# AUTOMATIC MATCHING OF TERRESTRIAL SCAN DATA USING ORIENTATION HISTOGRAMS

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**ABSTRACT:**

Terrestrial laser scanners allow to obtain accurate 3d model of the object as a point cloud. Real objects should be scanned with different instrument positions and then scan data is registered into the single coordinate system. In practice the process of registration is performed using manual or semi-automated registration techniques. First fully automatic methods were introduced about fifteen years ago. Many of the methods based on well-known iterative closest point algorithm (ICP) permit to obtain the exact solution of a problem. Nevertheless, the problem is difficult to solve due to necessity of information regarding the coarse relative orientation parameters of point clouds. In this paper authors present the algorithm based on usage of orientation histogram to solve a problem without any information concerning scan positions. Experimental studies of the algorithm have demonstrated its efficiency at any values of point clouds relative orientation.

## 1. INTRODUCTION

Terrestrial laser scanners have been widely adopted in problem solution deals with documentation of historic buildings and monuments, industrial complexes monitoring, industrial and city units mapping. The

result of scanning is performed by high density 3d model of the point cloud that precisely describes the surface of object survey. The *scan* is the point cloud obtained at immobile scanner position. The points of each scan have been obtained in the coordinate system of scanner arbitrary oriented in the space. To process several scans simultaneously we need to know relative orientation parameters for all scans obtained.

In practice before scanning process starts artificial markers are placed on the surface of surveyed object. Results of scanning these markers' are used to integrate the scans into a common coordinate system. Some commercially available programs allow realizing this operation in semi-automatic or automatic modes. Nevertheless, theoretically there is enough information coded in scans itself to carry out its integration. Therefore the majority of software solutions have an option for manual selection of corresponding scan areas that can be used to solve a problem. The problem of finding the registration parameters without artificial markers has wide range of features in automation area. That is why many research groups are involved in the problem. Quite lot solutions for point cloud registration with different range of accuracy have been introduced during last 10 years.

## 2. RELATED WORK

Iterative closest point algorithm (ICP) described in the article (Besl et al., 1992) becomes a standard solution for the problem of automatic scans joining. The main advantage of ICP algorithm is its simple implementation but the main disadvantage is necessity to know accurate values of first approximation of the scans orientation parameters.

But generally there is no any information concerning approximate relative point cloud orientation. Therefore the ICP algorithm is applied on the final stage of solution to improve precision. Scans pre-alignment is the major problem in its automatic registration process. Multiple solutions of this problem are proposed and analyzed by many research groups.

(Feldmar et al., 1996) have described a pre-alignment algorithm based on the corresponding point matching. (Ripperda et al., 2005) use a *normal distribution transform* for cloud alignment. (Liu et al., 2005) have introduced a solution based on the automatic scan segmentation. Authors applied scan segmentation based on difference between the normal vectors. Matching of the segments was performed using a special matching tree. However, the same segments of different scans often has a large difference in shape, therefore its matching is very difficult.

(Dold et al., 2004; Vanden Wyngaerd et al., 1999) have described a coarse pre- alignment by matching the same planes on the scans.

To detect angular orientation of scans the author of the paper (Dold, 2005) used an extended Gaussian images (EGI) matching algorithm on different levels of detail. (Makadia et al., 2006) used EGI to make orientation histograms that were compared with correlation function. In this paper the pre-alignment algorithm has been introduced to improve the method using simplification of mathematics.

## 3. ORIENTATION HISTOGRAM

EGI that were introduced in (Horn, 1984) article are one of the way for presentation of objects 3D shape. EGI creation was made by superposition of normal vectors of the object surface into the common centre - center of Gaussian sphere. The grid of meridians and parallels was applied to the Gaussian sphere and was used for EGI generation. The value of each EGI pixel is equal to 1 if any normal vector points to the corresponding grid square. Therefore EGI is a binary image. Orientation histogram $H$ is based on EGI but each pixel of the histogram contains a count of all normal vectors which are points to the grid square. Assume that each normal vector of the scan surface directs towards the scanner.

