Neural Network-based Detection of Taylor Vortices in Annular Flow Systems

Exposé for Master Thesis - Initial Presentation

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Problem Statement

Taylor-Couette flow

- a fluid dynamic phenomenon that occurs when a fluid is passing between two coaxial-rotating cylinders.

- Inner cylinder is typically rotating faster than outer cylinder.

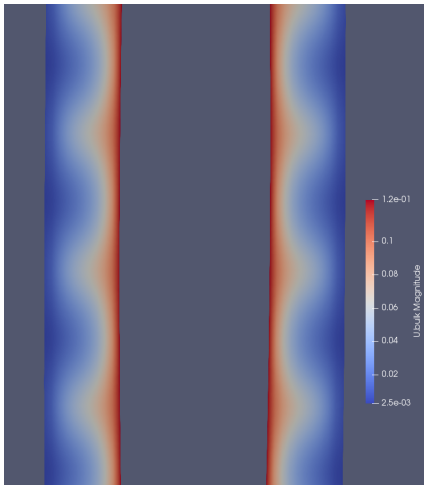- Dimensionless control parameters like Re, ω_{inner} and ω_{outter} are key factors

Abbildung: Taylor-couette flow at time-step 19

Objectives

- Governing equ:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\frac{1}{\rho}\nabla p + \nu\nabla^2\mathbf{u} + \mathbf{f} \tag{1}$$
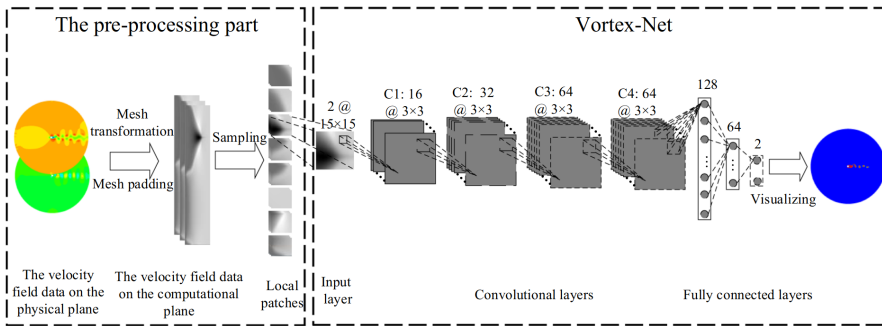
- w.r.t boundary conditions:

$$\mathbf{u} = \mathbf{u}_0 \quad \text{at} \quad \Gamma_1 \tag{2}$$

$$\mathbf{u} = 0 \quad \text{at} \quad \Gamma_2 \tag{3}$$

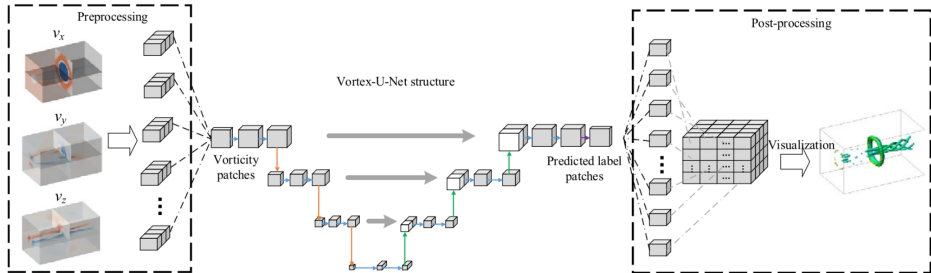$$\frac{\partial p}{\partial n} = 0 \quad \text{at} \quad \Gamma_3 \tag{4}$$

Litrature Review

(a) (Liang et al., 2018), a CNN-based vortex identification method to use both local and global information of flow field.

Litrature Review

(b) (Deng et al., 2022), replacing the fully-connected NN with a segmented network to reduce the computational complexity.
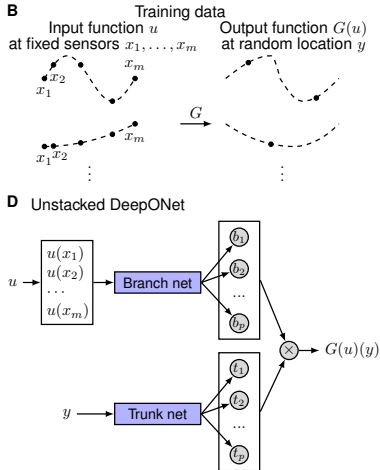
Approach

(a) Data preparation:
   - Running the *Taylor merve* case for different values of $\{\omega_{inner}, \omega_{outter}, Re\}$
   - Collecting the velocity fields and λ_2 vectors for all time steps.
(b) Model development:
   – Trying to Learn the mapping from a function in field to a **Region-like** method for detecting vortices.

