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PyGeM: Python Geometrical Morphing

Marco Tezzele *, Nicola Demo, Andrea Mola, Gianluigi Rozza

Mathematics Area, mathLab, SISSA, International School of Advanced Studies, Trieste, Italy

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ABSTRACT

PyGeM is an open source Python package which allows to easily parametrize and deform 3D object described by CAD files or 3D meshes. It implements several morphing techniques such as free form deformation, radial basis function interpolation, and inverse distance weighting. Due to its versatility in dealing with different file formats it is particularly suited for researchers and practitioners both in academia and in industry interested in computational engineering simulations and optimization studies.

Code metadata

Current code version	2.0
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2020-59
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/9903556/tree/v1
Legal Code License	MIT License (MIT)
Code versioning system used	git
Software code languages, tools, and services used	Python
Compilation requirements, operating environments & dependencies	PyGeM requires `numpy`, `scipy`, `matplotlib`, `sphinx` (for the documentation) and `nose` (for local test). To enable the CAD submodule, the module `pythonocc-core` is required to deal with IGES files.
If available Link to developer documentation/manual	http://mathlab.github.io/PyGeM/
Support email for questions	marco.tezzele@sissa.it nicola.demo@sissa.it andrea.mola@sissa.it

Software metadata

Current software version	2.0
Permanent link to executables of this version	https://github.com/mathLab/PyGeM/releases/tag/v2.0
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/9903556/tree/v1
Legal Software License	MIT License (MIT)
Computing platforms/Operating Systems	Linux, OS X, Unix-like
Installation requirements & dependencies	PyGeM requires `numpy`, `scipy`, `matplotlib`, `sphinx` (for the documentation) and `nose` (for local test). To enable the CAD submodule, the module `pythonocc-core` is required to deal with IGES files.
If available, link to user manual - if formally published include a reference to the publication in the reference list	http://mathlab.github.io/PyGeM
Support email for questions	marco.tezzele@sissa.it nicola.demo@sissa.it andrea.mola@sissa.it

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* Corresponding author.
E-mail addresses: marco.tezzele@sissa.it (M. Tezzele), nicola.demo@sissa.it (N. Demo), andrea.mola@sissa.it (A. Mola), gianluigi.rozza@sissa.it (G. Rozza).

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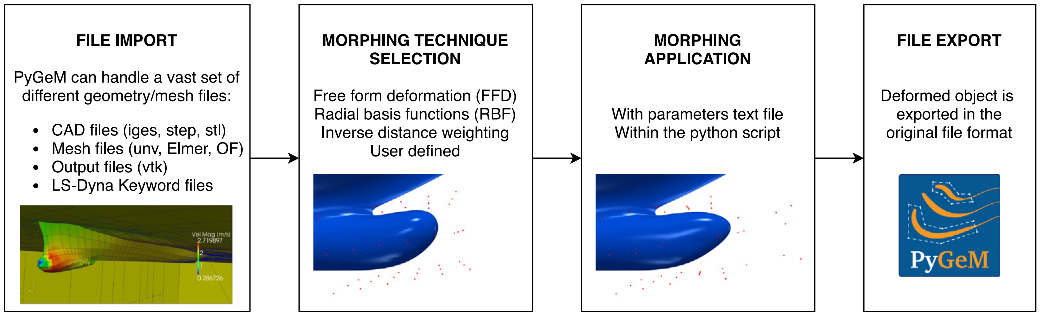

Fig. 1. PyGeM complete usage workflow. The coordinates of the points to morph can be read from different file formats. After selecting the proper parametrization technique and the corresponding parameters, we can export the deformed geometry into the original file format.

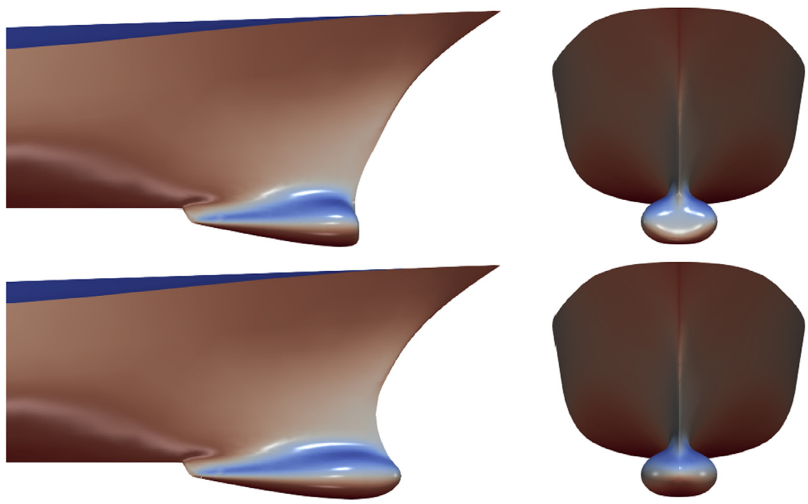

Fig. 2. Examples of two deformation on a naval hull, from lateral and frontal views.

