Signed Distance Based Reconstruction for Exploration and Change Detection in Underground Mining Disaster Prevention

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***Abstract*— This publication describes an application of a Truncated Signed Distance Mapping approach for disaster intervention in underground mine shafts through geometrical change detection of the shaft walls. The paper describes two main problems of such an approach (aligning two potentially huge point clouds and automatic change detection by comparing the reconstructed volumes) and explains in detail the proposed solution.**

I. Related Work

The base of the proposed approach is the well known Truncated Signed Distance (TSD) 3D representation. The approach was first introduced by Curless and Levoy [1]. Later, an accelerated version (KinectFusion) using one of the first consumer 3D sensors, the Microsoft Kinect camera, was published by Izadi et. al. [2] and Newcombe et. al. [3]. More applications using the TSD followed, i. e. Bleier et. al. [4].

Previously published work [5] ported the KinectFusion approach from a Graphic Processing Unit (GPU) based algorithm to a more energy efficient Central Processing Unit (CPU) algorithm.

II. Data Sources

This approach was developed in the iDeepMon project. The german company DMT and the German Aerospace Center (DLR) have developed a mine shaft inspection tool called *Pilot* which uses a stereo camera and an Inertial Measurement Unit (IMU) to build 3D maps of underground shafts ([6]). The iDeepMon prototype contains such a system to improve the localization.

(a) DMT Pilot *source: www.dmt.de*.

(b) iDeepMon prototype.

(c) Tiff3D reconstruction from the iDeepMon prototype.

Fig. 1. Sensors for mineshaft reconstruction.

For inspection purposes and depth map generation, the prototype has eight overlapping cameras. The pictures are combined to panoramic images. Stereo images are generated using a structure from motion approach. Figure 1a shows the Pilot system, figure 1b shows the iDeepMon prototype in a working ore mine in Kristineberg, Sweden. Figure 1c shows a TSD reconstructed partial cloud from the shaft in Sweden.

III. Alignment of Volume Reconstructions

Volumetric change detection is performed, by comparing the 3D reconstructions of different measurement runs. By repeating such runs in constant intervals, a change detection software can detect potentially small volumetric changes. Such changes can be signs of imminent disaster. In order to compare two reconstructed volumes, they need to be aligned first.

Small changes in the starting position and noise on localization or sensor data causes misalignment between the volumes which has to be corrected before. Therefore, an alignment procedure is required, which determines the error between both data sets. It consists of a Rotation Matrix $\mathbf{R}_{3x3}$ and a translation vector $\vec{t}(x, y, z)^T$, both combined in the transformation matrix $\mathbf{T}_{4x4}$.

Aligning potentially big point clouds is a difficult and expensive process, wherefore this publication proposes an iterative approach, exploiting the benefits of a TSD based representation. As its dense representation allows high resolution Raycasting, new sensor frames can be matched easily to an already existing model space.

In iDeepMon, new sensor frames are tagged with a localization generated by a sensor system. In the following, the reference data is called *Modelspace* and the to be matched data set *Scenespace*. To correct potential drift on the pose of the new scene data, it is matched against the already existing data of the Modelspace using Raycasting and a scanmatching approach.

The scene data is pushed from the corrected pose into the Scenespace, generating a drift corrected space which only contains the potentially dangerous volumetric changes which the second stage of the algorithm has to detect. Figure 2 shows the undistorted Modelspace, and the Scenespace with a simulated drift prior to alignment. The data used for this reconstruction has been provided by the DLR.

IV. Change Detection

The algorithm proposed in this approach exploits the benefits of the TSD based representation. The TSD-function can be transformed into a 2D image by coloring the referring pixel according to the value and sign of the TSD function in

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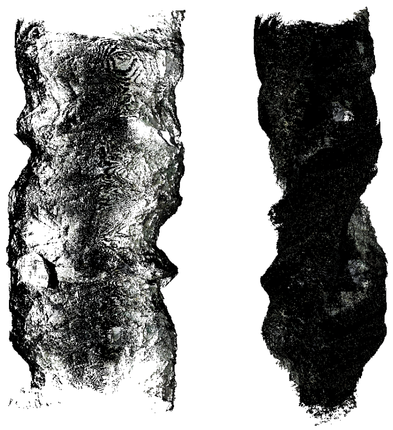
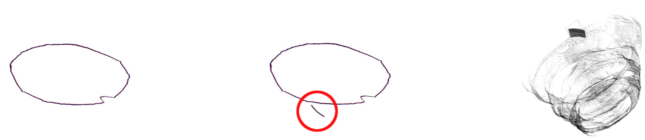


Fig. 2. TSD Shaft reconstructions before the alignment.

a slice of the representation. While this approach works for all dimensions, the proposed algorithm uses slices along the z-axis.



