3D Mapping the Kvarntorp Mine – A Field Experiment for Evaluation of 3D Scan Matching Algorithms

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I. Introduction

This paper presents the results of a field experiment in the Kvarntorp mine outside of Örebro in Sweden. 3D mapping of the underground mine has been used to compare two scan matching methods, namely the iterative closest point algorithm (ICP [1], [3], [5]) and the normal distributions transform (NDT [2], [4]). The experimental results of the algorithm are compared in terms of robustness and speed. For robustness we measure how reliably 3D scans are registered with respect to different starting pose estimates. Speed is evaluated running the authors' best implementations on the same hardware. This leads to an unbiased comparison.

II. Technical Approach

To compare the performance of ICP and NDT with respect to mine mapping, we proceeded as follows: For each of the selected scan pairs, a reference pose was determined and the registration algorithms were run at a number of start poses with varying translation and rotation offsets from the reference pose. We then counted which start poses resulted in an end pose sufficiently close to the reference pose. Unfortunately ground truth data are not available in this type of field experiment. The reference poses were therefore determined manually, by performing a number of registrations and choosing the mean of the poses that led to visually correct results. Because of the low accuracy of this referencing, all registrations resulting in a pose within a specified translation and rotation distance from the reference pose were regarded as "successful".

In addition to this scan-to-scan evaluation we executed both algorithms with incremental pairwise scan matching. During the experiments, we closed several loops, and therefore, we can measure the transformation that is necessary to match the first scan against the last on of a closed loop. By doing so, we measured the accumulated error of both methods.

As another measurement of robustness, we counted the number of occasions where the odometry had to be corrected.

III. Results

The sensitivity to error in the initial pose estimate was tested using two partly overlapping scans from a slightly curved tunnel section. The success rate was 77% for NDT and 30% for ICP. ICP failed for most of the attempts where the initial pose was translated backwards. Although the rotation of the pose estimate after registration was generally correct, the algorithm stopped prematurely in these cases at a pose with maximum overlap between the two scans. NDT overcame this local optimum in more cases. However, for the cases where NDT did fail, it was sometimes the case that both the translation and rotation of the final pose were wrong. In other words, NDT succeeded more often, but for the cases where it failed, the result was sometimes worse than for ICP. A registration result where the rotation is well-aligned but the translation is off along the tunnel's direction is often more acceptable than a result with large rotation error. If the rotation error only is used as the criterion for successful registration, the results look quite different. Then, the success rate is 89% for NDT and 95% for ICP. The median execution times were 2.4 s for NDT and 4.8 s for ICP.

For evaluating registration accuracy, a larger data set was used: a sequence of 55 scans, going around a loop, with the last two scans partly overlapping the first scan. The total distance traveled around the loop is about 150 m. The registration accuracy was measured by looking at the accumulated pose error for the last scan, as compared to the pose achieved when registered to the first scan. For NDT, the accumulated translation error was 2.26 m and the rotation error was 1.9°. For ICP an accumulated translation error of 2.97 m can be reported.

When registering the loop data set, the initial pose of one scan had to be adjusted both for ICP and NDT. For ICP, scan number 33 could not be aligned without adjusting the odometry. For NDT, scan number 23 had to be altered.

IV. Conclusions

In these experiments, NDT was shown to converge form a larger range of initial pose estimates than ICP, and to perform faster. However, the poses from which NDT converged were not as predictable as for ICP. In several cases, a scan would be successfully registered from a pose estimate with large initial error but fail from a pose estimate with less error. Also, in some cases where NDT failed, the resulting pose was worse than the result of ICP, because the rotation error was larger.

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