Deep Learning to predict extreme wind loads on buildings

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Stanford University - CS 230: Deep Learning

Motivation & objective

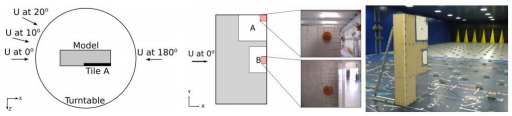
Motivation: Glazed panels, covering high-rise building's external facades, can be subjected to extreme pressure events due to wind, which can be critical for these components.

Goal: enable efficient and reliable computation of extreme pressure occurring on high-rise buildings' external facades.

Wind tunnel measurements

Several experiment on a high-rise building model have been performed in the wind tunnel of Politecnico di Milano [1]:

- *outcome*: 300s time-series of pressure (p) in critical regions, i.e. near corners and edges (tiles A-B), at different wind directions.



Output: $C_{p,rms} = \frac{\sqrt{\text{var}(p)}}{p_{ref}}$

RANS simulations

Reynolds-averaged Navier-Stokes (RANS) simulations, solve the time-averaged Navier-Stokes equations, while modeling turbulence transport [2]:

- *outcome*: mean pressure (P) and velocity (U); turbulence kinetic energy (k), dissipation rate (ϵ) and viscosity (ν_t),
- *pros*: relatively low computational cost,
- *cons*: need of model to retrieve pressure fluctuations over time.

Construct 8 quantities from RANS variables [3]:

Features: $\mathbf{x} = \mathbf{x}(P, U, k, \epsilon, \nu_t, \nabla P, \nabla U)$

Complete dataset

- 224 examples on tile A, 223 examples on tile B.
- 8 wind directions: $0°, 10°, 20°, 170°, 180°, 190°, 200°, 260°$.

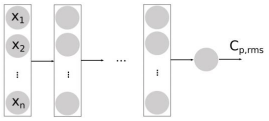
Total: 3,584 examples

	Train	Dev	Test
Tile A	$0°, 10°, 170°, 180°, 260°$	$190°$	$20°$
Tile B	$0°, 10°, 170°, 180°, 190°$	$0°, 180°, 260°$	$20°$

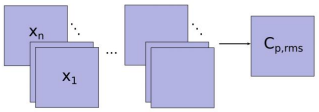
Additional test set: data around the whole facade at $0 - 180°$, are available from a high-fidelity simulation.

Models

Artificial neural network (ANN):



Convolutional neural network (CNN):



- Each pressure tile is treated as a $2D$ example with 224 pixel values.

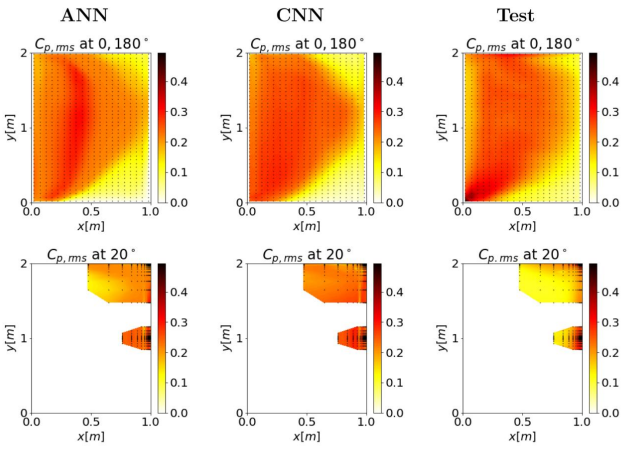
Results

Hyper-parameters tuning:

Hyper-parameter	ANN	CNN
# epochs	300	1,000
# hidden layers	5	1
# hidden units	7	-
activation	reLu	reLu
learning rate	0.01	0.01
dropout	None	None
batch-normalization	None	None
# number of filters	-	14
filter size	-	1

Evaluation metric: $\frac{\Sigma_i |y_i - y_{pred,i}|}{\Sigma_i |y_i|}$

Set	ANN	CNN
Train	4.8%	21.5%
Dev	1.7%	8.8%
Test: tiles A-B at $20°$	10.0%	24.6%
Test: whole facade $0 - 180°$	3.9%	11.5%



Conclusions and future work

- The ANN seems to perform better in extrapolating to different regions of the building, and different wind directions.
- Future work will focus on testing the models in different geometries.

References

[1] L. Amerio, *Experimental high resolution analysis of the pressure peaks on a building scale model façades.* PhD thesis, Politecnico di Milano, 2018.

[2] S. B. Pope, "Turbulent flows," 2001.

[3] J. Ling and J. Templeton, "Evaluation of machine learning algorithms for prediction of regions of high reynolds averaged navier stokes uncertainty," *Physics of Fluids*, vol. 27, no. 8, p. 085103, 2015.