1. The PyGeM package

In many simulation based processes, the performances of a certain product have to be evaluated varying the shape of the object itself. In all these parametric contexts, it is extremely useful a shape parametrization technique, associating the deformations to some numerical parameters, in order to enable some advanced algorithms — e.g. shape optimization, approximation of the parametric solution manifold, reduced order modeling techniques.

PyGeM is an open source Python package which implements advanced 3D geometrical parametrization and deformation techniques such as free form deformation (FFD) [1], radial basis functions (RBF) interpolation [2], inverse distance weighting (IDW) [3–5], and user defined custom deformations. Moreover it is able to interact with a vast range of mesh and geometry file commonly used both in academia and in industry. The complete list is the following:

- Computer Aided Design files (in .iges, .step, and .stl formats);
- mesh files (in .unv, Elmer, and OpenFOAM formats);
- output files (in .vtk format);
- LS-Dyna Keyword files (.k format).

Moreover, it is possible to apply the deformations to the points contained into a generic `numpy.ndarray`, extending further the applicability of such software.

The complete workflow describing the usage of the PyGeM package is illustrated in Fig. 1. After importing the mesh coordinates or, for the CAD files, the control points coordinates, we can select the desired parametrization technique, and the corresponding parameters. The user can also define a custom deformation. The numerical parameters whose control the deformation can be set directly within the code or parsing a simple formatted text file, allowing for an easy integration in many existing frameworks. Finally the morphed object can be exported into the original file format. In Fig. 2 we show two demonstrative examples of geometric files which have been deformed by using PyGeM. The entire workflow can be implemented by the end user in few lines of code, thanks to the object oriented paradigm, which allows to maintain the interface clean and intuitive and encapsulate the algorithmic core within hierarchical classes.

The package is distributed with several tutorials that show its capabilities tackling the most common use cases. Additionally, an online documentation is provided [6].

2. The impact to research fields

A diverse range of numerical simulations made use of this geometrical morphing package, especially for parametric studies in the context of reduced order methods [7–9]. In the biomedical field we cite [10,11] where they employ RBF interpolation. In the naval field FFD has gained lots of attention thanks for its application to CAD files, for example in shape optimization studies [12–17], or in the context of isogeometric analysis [18]. For nautical application we mention [19], while for a benchmark CFD application see [20], where they also perform a reduction of the FFD parameters. The package has been successfully adopted also in automotive engineering, for example in [21,22].

3. The impact to industrial collaborations

PyGeM has been involved in several industrial collaborations and projects, matching the demand of an intuitive, easily integrable tool for shape parametrization. In the Higher Education and Development programme, of the European Social Fund, it was exploited during the collaboration with Fincantieri S.p.A. within a shape optimization procedure developed to improve the hull shape of cruise vessels. Thanks to the numerical parametrization of the ship, it was in fact possible to feed the optimization algorithm in a completely automated fashion and, starting from the initial shape, converge to the geometrical configuration which minimizes the total resistance. The overall efficiency of the optimization cycles were further improved through the application of reduced order modeling techniques which significantly accelerated the simulations.

Further applications of PyGeM to industrial problems have been carried out in the context of the projects Underwater Blue Efficiency (UBE) and Seakeeping of Planing Hull Yachts (SOPHYA). Both projects have been funded by the Friuli Venezia Giulia regional government by means of the European Regional Development Fund and involve both academic and industrial partners such as Università di Trieste, Monte Carlo Yachts S.p.A. and MICAD s.r.l. The focus of both projects has been the overall hydrodynamic design of a motor yacht hull, and the detailed study of specific components such as underwater exhaust outlets. In such framework, PyGeM was used to deform the hull CAD geometry, and to parametrize the underwater exhaust outlet scoops. In addition, RBF algorithms have been used to extend the resulting CAD surface modifications to the surrounding volume and adjust accordingly the computational grids for the fluid dynamic simulations involved in the project. Again, this resulted in the possibility to run fully automated optimization cycles for the design of the full hull or its components.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.simpa.2020.100047.

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