
Summary:

Thanks very much for taking your time to review this manuscript. I really appreciate all your comments and suggestions! Please find my itemized responses in below and my revisions/corrections in the resubmitted files.

Reviewer:

The study is interesting in estimating an accurate tunnel deformation using laser scanner measurements and algorithm, B-spline, and ICP. The following comment may improve the study presentation:

Comments 1: *In abstract: numerical accuracy presentation in the abstract is required; this may improve the abstract and address the manuscript's aim in this section.*

Response 1: We appreciate the Reviewer's suggestion. Numerical accuracy presentation in the abstract has been required. The details of the additions are highlighted in red in the following quotation marks.

"The application of three-dimensional laser scanning technology in the field of tunnel deformation monitoring has changed the traditional measurement method. It provides an automated and intelligent solution for monitoring the geometric deformation of tunnel sections due to its high efficiency and independence from environmental influences. In this paper, based on B-spline fitting and iterative nearest point (ICP) alignment, the calculation of the difference between the radial distance and the design radius of a tunnel is transformed into a curve transformation that iterates over the nearest-neighbor points and calculates the difference in the distance between the corresponding points. The innovation of this paper is that the high-precision tunnel deformation monitoring method integrating B-spline fitting and ICP alignment can automatically compensate for the missing point clouds, is not affected by the point clouds of the tunnel inner and outer liner appendages, is more sensitive in the local deformation feedback and can be applied to a variety of tunnel shapes. **The results indicate that our method maximally improves the accuracy of the horizontal convergence calculation by 28.6 mm and the accuracy of the vault settlement by 27.8 mm in comparison with the least squares circle fitting algorithm.**"

Comments 2: *In introduction: The organization of this section should be improved, Line 86 for example, the authors present a conclusion of the above literature; however, after that, there is another literature section was presented. I think this affects the fellow of the manuscript.*

Response 2: We appreciate the Reviewer's suggestion. The organization of this section has been improved. Line 86, "The constant cycle monitoring of ...Therefore, the cross-section-based method is more often applied and improved." has been adjusted to the beginning of the next paragraph. The details of the additions are highlighted in red in the following quotation marks.

"In conclusion, the advantage of the model-based approach is that it can reflect the overall topological relationship of the tunnel and monitor the health of the whole tunnel. The efficiency of analyzing large-scale point cloud data is increasing with the rapid

improvement of computer performance. However, noise points, outliers and missing regions are still a great challenge for model construction. ~~The constant cycle monitoring of tunnel segments can provide an effective guarantee for safe tunnel operation in engineering practice. The cross-section-based method is more efficient in data processing for long mileage tunnels and more accurate in calculating local deformation than the model-based method because the point cloud data of the whole tunnel is divided into a series of cross-sections [20]. Therefore, the cross-section-based method is more often applied and improved.~~

The constant cycle monitoring of tunnel segments can provide an effective guarantee for safe tunnel operation in engineering practice. The cross-section-based method is more efficient in data processing for long-mileage tunnels and more accurate in calculating local deformation than the model-based method because the point cloud data of the whole tunnel is divided into a series of cross-sections [20]. Therefore, the cross-section-based method is more often applied and improved. The section-based approach assesses the lining health by extracting a series of cross-sectional planes perpendicular to the center axis of the tunnel and comparing them with the design planes."

Comments 3: *Algorithm presented in Figure 1: however, data processing and extract accuracy of measurements are missing. I think the whole data processing and accuracy estimation should be presented in the flowchart.*

Response 3: Express our gratitude to the Reviewer. In the algorithm shown in Figure 1, the key steps of data processing, including projection, slicing and denoising, are shown in the "Preprocessing". The key steps of accuracy estimation, including horizontal convergence, vault settlement and overall convergence are shown in the "Deformation Calculation". Detailed descriptions are given in Sections 2.1 and 2.3.

Comments 4: *The overall accuracy of the proposed model should be revised and improved, point 3 accuracy is very low. why? even the point accuracy in the horizontal and vertical directions is acceptable.*

Response 4: We appreciate the Reviewer's suggestion. Line 327, the connection between Figures 9-14 and Figure 8 has been added. Line 340, the reason for the higher deformation of Section 3 at the vault settlement is added.

Line 327, "Furthermore, the advantages of our method over the least squares circle fitting algorithm are investigated. ~~Figures 9-14 corresponding to the cross-sections 2-8 in Figure 8 show the advantages of our method over the circle fitting algorithm in detail.~~"

Line 340, "Our method can effectively compensate for the continuous and long-distance point cloud missing, showing smoother deformation curves in the converged deformation map, and the neglected part can predict the corresponding deformation by the a priori knowledge. ~~It is verified that our method calculates the higher deformations for vault settlement in section 3.~~"

Comments 5: *Data noises affected the designed model accuracy; this of course will increase with noise effects. this point should be described and discussed in the revised manuscript. see figures 9-14.*

Response 5: We appreciate the Reviewer's suggestion. Line 284, the description of the design model has been added. The details of the additions are highlighted in red in the following quotation marks.

"In this paper, the point cloud of a 48 m long 5.5 m diameter circular tunnel was collected by a laser scanner, as shown in Figure 5. Firstly, the point cloud data is pre-processed, cut into eight groups of lined pipe rings according to 6 m width and projected on the XOZ plane. The workers, cables, tracks and tunnel lining appendages and other interfering point clouds are then removed to get the eight purer groups of tunnel cross-sectional point clouds. The number of the eight groups of tunnel cross-section point clouds is shown in Table 1, and the closer the cross-section of the point cloud to the site of the laser scanner, the denser it is. **The tunnel design section relies on MATLAB to automatically generate and uniformly sample a circular model with a diameter of 5.5 m. The number of point clouds of design section is approximated to cross-section collected by the laser scanner. There is no noise interference in the design section, so it has no impact on the experimental results.**"

Comments 5: *Limitations of the proposed models should be presented and discussed.*

Response 6: We appreciate the Reviewer's suggestion. Line 381, the limitation of the tunnel simulation model has been added. The details of the additions are highlighted in red in the following quotation marks.

"A rectangular-like tunnel and a horseshoe-shaped tunnel are modelled in computer-aided design to verify the applicability of our method. Then, set the tunnel model rule for horizontal convergence and vault settlement, move, and rotate to other coordinate positions. The models before and after the deformation of the tunnel in (a) can be accurately aligned, and the displacements of the points in (b) are consistent with the deformation characteristics of the rule, as shown in Figures 15-16. Our algorithm can be applied to various tunnel shapes as it iterates over the nearest neighbor points and calculates the difference in distance between the corresponding points by curve transformation. **The tunnel simulation model is limited in its inability to provide feedback on the real deformation, so it is discussed further after the field data is collected.**"