Online Monitoring of Unstructured Varying-size Point Cloud Data: A Registration-free Approach

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Advances in additive manufacturing now allow the fabrication of complex shapes that are gaining widespread use across various domains. Non-destructive inspection of such innovative shapes is performed by non-contact sensors, collecting large, noisy, and unstructured point clouds of varying size. Surface reconstruction and registration (i.e., alignment of the nominal and real point clouds) are typically applied as a preprocessing step prior to monitoring. However, surface reconstruction techniques may introduce artifacts and spurious connections, thereby affecting monitoring outcomes. In addition, registration is computationally expensive, sensitive to initialization, noise, and partial overlaps. Nevertheless, registration can be avoided by leveraging intrinsic geometric properties of the shape [3]-[4]. To avoid both registration and surface reconstruction, we operate directly on point cloud data and propose a novel monitoring approach. Our proposal combines two alternative feature extraction techniques and a unified monitoring scheme. In particular, the intrinsic properties of printed parts are captured via robust Laplacian [2] and geodesic distances, computed using the heat method [1]. The proposed monitoring scheme exploits thresholding techniques to select features most indicative of potential out-of-control conditions. Numerical experiments highlight the potential of the proposed approach in identifying various defect types across different shapes.

Keywords: Point Cloud Data, Laplace Operator, Discrete Differential Geometry, Online Monitoring

References

[1] Crane, K., Weischedel, C., and Wardetzky, M. (2017). The heat method for distance computation. Commun. ACM, 60(11):90–99.
[2] Sharp, N. and Crane, K. (2020). A Laplacian for Nonmanifold Triangle Meshes. Computer Graphics Forum (SGP), 39(5).
[3] Zhao, X. and Del Castillo, E. (2021). An intrinsic geometrical approach for statistical process control of surface and manifold data. Technometrics, 63(3):295–312.
[4] Zhao, X. and Del Castillo, E. (2022). A registration-free approach for statistical process control of 3D scanned objects via FEM. Precision Engineering, 74:247–263.