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**Satchit Ramnath, Jami Shah, Patricia Wollstadt,
Mariusz Bujny, Stefan Menzel, Duane Detwiler**

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OSU-Honda Automobile Hood Dataset (CarHoods10k)

Authors: S. Ramnath^{1,*}, J.J. Shah^{2,*}, P. Wollstadt³, M. Bujny³, S. Menzel³, D. Detwiler⁴

* Corresponding authors: Satchit Ramnath ramnath.17@osu.edu, Jami J. Shah shah.493@osu.edu

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Abstract

The CarHoods10k data set comprises a set of over 10,000 3D mesh geometries for variants of car hood frames, generated through an automated, industry-grade Computer Aided Design (CAD) workflow described in [1]. The data set provides realistic designs that were validated by experts with respect to realism, manufacturability, variability, and performance. Variations in geometries were generated by a feature-based approach that varies parameter values describing design features on 109 parameterized base geometries ('skins'). Parameters describe feature patterns such as cut-outs or ribs on the hood frame as well as their properties, for example, rib location and height, or cut-out location. Geometries are represented as surface meshes (STL files) and are provided with the corresponding design parameter values and performance metrics from structural mechanics, generated through finite element analysis (FEA). The data set provides realistic and validated designs for the evaluation and development of methods such as optimization approaches or machine learning for metamodeling or performance prediction. CarHoods10k thus enables the evaluate of data-driven approaches for application in the automotive engineering design domain and others.

Meta Data

For details on the data generation process refer to [1] and the related publication:

P. Wollstadt, M. Bujny, S. Ramnath, J. J. Shah, D. Detwiler and S. Menzel, "CarHoods10k: An Industry-grade Data Set for Representation Learning and Design Optimization in Engineering Applications," in *IEEE Transactions on Evolutionary Computation*, <https://doi.org/10.1109/TEVC.2022.3147013>.

Keywords: automotive engineering, mechanical engineering, research and development, prediction algorithms, classification algorithms, clustering algorithms, machine learning, artificial neural networks, optimization methods, optimization.

Research domains:

- Mechanical engineering (optimization, metamodeling)

¹ Simulation Innovation & Modeling Center, The Ohio State University Columbus, Ohio, USA

² Digital Design & Manufacturing Lab, The Ohio State University Columbus, Ohio, USA

³ Honda Research Institute Europe, Offenbach/Main, Germany

⁴ Honda Development & Manufacturing of America, Raymond, Ohio, USA

- Computer and information sciences (machine learning, deep learning, artificial intelligence)

Methods used in Data Generation

Generation of hood geometries

Geometry data were generated using a feature-based modeling approach. In the context of automotive car hoods, features describe components that contribute to desirable properties of the design, e.g., ribs to add stiffness during driving or impact, or cut-outs and pockets to reduce overall weight. Real car hood designs were simplified by removing features that were irrelevant for the hood's performance. Remaining features were created independent of the base surface to allow for the generation of a sufficiently large variety of hoods by combining features and feature patterns with a set of 100 base geometries ('skins'). Features were parametrized and generated using an automated workflow in CATIA v5 (see referenced publications for details). Note that some parametrizations led to invalid geometries (e.g., intersecting features) such that in total 10,478 unique hood geometry files were generated. CAD models were converted to watertight STL surface meshes in the STL format.

Generation of Simulation Results

For each car hood, structural mechanics performance values were simulated using finite element analysis (FEA). FEA was performed for a hood lift load case under driving conditions, which is an important structural requirement when designing car hood frames. The obtained performance values are maximum equivalent stress [MPa] and maximum directional deformation [mm]. Additionally, the geometry mass [kg] is provided for each design. FEA was performed using a standardized setup over all geometries (including mesh, boundary conditions, loads, etc.) to allow for automated generation of simulation results. Again, not all FEA were successful such that for 10,070 of the 10,478 geometries, performance results are available.

Usage Notes

Data Set Organization

```
hood_data/
|- design_tables/
|  |- skin_1.csv
|  |- skin_2.csv
|  |- ...
|  |- skin_109.csv
|
|- geometries/
|  |- skin_1/
|     |- geometry_1.stl
|     |- geometry_2.stl
|     |- ...
|     |- geometry_100.stl
|  |- skin_2/
```

```

| | | - geometry_1.stl
| | | - geometry_2.stl
| | | ...
| | | - geometry_100.stl
| - ...
| | - ...
| - skin_109/
| | - ...
- performance_values/
| - performance_design_parameters/
| | - skin_1.csv
| | - skin_2.csv
| | ...
| | - skin_109.csv
| - performance_only/
| | - skin_1.csv
| | - skin_2.csv
| | ...
| | - skin_109.csv
| README.txt