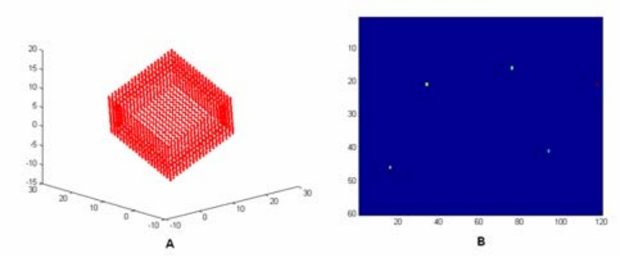


Figure 1. The points on the cube surface (A) Orientation histogram (B). Each local maximum on the image corresponds to the cube plane. The angular step of discretization is 3º.

Orientation histogram is invariant to the translation but it depends on the rotation of 3D object. We can obtain the orientation histogram $H'$ of rotated object using initial histogram $H$ . Let's define a rotation procedure for the orientation histogram as the rotation of all single vectors corresponding to each histogram pixel. By placing rotated single vectors into the center of Gaussian sphere we can calculate new orientation histogram:

$$H' = R \cdot H \,, \tag{1}$$

where $\underset{3x3}{R} \in SO(3)$ - rotation matrix.

Thus we can fast generate orientation histograms for any rotations of 3D object based on one orientation histogram $H$ .

Define a correlation function $C(H_1, H_2)$ for two orientation histograms $\underset{MxN}{H_1}$ and $\underset{MxN}{H_2}$ :

$$C(H_1, H_2) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} H_1(i,j) H_2(i,j)}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M} H_1(i,j)^2 \sum_{i=1}^{N}\sum_{j=1}^{M} H_2(i,j)^2}} \tag{2}$$

## 4. REGISTRATION ALGORITHM

The pre-alignment algorithm for two point clouds $P_1$ and $P_2$ consists of an estimation of shift vector $T$ and rotation matrix $R$ between local coordinate systems for each scan. Our algorithm includes two steps: angular orientation of two clouds and its relational shift.

### 4.1 Estimation of the angular orientation

Estimation of the angular orientation consists of the following steps:

1. Generate two orientation histograms $H_1$ and $H_2$ for scans $P_1$ and $P_2$ respectively;
2. Search the maximum of correlation function $C(H_1, H'_2)$ for all possible values of rotation matrix $R$ .

The value of rotation matrix $R_{C\max}$ , corresponded to the maximum of correlation function, is a required angular scans orientation value.

### 4.2 Estimation of the shift translation

Firstly the rotation procedure is applied for cloud $P_2$ using values of rotation matrix $R_{C\max}$:

$$P_2' = R_{C\max} P_2 \tag{3}$$

Than the binary voxel presentation $V_1$ and $V_2'$ for scans $P_1$ and $P_2'$ should be calculated using 3D discretization procedure [Chibunichev 2007]. The element of $V$ is equal to 1 if at least one scan point is inside this voxel and is equal to 0 otherwise.

Estimation of the shift between scans coordinate systems is defined by maximum of the correlation function:

$$G(\tau) = \int_{p \in R^3} V_1(p) \cdot V_2'(p - \tau) dp \tag{4}$$

The convolution integral (4) can be calculated by using traditional Fourier transform on R3 (see appendix A). This solution gives us such a value of the shift parameter that guarantees the maximal coincidence of nonzero elements of $V_1$ and $V_2'$

