle difference
 - Atmospheric losses
 - Sensor sensitivity
 - Surface geometry
 - Temperature of the Electronic system
- Same materials have different intensity values

Intensity Range Correction

- Range correction (Wagner et al., 2006)

$$I_{norm} = I_{raw} \left(\frac{R_{act}}{R_{ref}} \right)^n$$

- $n=2$ for homogeneous surfaces
- I_{norm} is normalized intensity
- I_{raw} is recorded intensity
- R_{act} is actual distance between the laser instrument and the return
- R_{ref} is a reference distance either determined by examining the distribution of R_{act} from all returns of specified arbitrarily by users.

Intensity Incidence Angle Correction

- Incidence angle correction (Gross et al., 2008) for planar points

$$I_{norm} = I_{raw} \left(\frac{1}{\cos(i)} \right)$$

- I_{raw} is recorded intensity
- I_{norm} is normalized intensity
- i is the incidence angle

Intensity Correction formula

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

- I_{norm} is normalized intensity
- I_{raw} is recorded intensity
- R_{act} is actual distance between the laser instrument and the return
- R_{ref} is a reference distance either determined by examining the distribution of R_{act} from all returns of specified arbitrarily by users.
- i is the incidence angle

Intensity Augmented ICP

- Adding intensity information as 4th dimension along with spatial coordinates (x, y, z, Intensity)
- Intensity must be scaled by varying the value of R_{ref}
- Changing value of weight matrix
- Statistical score normalization can be employed

Methodology

Intensity Normalization

Coarse Registration – Stage 1

Z score Normalization

- Raw intensity captured by sensor is normally distributed (Hefford and Samson, 2009)

$$I_{znorm} = \frac{I_{norm} - \mu_{I_{norm}}}{\sigma_{I_{norm}}}$$

I_{znorm} = Z score Normalized Intensity

I_{norm} = Normalized Intensity

$\mu_{I_{norm}}$ = Mean of Normalized Intensity

$\sigma_{I_{norm}}$ = Standard Deviation of Normalized Intensity

- After Z-score normalization, the intensity values have a mean of zero and unit standard deviation. (Jain et al., 2005)

Fine Registration – Stage 2

Results – Intensity Normalization

Data Set No	Material	Scan No	Raw Mean	Raw SD	Normalized Mean	Normalized SD
Set 1	Brick wall	Scan 1	3290	622	44	8
		Scan 2	4365	778	53	9
Set 2	Brick wall	Scan 1	4365	778	53	9
		Scan 2	1728	361	67	14
Set 3	Concrete Wall	Scan 1	418	192	104	48
		Scan 2	1385	505	147	53
Set 4	Iron Door	Scan 1	1900	284	34	5
		Scan 2	1680	206	30	4
Set 5	Concrete Wall	Scan 1	406	200	120	60
		Scan 2	1070	603	136	68
Set 6	Plastic Object	Scan 1	2186	441	36	7.5
		Scan 2	1805	553	31	7.9

Histograms of Data Set 1.
 Number of points in scan 1 = 30293 and scan 2 = 30247

Histograms of Data Set 2.
 Number of points in scan 1 = 30247 and scan 2 = 24625

Histograms of Data Set 3.
 Number of points in scan 1 = 7368 and scan 2 = 4328

Histograms of Data Set 4.
 Number of points in scan 1 = 7128 and scan 2 = 6205

Histograms of Data Set 5.
 Number of points in scan 1 = 1976 and scan 2 = 998

Histograms of Data Set 6.
 Number of points in scan 1 = 11976 and scan 2 = 11312

Testing the Normalization Results

$$\rho = \frac{\mu_i - \mu_j}{\sigma_i + \sigma_j}$$

ρ is the distance co-efficient for the distribution

μ is the mean of the intensity values

σ is the standard deviation of intensity values
with i and j are scan numbers

Data Set	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Raw	0.77	2.31	1.39	0.45	0.83	0.39
Normalized	0.53	0.61	0.43	0.44	0.13	0.32

Conventional ICP Vs IAICP

DATA SET 1

DATA SET 2

DATA SET 3

DATA SET 4

- Only coarse stage
- Intensity Normalization performed

Data Set - 1

Geometric ICP

Intensity Augmented ICP

Method	Geometric ICP	Intensity Augmented ICP
RMS Error	0.3563 m	0.0577 m

Data Set - 2

Geometric ICP

Intensity Augmented ICP

Method	Geometric ICP	Intensity Augmented ICP
RMS Error	0.3563 m	0.0577 m

Data Set - 3

Geometric ICP

Intensity Augmented ICP

Method	Geometric ICP	Intensity Augmented ICP
RMS Error	0.0326 m	0.0261 m

Accuracy of the Proposed Algorithm

$$E_{RMS} = \sqrt{\frac{1}{N} \sum_i^N ||M_i - (RD_i + T)||^2}$$

M – Master point cloud

D- Slave point cloud

R- Rotation matrix

T- Translation matrix

N- Number of correspondences

RMS – Normalized root mean square error

Accuracy – Data Set 1

Before Registration

After Registration

Accuracy – Data Set 1

Parameter	True Value	Estimated Value	Error
Tx	0.5 m	0.53 m	-0.03 m
Ty	-0.3 m	-0.25 m	-0.05 m
Tz	0.2 m	0.18 m	0.02 m
Rx	0.30 rad	0.2998 rad	0.0002 rad
Ry	-0.20 rad	-0.1997 rad	-0.0003 rad
Rz	0.05 rad	0.0540 rad	-0.004 rad
Translation Error, $ \mathbf{E}_t $		0.0612 m	
Rotation Error, $ \mathbf{E}_\theta $		0.0040 rad

Accuracy – Data Set 2

Before Registration

After Registration

Accuracy – Data Set 2

Parameter	True Value	Estimated Value	Error
Tx	10 m	10.44 m	-0.44 m
Ty	30 m	29.886 m	-0.114 m
Tz	-0.2 m	-0.3 m	0.1 m
Rx	0.01 rad	0.01 rad	0 rad
Ry	-0.03 rad	-0.0299 rad	-0.0001 rad
Rz	0.2 rad	0.2 rad	0 rad
Translation Error, $ \mathbf{E}_t $		0.465 m	
Rotation Error, $ \mathbf{E}_\theta $		0.0001 rad

Conclusion

- Novel approach for Intensity Normalization
- New approach for Automatic LiDAR data registration
- Efficiency of the algorithm tested

Future Works

- Testing on IDEs other than MATLAB
- Multiple data handling
- Intensity Normalization Algorithm
- Accuracy
- Flash LiDAR data processing (Lohani et al., 2013)

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