(a) Slice of Modelspace. (b) Slice of Scenespace with marked damage. (c) Difference cloud.

Fig. 3. Slice comparism.

The so generated difference images are converted back into a point cloud. To localize the changes, a clustering approach and a principal component analysis implementation generate bounding boxes. Figure 3a shows z-slice taken from the Modelspace. Figure 3b shows the corresponding scene slice with a marked change. Figure 3c shows the Scenecloud with added Differencecloud containing a marked change.

V. Experiments

A. Pilot data

At the current project stage, the DMT pilot is the only available data source. A measurement run from top to bottom and back contains a significant drift ((x, y)-axis approximately $5\mathrm{m}$). The TSD volume is able to correct this drift so the top to bottom measurement run can be compared to the bottom to top.

B. Simulated Tiff3D data

The DLR provides simulated Tiff3D data. The reconstructed shaft is twisted and elongated using a simulated random drift. The threshold for the random data is increased in every stage of the algorithm to evaluate the capabilities of the alignment algorithm.

C. Change Detection

In order to test the change detection, a partial area in the simulated Tiff3D data is shifted geometrically. In order to test the capabilites of the change detection, the size of the area is decreased in every step of the experiment.

VI. Conclusion

In this paper, we presented a novel application for a TSD based 3D reconstruction. By exploiting the special design features of this representation, we created an application which can be used for disaster intervention vertical mine-shafts.

However, most experiments have been done with simulated data or the wrong sensor. Therefore, in future work, the approach has to be tested with data from the iDeepMon prototype.

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This project uses the point cloud library: (*http://www.pointclouds.org/*).

References

[1] B. Curless and M. Levoy, "A volumetric method for building complex models from range images," in *Proceedings of the 23rd Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '96, (New York, NY, USA), pp. 303–312, ACM, 1996.

[2] R. A. Newcombe, S. Izadi, O. Hilliges, D. Molyneaux, D. Kim, A. J. Davison, P. Kohli, J. Shotton, S. Hodges, and A. Fitzgibbon, "Kinectfusion: Real-time dense surface mapping and tracking," in *Mixed and Augmented Reality (ISMAR), 2011 10th IEEE International Symposium on*, pp. 127–136, Oct 2011.

[3] S. Izadi, D. Kim, O. Hilliges, D. Molyneaux, R. Newcombe, P. Kohli, J. Shotton, S. Hodges, D. Freeman, A. Davison, and A. Fitzgibbon, "Kinectfusion: Real-time 3d reconstruction and interaction using a moving depth camera," in *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology*, UIST '11, (New York, NY, USA), pp. 559–568, ACM, 2011.

[4] M. Bleier, A. Dias, A. Ferreira, J. Pidgeon, J. M. Almeida, E. Silva, K. Schilling, and A. Nchter, "Signed Distance Function Based Surface Reconstruction of a Submerged Inland Mine Using Continuous-Time SLAM," in *Proceedings of the 20th World Congress of the International Federation of Automatic Control (IFAC WC '17)*, (Toulouse, France), July 2017.

[5] S. May, P. Koch, R. Koch, C. Merkl, C. Pfitzner, and A. Nüchter, "A generalized 2d and 3d multi-sensor data integration approach based on signed distance functions for multi-modal robotic mapping," in *VMV 2014: Vision, Modeling & Visualization, Darmstadt, Germany, 2014. Proceedings*, pp. 95–102, 2014.

[6] N. Benecke, A. Born, A. Börner, S. Rapp, P. Stelzer, N. Tsirigotis, M. Weber, and S. Zuev, "Mobile solution for positioning, 3d-mapping and inspection in underground mining," in *ISM2016, XVI International Congress for Mine Surveying*, April 2016.