`pykitPIV`: PyTorch-compatible synthetic image generation for training flow estimation algorithms in particle image velocimetry

Kamila Zdybał*[a], Claudio Mucignat[a] and Ivan Lunati[a]

[a]*Laboratory for Computational Engineering, Swiss Federal Laboratories for Materials Science and Technology, Empa, Dübendorf, Switzerland*

ARTICLE INFO

Keywords:
particle image velocimetry; flow estimation; convolutional neural networks; Python

ABSTRACT

We describe `pykitPIV`, a PyTorch-compatible Python library for generating synthetic images that mimic those obtained from particle image velocimetry (PIV) experiments. The library can be readily ported to training machine learning algorithms, such as convolutional neural networks (CNNs), or reinforcement learning (RL). Our image generation exploits the kinematic relationship between two PIV snapshots and advects particles from one time frame at t_1, to the next at $t_1 + \Delta t$, with a second-order accurate numerical scheme. This results in paired image intensities, I_1 and I_2 that are separated by Δt in time. The goal of this library is to give the user a lot of flexibility in selecting various parameters that would normally be available in an experimental setting such as particle seeding density, thickness of the laser plane, camera exposure, particle loss due to out-of-plane movement, or time separation between images. The richness of image generation can find application in training machine learning algorithms such as CNNs or RL.

1. Introduction

The last decade has seen many advances in training convolutional neural networks (CNNs) for flow estimation, *i.e.*, predicting motion information from consecutive static image frames. To date, numerous interesting network architectures have been developed. This includes various implementations of FlowNets [1–3], spatial pyramid network (SPyNet) [4], and pyramid, warping and cost-volume network (PWC-Net) [5]. In addition, the idea of the iterative residual refinement (IRR) [6] allowed for significant reduction in the number of trainable parameters thanks to weight-sharing at several levels of successively upscaling image resolution. More recently, RAFT-PIV [7] and LIMA [8] were proposed as versions of CNNs that are specifically optimized for predicting flow targets from velocimetry experiments. Thanks to this targeted optimization of CNN architecture and training parameters, RAFT-PIV achieves high accuracy and LIMA is significantly lighter than its predecessors.

To advance the accuracy of training CNNs for PIV applications, a number of research questions will have to be addressed next:

1. How rich does the training dataset need to be to remain applicable in a given experimental setting?
2. What degree of data augmentation is sufficient to transfer knowledge from one trained CNN to the next when changing experimental settings?
3. At what time separation, Δt, would the current CNN architectures fail?

To help researchers answer those questions, we propose the present Python library, `pykitPIV` – **Py**thon **ki**nematic **t**raining for **PIV**.

kamila.zdybal@gmail.com (K. Zdybał*)
ORCID(s):

2. Software overview

The PIV image pair tensor has shape $(N, 2, H, W)$, where N is the batch size, H is image height and W is image width. The second dimension can be thought of as the number of channels and those correspond to I_1 and I_2, respectively. This is compatible with tensor shape accepted by convolutional layers implemented in PyTorch.

2.1. Class: `Particle`

2.2. Class: `FlowField`

The user also has the option of uploading an external velocity

2.3. Class: `Motion`

2.4. Class: `Image`

2.5. Class: `Postprocess`

3. Discussion

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna,

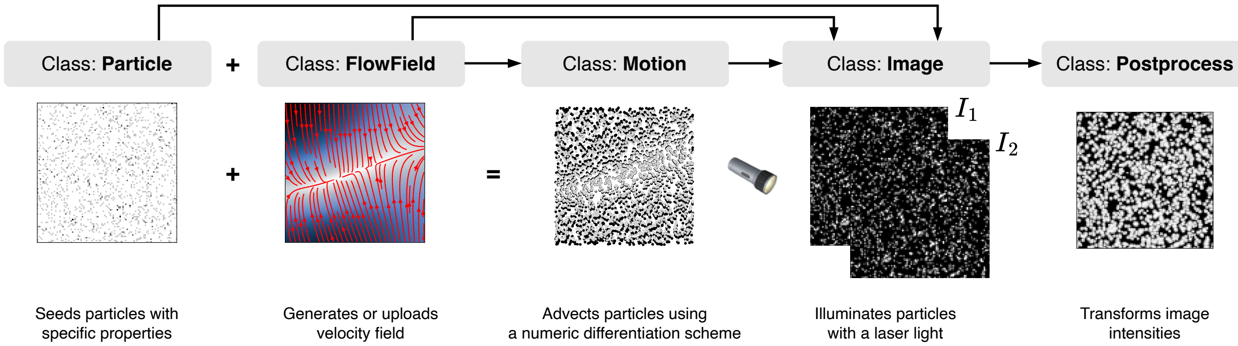

Figure 1: Order of using `pykitPIV` classes. At each stage of synthetic image generation, the user has freedom in selecting various parameters that would normally be available in an experimental setting such as particle seeding density, thickness of the laser plane, camera exposure, particle loss due to out-of-plane movement, or time separation between images.

vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

4. Conclusions

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.

Author contributions

Acknowledgments

References

[1] A. Dosovitskiy, P. Fischer, E. Ilg, P. Hausser, C. Hazirbas, V. Golkov, P. Van Der Smagt, D. Cremers, T. Brox, Flownet: Learning optical flow with convolutional networks, in: Proceedings of the IEEE international conference on computer vision, 2015, pp. 2758–2766.

[2] E. Ilg, N. Mayer, T. Saikia, M. Keuper, A. Dosovitskiy, T. Brox, Flownet 2.0: Evolution of optical flow estimation with deep networks,

in: Proceedings of the IEEE conference on computer vision and pattern recognition, 2017, pp. 2462–2470.
[3] T.-W. Hui, X. Tang, C. C. Loy, Liteflownet: A lightweight convolutional neural network for optical flow estimation, in: Proceedings of the IEEE conference on computer vision and pattern recognition, 2018, pp. 8981–8989.
[4] A. Ranjan, M. J. Black, Optical flow estimation using a spatial pyramid network, in: Proceedings of the IEEE conference on computer vision and pattern recognition, 2017, pp. 4161–4170.
[5] D. Sun, X. Yang, M.-Y. Liu, J. Kautz, PWC-Net: CNNs for optical flow using pyramid, warping, and cost volume, in: Proceedings of the IEEE conference on computer vision and pattern recognition, 2018, pp. 8934–8943.
[6] J. Hur, S. Roth, Iterative residual refinement for joint optical flow and occlusion estimation, in: Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, 2019, pp. 5754–5763.
[7] C. Lagemann, K. Lagemann, S. Mukherjee, W. Schröder, Deep recurrent optical flow learning for particle image velocimetry data, Nature Machine Intelligence 3 (7) (2021) 641–651.
[8] L. Manickathan, C. Mucignat, I. Lunati, A lightweight neural network designed for fluid velocimetry, Experiments in Fluids 64 (10) (2023) 161.