15th World Congress on Computational Mechanics (WCCM-XV)
8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII)
31 July – 5 August 2022, Yokohama, Japan

Deformation Clustering Methods for Topologically Optimized Structures under Crash Load based on Displacement Time Series

Yasuyuki Shimizu[1*], Nivesh Dommaraju[1], Mariusz Bujny[2]

Stefan Menzel[2], Markus Olhofer[2], and Fabian Duddeck[1]

[1]Technical University of Munich, Arcisstraße 21 80333 Munich, Germany
[2] Honda Research Institute Europe GmbH, Carl-Legien-Straße 30 63073 Offenbach/Main, Germany
Email: yasuyuki.shimizu@tum.de

Key Words: *Deformation Behavior, Topology Optimization, Crash Load, Clustering, Time Series data, Dynamic Time Warping*

Multi-objective topology optimization has been receiving more and more attention in structural design recently. It attempts to maximize several performance objectives by redistributing the material in a design space for a given set of boundary conditions and constraints, yielding many Pareto-optimal solutions. However, the high number of solutions makes it difficult to identify preferred designs. Therefore, an automated way of summarizing solutions is needed for selecting interesting designs according to certain criteria, such as crashworthiness, deformation, and stress state. One approach for summarization is to cluster similar designs and obtain design representatives based on a suitable metric [1]. For example, with Euclidean distance of the objective vectors as the metric, design groups with similar performance can be identified and only the representative designs from different clusters may be analyzed. However, previous research has not dealt with deformation-related time-series data and structures with different topology. Since the non-linear dynamic behavior of designs is important in various fields such as vehicular crashworthiness, clustering methods based on the time-dependent behavior of structures is proposed here using metrics of time-series, such as DTW (Dynamic Time Warping) [2], for the comparison of displacement data of selected points on the structure. This is combined with clustering techniques such as *k*-Medoids [3] and OPTICS (Ordering Points To Identify the Clustering Structure) [4], and we investigate the use of unsupervised learning methods to identify and group similar designs using the time series of nodal displacement data. In the first part, we create artificial time-series datasets using mass-spring systems and a beam structure to validate the proposed methods. Each dataset has clusters of data with distinct behavior such as different periods or modes. Then, we find that the combination of DTW and OPTICS can identify the clusters of similar behavior accurately. In the second part, we apply these methods to a more realistic, engineering dataset which contains the crash behavior of topologically-optimized designs. We identify similar structures and obtain representative designs from each cluster, demonstrating the capability of our method for analyzing dynamic behavior, which supports the designers in selecting representative structures based on deformation data at the early stages of design process.

REFERENCES

[1] N. Dommaraju, M. Bujny, S. Menzel, M. Olhofer, and F. Duddeck, “Simultaneous Exploration of Geometric Features and Performance in Design Optimization,” in 16th International LS-DYNA Conference, 2020, p. 12.

[2] D. J. Berndt and J. Clifford. “Using dynamic time warping to find patterns in time series.” In: KDD workshop. Vol. 10. 16. Seattle, WA, USA: 1994, pp. 359–370.

[3] L. Kaufman and P. J. Rousseeuw, “Partitioning Around Medoids (Program PAM),” in Finding Groups in Data, John Wiley & Sons, Inc., 1990, pp. 68–125.

[4] M. Ankerst, M. M. Breunig, H. P. Kriegel, and J. Sander, “OPTICS: Ordering Points to Identify the Clustering Structure,” SIGMOD Record (ACM Special Interest Group on Management of Data), vol. 28, no. 2, Art. no. 2, 1999.