An Accelerated ICP-Algorithm

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Figure 1: Range images from different viewpoints have to be transformed into the same coordinate system.

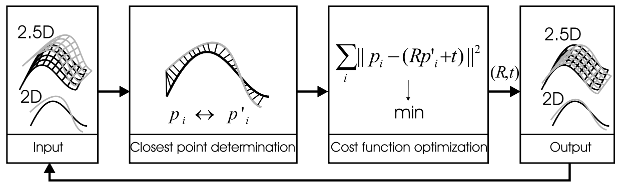

Figure 2: The general structure of an ICP algorithm. The output of each iteration is the input for the next iteration.

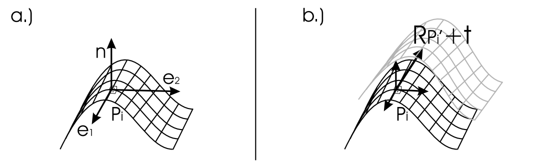

Figure 3: a.) The normal and the directions of minimal and maximal curvatures define a local coordinate system in each data point. b.) The difference vector of $\mathbf{p}_i$ to the transformed closest point $\mathbf{p}'_i$ in the second data set can be represented in the local coordinate system of $\mathbf{p}_i$.

In [1] we presented a comparison of Iterated Closest Point (ICP) algorithms. Now, a theoretical work regarding the localization accuracy of surfaces [2] motivated the use of a new cost function for ICP algorithms. The comparison with a usual cost function shows that the new approach enables more robust results with significantly less computation time.

ICP algorithms are used to align range images of an object taken from different viewpoints into a common coordinate system (Fig. 1). The general structure of an ICP-algorithm is illustrated in Fig. 2. To find the rotation and translation between two range images of overlapping regions in a first step closest points between the two data sets are determined. In a second step a cost function depending on the distances of closest points is minimized with respect to the six rotation and translation parameters. In a final step the resulting transformation is applied to the respective data set, so that both data sets come closer to each other. These three steps are iterated until convergence.

Usually, the cost function used in an ICP algorithm is a least squares sum of closest points $\mathbf{p}_i$ and $\mathbf{p}'_i$,

$$\Phi = \sum_i ||\mathbf{p}_i - (\mathbf{R}\mathbf{p}'_i + \mathbf{t})||^2 \tag{1}$$

with the translation vector $\mathbf{t}$ and the rotation matrix $\mathbf{R}$. $\mathbf{R}$ and $\mathbf{t}$ resulting from optimization of this cost function are the maximum likelihood solutions to the problem of aligning the two data sets under the assumptions that the closest points are corresponding points and data noise is Gaussian distributed. However, the detailed analysis of localization accuracy in [2] shows that a point with a small neighborhood can be best localized in its normal direction $\mathbf{n}$, and the localization accuracies in its directions $\mathbf{e}_1$, $\mathbf{e}_2$ of minimal and maximal curvatures are proportional to the respective extremal curvatures. Therefore it makes sense to introduce for each data point in the cost function (1) three confidence values that take into account the different localization accuracies in each of these directions. Before introducing these confidence values we rewrite (1) with the help of the difference vector

$$\mathbf{d}_i = \mathbf{p}_i - (\mathbf{R}\mathbf{p}'_i + \mathbf{t}) \tag{2}$$

as

$$\Phi = \sum_i \mathbf{d}_i^2 = \sum_i \left[(\mathbf{d}_i \cdot \mathbf{n}_i)\,\mathbf{n}_i + (\mathbf{d}_i \cdot \mathbf{e}_{1i})\,\mathbf{e}_{1i} + (\mathbf{d}_i \cdot \mathbf{e}_{2i})\,\mathbf{e}_{2i} \right]^2 \tag{3}$$

where in (3) we represented $\mathbf{d}_i$ in the local coordinate system of $\mathbf{p}_i$ (Fig. 3).

Now we are able to introduce the point-wise confidence values c_{1i}, c_{2i} and c_{3i},

$$\tilde{\Phi} = \sum_i \left[c_{1i}\,(\mathbf{d}_i \cdot \mathbf{n}_i)\,\mathbf{n}_i + c_{2i}\,(\mathbf{d}_i \cdot \mathbf{e}_{1i})\,\mathbf{e}_{1i} + c_{3i}\,(\mathbf{d}_i \cdot \mathbf{e}_{2i})\,\mathbf{e}_{2i} \right]^2. \tag{4}$$

Using realistic values for c_{li} from [2] we can even neglect the confidence values for the tangential directions against the confidential value for the normal direction, i.e. $c_{1i} = 1$, $c_{2i} \approx c_{3i} \approx 0$. Experiments with the cost function (4) confirm theoretical results that we need less iterations of the ICP until convergence: on average 1/10 of the iterations are needed compared to the standard cost function (1).

[1] B. Glomann, X. Laboureux, S. Seeger, Comparison of ICP-Algorithms, ann. rep. 1999, p. 62,Erl.
[2] X. Laboureux, G. Haeusler, Localization and registration of three-dimensional objects in space - where are the limits?, Applied Optics, Vol. 40, No. 29, 10 Oct. 2001, p. 5206 - 5216.