ICP fitness analysis for 3D scan data matching

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ABSTRACT

Full automation of the registration of 3D scan data is, in general, still an unsolved problem. If supplementary data is provided, either by human assistance, or by additional devices, the registration process can be completed. We have analyzed under which conditions supplementary data is required, where the conditions are specified as subsets of configuration space. As a matching tool an ICP-based (iterative closest point) algorithm was deployed. A point in configuration space represents the amount of translation and rotation needed to obtain a match between 3D scans of two partial overlapping surfaces. As a function of the coordinates in configuration space, we determine the successfulness of the algorithm and hence whether additional information is required. Our shape matching method does not rely on pre-computation of surface invariants, nor on the identification of shape features. The possible application of the analysis results for practical 3D scanning purposes are described.

Keywords

Freeform shape design, 3D scanning, registration, automation

1. INTRODUCTION

The reconstruction of a 3D geometric model of a physical model from measurements of points on its surface is a widely applied process. Although theoretically a fully automatic registration process can be exclusively based on the individual views it can still be opted to include supplementary data about the initial relative or absolute poses of the views for the following reasons: 1) The number of wrong pair-wise matches can be reduced, making the whole process more robust, 2) the algorithm can be faster as significant portions of the transform spaces need not to be considered in a search. In this paper we explore when information would be required in order to obtain the initial transform. In section 2 we provide the problem statement and the numerical setup. In section 3 we present a few numerical results and some examples.

Posters proceedings ISBN 80-86943-04-6
WSCG'2006, January 30-February 3, 2006
Plzen, Czech Republic.

2. PROBLEM DESCRIPTION AND NUMERICAL PROCEDURE

We consider the local registration of two (out of possibly many) datasets, *A* and *B*, each representing a portion of the surface of an object.

We define a matching criterion as a discrete mapping $M(X, Y) \to \{0,1\}$, where X and Y are geometric sets. $M(X, Y) = 0$ means that X and Y match, and $M(X, Y) = 1$ means that X and Y do not match. In the literature there exist several real-valued distance measures of geometric sets [Hub2003] and threshold versions of them.

For this numerical analysis we assume to have pre-knowledge about the optimal relative pose of A and B, which we set to the identity pose I without losing generality. The input to the problem are the sets A and $T(B)$, where $T \in 3^3 \times SO(3)$ is a known transform, consisting of a rotation specified by a 3×3 matrix of the orthogonal group SO(3) followed by a translation specified by a vector $(d_x, d_y, d_z)^T$ in 3^3.

$$T=\begin{pmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta\sin\gamma-\sin\alpha\cos\gamma & \cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma & d_x \\ \sin\alpha\cos\beta & \sin\alpha\cos\beta\sin\gamma-\cos\alpha\cos\gamma & \sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma & d_y \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma & d_z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where the angles α, β and γ can be interpreted following the *x-y-z* fixed-angles convention [Cra1989]. Wanted is the transform S such that $M(A, S(T(B))) = 0$.

The search method that we use is based on Levenberg-Marquardt (LM) minimization of an ICP distance function of *A* and *B* [Lev1944, Lou2003].

3. CONFIGURATION SPACE ANALYSIS

For the numerical test we used a test set *A* of unordered points obtained by scanning of a physical object. Set *A* consists of 2307 points and represents a surface portion of about 30×20 mm, see Fig. 1. The spacing between the points was typically 0.5mm.

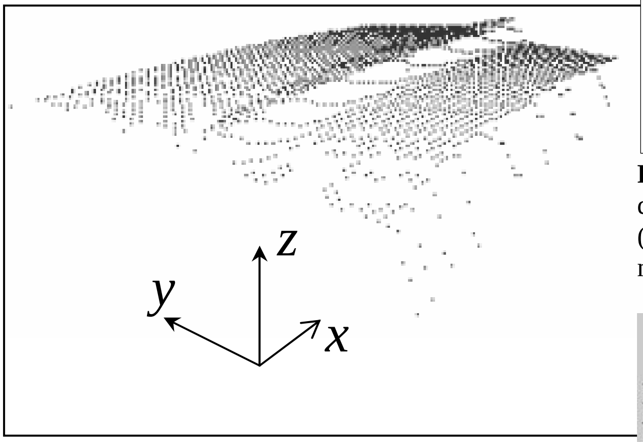

Figure 1. Unordered set *A* of points

Set *B* was taken identical to *A*, implying that the algorithm might achieve a perfect match of *A* and *T*(*B*). We also disregard the problem of finding the overlap region and of possible differences between *A* and *B* 's scanning accuracy and resolution. A general impression of the performance of the algorithm is shown in Figure 2. In Figures 3 and 4 the resulting deviation is shown as a function of two variables, keeping the remaining 4 variables fixed to zero. The results indicate that a combination of rough pre-alignment and sampling can support the registration process.

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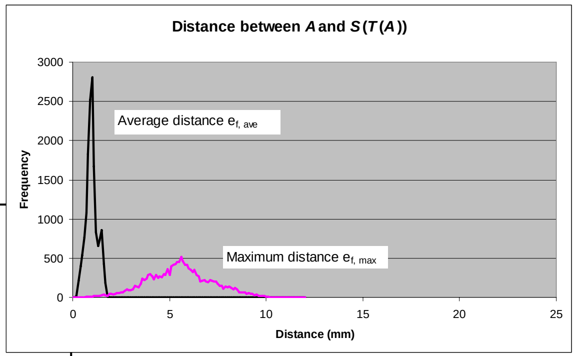

Figure 2. Distribution of maximum and mean distance (15625 entries) between point clouds before (upper picture) and after (lower picture) the ICP matching process.

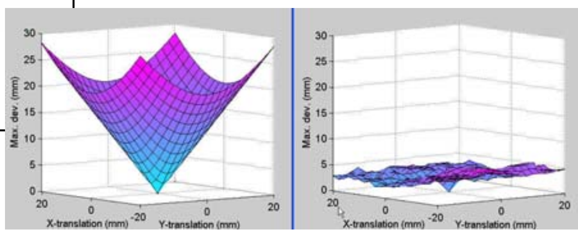

Figure 3. Distance between the point clouds before and after matching. Max deviation between *T*(*A*) and *A* (left) and between *S*(*T*(*A*)) and *A* (right) for initial translations in *x*- and *y*-directions. The remaining variables are fixed to zero.

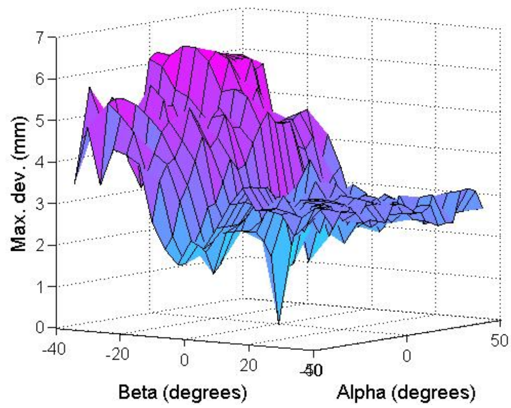

Figure 4. Max. deviation after matching as function of large initial α- and β-rotation, with remaining variables fixed to zero.