```

The top-level folder contains three folders:

1. '*design_tables*': contains one csv file per base geometry/skin, where each file has 100 entries with design parameter settings for each geometry variation of the current skin
2. '*geometries*': contains one subfolder 'skin_*' per base geometry/skin, where each subfolder contains 100 STL files of the geometry variations of the current skin
3. '*performance_values*': contains two subfolders
 - a) '*performance_design_parameters*': contains one csv file per base geometry/skin, where each file has at most 100 entries with design parameter settings and performance values from FEA simulation for each geometry variation of the current skin. Note that not all simulations were successful, hence some results are missing. The column 'OutputNumber' holds the geometry ID for each simulation result, i.e., OutputNumber 10 in file performance_values/performance_design_parameters/skin_20.csv corresponds to geometry file geometries/skin_20/geometry_10.stl. If the performance value for a specific geometry is missing, the corresponding line is not present in the table.
 - b) '*performance_only*': contains one csv file per base geometry/skin, where each file has at most 100 entries with performance values from FEA simulation for each geometry variation of the current skin. Note that not all simulations were successful, hence some results are missing and there is no entry in the table for the respective geometry. Again, geometry IDs are given in column 'OutputNumber'.

File Contents

Tables contain the following variables:

'*design_tables*': Tables with a subset of the following variables:

- Ribs:

- 'RearRibDepth'
- 'RearRibEndPointX'
- 'RearRibEndPointY'
- 'RearRibOffset'
- 'RearRibWidth'
- 'FrontRibDepth'
- 'FrontRibEndPointY'
- 'FrontRibOffset'
- 'FrontRibWidth'
- 'RibDepth'
- 'RibWidth'
- 'MainRibWidth'
- 'MiddleRibWidth'
- 'CentralRibWidth'
- 'SubsidiaryRibWidth'

- Pockets (with #1-4):

- 'Pocket#_Offset'
- 'Pocket#_Position'
- 'Pocket#_Radius'
- 'Pocket#_X'
- 'Pocket#_Y'
- 'PocketAngle'
- 'PocketCombinedWidth'
- 'PocketLength'
- 'PocketWidth'
- 'Pocket_XDistance'
- 'Pocket_YDistance'

- Other:

- 'CircleCenter'
- 'CornerPoint'
- 'Cutout2Size'
- 'EdgeLength'
- 'FrontCurveHeight'
- 'OuterRadius'
- 'Radius'
- 'RearCurveHeight'
- 'hinge_x'
- 'hinge_y'
- 'lock_x'
- 'offset'

Values are arbitrary parameter values used by CATIA to generate the feature.

'*performance_values*': Tables in '*performance_only*' have four columns:

- 'Equivalent Stress Maximum (MPa)'
- 'Geometry Mass (kg)'
- 'Directional Deformation Maximum (mm)'
- 'OutputNumber': geometry ID for current skin

Tables in '*performance_design_parameters*' have additional columns with design parameters similar to the '*design_tables*' described above. Note that some values are missing due to failure of the FEA and the corresponding line is not present in the table.

'*geometries*': Provided as STL files (Standard Triangle Language/Standard Tessellation Language), which is a common format in 3D processing that describes the triangulated surface of a 3D object. The surface is represented as an unordered set of triangles, where each triangle is described by its vertices in Euclidean space and a face normal pointing outward from the object.

Each triangle is described by the following block in the STL file:

```
facet normal n1 n2 n3
  outer loop
    vertex x1 y1 z1
    vertex 2x y2 z2
    vertex 3x y3 z3
  endloop
endfacet
```

Note that STL files for some geometries are missing because the generation of these particular variants by the CAD workflow failed. CAD Failures are mainly due to parameter combinations leading to invalid geometries (e.g., geometries with intersecting features).

References

- [1] Ramnath, Haghghi, Kim, Detwiler, Berry, Shah, Aulig, Wollstadt, Menzel (2019, August) "Automatically Generating 60,000 CAD Variants for Big Data Applications." International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Vol. 59179. [<https://doi.org/10.1115/DETC2019-97378>]
- [2] Ramnath, Haghghi, Ma, Shah, Detwiler, (2020, August). "Design science meets data science: Curating large design datasets for engineered artifacts". In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 83983, p. V009T09A043). American Society of Mechanical Engineers. [<https://doi.org/10.1115/DETC2020-22377>]
- [3] Ramnath, Ma, Shah, Detwiler, (2021, August) "Intelligent Design Prediction aided by Experiment Design and Machine Learning in Feature based Product Development". In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers.
- [4] Ramnath, Li, Shah, Detwiler, (2021, October) "Design Exploration of Automotive Hood based on Non-Uniform Feature Parameters", NAFEMS World Congress, 2021