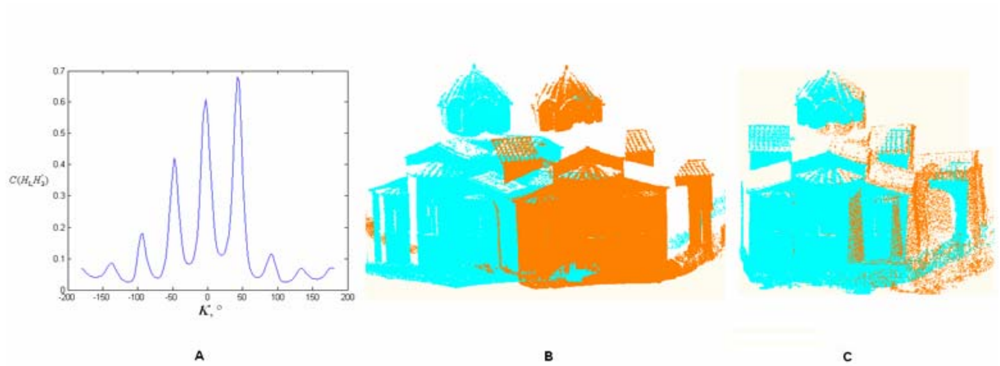


Figure 2. The graph of dependence of the correlation function $C(H_1, H_2)$ on the rotation angle $\kappa$ on Z axis (A), initial not oriented point clouds (B), pre-alignment results using orientation histograms (C), Sanmarina Church (Greece), ISPRS, Working Group V/3, standard, real world datasets.

## 5. EXPERIMENTAL RESULTS

There is no need to search rotation matrix values for all $\underset{3x3}{R} \in SO(3)$ area in laser scanning practice. Most of laser scanners have a compensatory mechanism which guarantees the parallelism of $Z$ axis for all scans. Therefore, we have found the correlation function considering rotation of the coordinate system of the second scan around $Z$ axis only by angle $\kappa \in (-180°, 180°)$ with step of 3º. The pre-alignment results using orientation histograms are presented on figure 2(B). The size of $V$ is limited to 75x75x75 voxels. The size of each scan is about 500 000 points.

## 6. CONCLUSIONS

We have presented the fully automated pre-alignment algorithm using orientation histograms. The accurate solution of the whole problem can be found after applying ICP based algorithm using founded initial estimations. Presented algorithm is effective even with large initial angles (> 100º) between registered point clouds. This algorithm is simple in the implementation. The practical tests show robust and reliable results.

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## APPENDIX A

Lets $\underset{MxNxK}{V_1}$ and $\underset{MxNxK}{V_2}$ be the binary voxel presentations of scans $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$ respectively with the same angular orientation. Lets

$$P_1 = P_2 + \Delta T\ , \tag{5}$$

where $\Delta T = \begin{pmatrix} dx \\ dy \\ dz \end{pmatrix}$, is a vector that corresponds to the maximum of correlation function (4).

Adds additional zero values to $\underset{MxNxK}{V_1}$ and $\underset{MxNxK}{V_2}$ :

$$\underset{(3M-2)x(3N-2)x(3K-2)}{V_1} = [V_0 \quad \underset{MxNxK}{V_1} \quad V_0] \tag{6}$$

and

$$\underset{3M-2)x(3N-2)x(3K-2)}{V_2} = [\ \underset{MxNxK}{V_2} \quad V_0 \quad V_0], \tag{7}$$

where $\underset{M-1xN-1xK-1}{V_0} = 0$ .

Values of corresponding normalized correlation function $\overline{G}$ can be calculated using (8):

$$\overline{\overline{G}} = \frac{ifft(\,fft(V_1)\cdot conj(\,fft(V_2)))}{\sqrt{\sum_{i=M}^{2M}\sum_{j=N}^{2N}\sum_{l=K}^{2K} V_1(i,j,k)\cdot \sum_{i=1}^{M}\sum_{j=1}^{N}\sum_{l=1}^{K} V_2(i,j,k)\cdot}}\ , \tag{8}$$

where

$fft()$ - discrete forward Fourier transform on R3,

$ifft()$ - discrete inverse Fourier transform on R3,

$conj()$ - function for calculation of complex conjugating elements of matrix.

Accordingly,

$$\Delta T = \begin{pmatrix} i_{G_{max}} - M - 2 \\ j_{G_{max}} - N - 2 \\ l_{G_{max}} - K - 2 \end{pmatrix}\cdot S_v + \begin{pmatrix} \min(x_1) \\ \min(y_1) \\ \min(z_1) \end{pmatrix} - \begin{pmatrix} \min(x_2) \\ \min(y_2) \\ \min(z_2) \end{pmatrix}, \tag{9}$$

where

$(i_{G_{max}}, j_{G_{max}}, k_{G_{max}})$ - indices of the maximal element of $\overline{G}$ ,

$S_v$ - the size of the voxel side.