Deep operator networks(Lu, Jin, Pang, Zhang & Karniadakis, 2021) (DeepONets)

B Training data
Input function u at fixed sensors $x_1, \ldots, x_m$ — Output function $G(u)$ at random location y

D Unstacked DeepONet

- Each input function u is evaluated at fixed sensor points $\{x_1, x_2, \ldots, x_m\}$
- y with d components and $u(x_i)$ for $i = 1, 2, \ldots, m$ are not matched. Therefor, it is needed to use two subnets. **Branch** for encoding input function at sensor points - **Trunk** for the location to evaluate output function

$$G(u)(y) \approx \sum_{k=1}^{p} b_k\, t_k + b_0 \qquad (5)$$

Deep operator networks (DeepONets): prediction of λ_2

Inputs of branch:
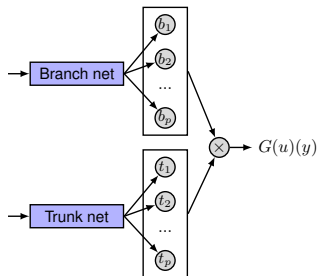$\mathbf{u} \in \mathbb{R}^3$, $(N_s, 3)$
Outputs of branch:
$\boldsymbol{b} \in \mathbb{R}^{N_f}$, (N_s, N_f)

Inputs of trunk:
$\mathbf{X} \in \mathbb{R}^{128000}$, $(128000, 3)$
Outputs of trunk:
$\boldsymbol{t} \in \mathbb{R}^{N_f}$, $(128000, N_f)$

Outputs:
$\boldsymbol{u} \in \mathbb{R}^{1 \times 128000}$,
$(N_s, N_f) \bigotimes (128000, N_f)^T$

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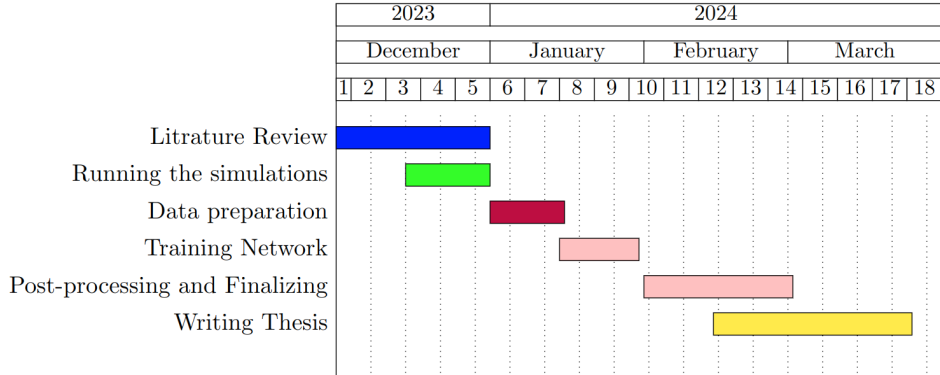
Motivation

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Timeline

Abbildung: Timeplan

Thank you!
Any questions?

TU Clausthal

Deng, L., Bao, W., Wang, Y., Yang, Z., Zhao, D., Wang, F., . . . Guo, Y. (2022).
Vortex-u-net: An efficient and effective vortex detection approach based on
u-net structure. *Applied Soft Computing*, *115*, 108229. Zugriff auf `https://`
`www.sciencedirect.com/science/article/pii/S1568494621010620` doi:
https://doi.org/10.1016/j.asoc.2021.108229

Liang, D., Wang, Y., Liu, Y., Wang, F., Li, S. & Liu, J. (2018, 10). A cnn-based
vortex identification method. *Journal of Visualization*, *22*. doi:
10.1007/s12650-018-0523-1

Lu, L., Jin, P., Pang, G., Zhang, Z. & Karniadakis, G. E. (2021). Learning nonlinear
operators via DeepONet based on the universal approximation theorem of
operators. *Nature Machine Intelligence*, *3* (3), 218–229.