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Hue-assisted automatic registration of color point clouds

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Abstract

This paper describes a variant of the extended Gaussian image based registration algorithm for point clouds with surface color information. The method correlates the distributions of surface normals for rotational alignment and grid occupancy for translational alignment with hue filters applied during the construction of surface normal histograms and occupancy grids. In this method, the size of the point cloud is reduced with a hue-based down sampling that is independent of the point sample density or local geometry. Experimental results show that use of the hue filters increases the registration speed and improves the registration accuracy. Coarse rigid transformations determined in this step enable fine alignment with dense, unfiltered point clouds or using Iterative Common Point (ICP) alignment techniques.

Keywords: Computational geometry; Mesh processing; Reverse engineering; Building information modeling (BIM); Computer graphics

1. Introduction

A number of 3D point cloud data registration techniques currently exist for generating accurate global maps by merging multiple point cloud maps from different vantage positions into a single global coordinate system [1]. In most cases 3D range points acquired from laser scanning devices contain detailed spatial information of the scanned environment saved with respect to the local coordinate reference frame defined by the scanned location and orientation. Creating an accurate global map from the individual point clouds scanned with local reference frames is an essential task for a number of different applications including construction / architectural surveying, area mapping, and autonomous robotic exploration.

If the scanner is precisely localized (location and pose are known), the registration is trivial. However, localizing a moving robot may be challenging or imprecise at best without the aid of locating beacons (e.g., GPS) and the localization errors translate to mapping errors. Registration algorithms analyze the scan data gathered from two locations for overlapping goemetry and use the geometric features to register a new unregistered point cloud (termed as the data cloud) into the reference frame of registered point clouds (model cloud). A well-known algorithm for 3D point cloud data registration is the Iterative Closest Point (ICP) [2] algorithm, which has been applied to stitch two neighbor 3D point cloud maps into one map based on their overlap coverage area. Several variants of ICP are reported in the literature to increase the speed and precision [3]. Corresponding points ampling, matching, weighting and rejecting are some methods used to accelerate the ICP algorithm. In the ICP algorithm, associating corresponding points in two point cloud data sets is the most critical step.

Nearest neighbor search in 2D or 3D space is commonly used for associating the corresponding points. Parallel ICP algorithms have been developed [4] to accelerate computation speed. Point to plane registration method accelerates the ICP iteration and convergence [5]. A good initial (or rough) alignment with small translation and rotation errors is required for ICP [2]. Therefore, manual alignment often precedes the use of ICP.

Other techniques for registration include the point signature method [6] that used signature points to describe curvatures of point cloud data and matches corresponding signature points during the registration process. Spin image based methods compute 2D spin image to represent surface characterization and solve the registration problem by finding the best correspondence between two different scan spin images [7]. Methods such as the principle component analysis [8] and algebraic surface model [9] are based on matching the point cloud surface geometrical features.

Of these methods, the Extended Gaussian Image (EGI) based techniques [10] are capable of automatically performing rough alignment. EGI techniques determine the optimal rigid transformations that correlate the surface normal vector

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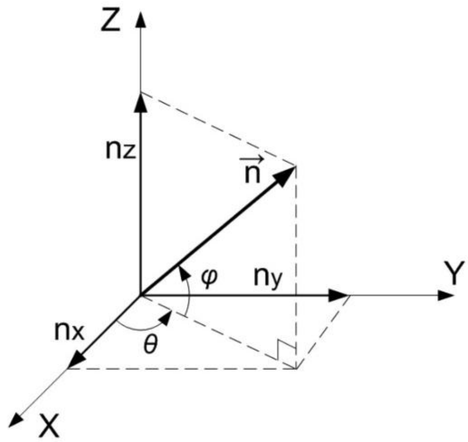

Figure 1. Surface normal orientation angle and vector.

distributions in the data and model point clouds. The rotation required to register two point clouds is solved using a cross-correlation function of the two EGI images. Computing the cross-correlation in the frequency domain using Discrete Fourier Transform on Rotation Group on SO(3) (SOFT) is efficient and economical. Makadia et al. [10] illustrated the rotational alignment by EGI and suggested translational registration with cross-correlation of discrete occupancy grids. Rough alignment methods coupled with ICP can lead to a fully automatic registration of point clouds into a fixed reference frame.

Recently, scanners have been integrating the color information at the ranged point producing 3D color point clouds [11]. A color camera is combined with a 3D LIDAR ranging system can generate visually realistic and geometrically accurate representation of the scene. Several algorithms take advantage of the available color property to accelerate the map registration process and increase accuracy. Hue value from Hue-Saturation-Lightness (HSL) color model has been computed and utilized in all iterations during the ICP registration process [12]. Color data on depth image can be used to estimate initial alignment of a scans pair with the Scale Invariant Feature Transform (SIFT) has been proposed as a variant of the ICP fine registration [13]. The Depth-interpolated Image Feature (DIFT) algorithm associates the corresponding points between two images and registers the color point clouds based on the extracted correspondences [14]. Probabilistic scan registration methods trace laser beam to exploit maximum range readings to increase likelihood of alignment. Color attribute has been applied as kernel extension in Normal Distributions Transform (NDT) process so that robustness is increased [15].

This paper presents a variant on the EGI for automatic coarse alignment. The registration process is fully automatic because it requires no manual pre-alignment or user identification of corresponding points. As more and more scans are registered, the size of the model point cloud increase and down sampling of the point clouds becomes necessary. Geometry-based or sample density based down sampling techniques may indiscriminately cull points from overlapping areas. Since the hue information must match in the overlapping areas of the data (unregistered) and model (already registered) point clouds, hue filters designed with hue-distribution patterns of the data point cloud ensure that the points in the overlap areas in the model point clouds are preferentially retained. The traditional EGI algorithm for registration and hue filters used for selective clustering of points for EGI registration is described in the next section. A two scan matching scenario and an eight scan matching scenario are considered as illustrative examples. Performance measurements on the example scans are described in the third section. The paper concludes with remarks on the effectiveness of using hue filtering.

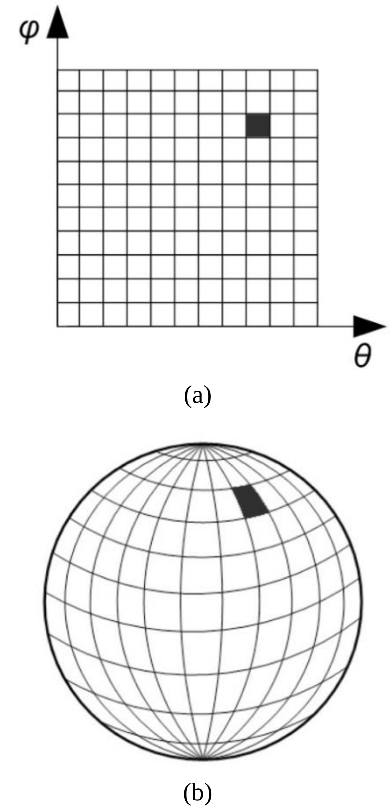

Figure 2. Surface point normal histogram representations: (a) surface normal histogram on the (θ, φ) plane, (b) surface normal histogram on EGI.

2. Hue assisted automatic registration algorithm

The automatic registration algorithm includes two parts: rotational alignment and translational alignment. Registration with the EGI follows the technique developed by Makadia et al. [10]. Rotational alignment is executed before translational alignment. A summary of rotational alignment based on EGI is presented for the sake of the completeness. The rotational alignment is solved by correlating point surface normal histograms from different point clouds in frequency domain.

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