

Convolutional Neural Network for Detection and Quantification of Pilot-Induced Oscillations

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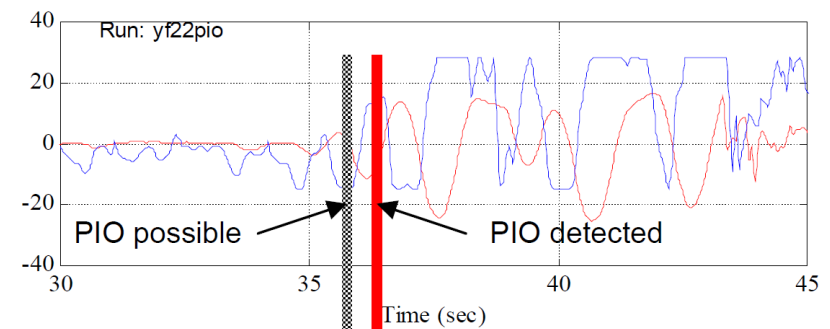
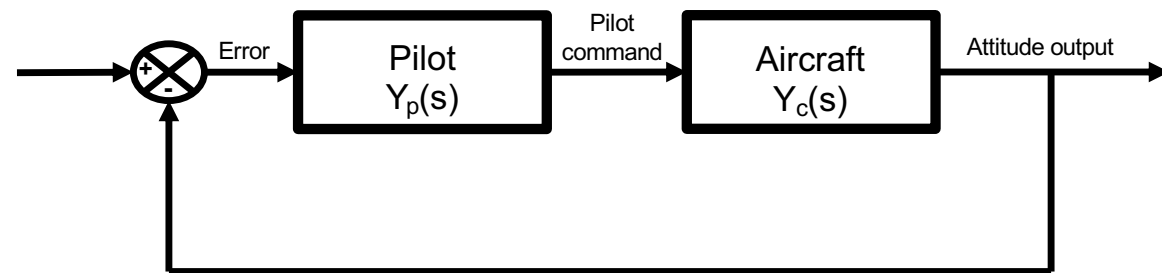
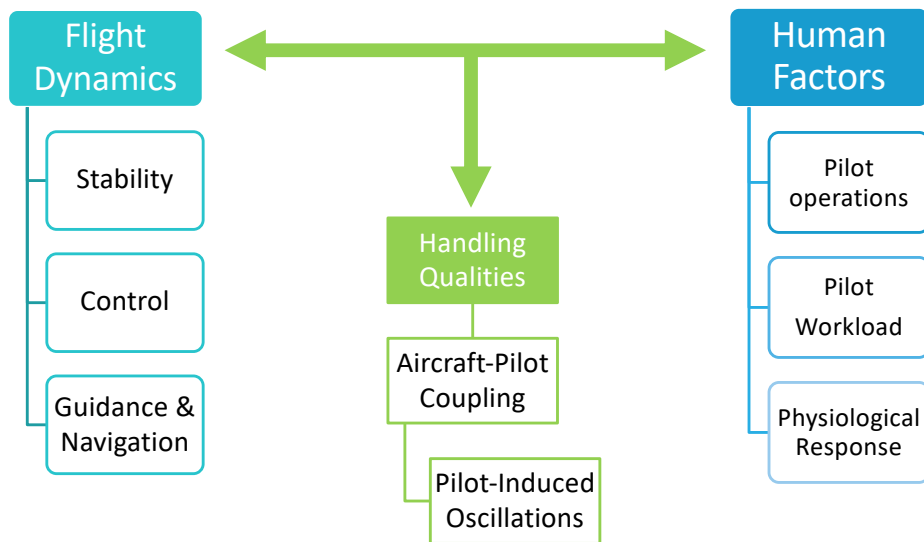
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PIO definitions

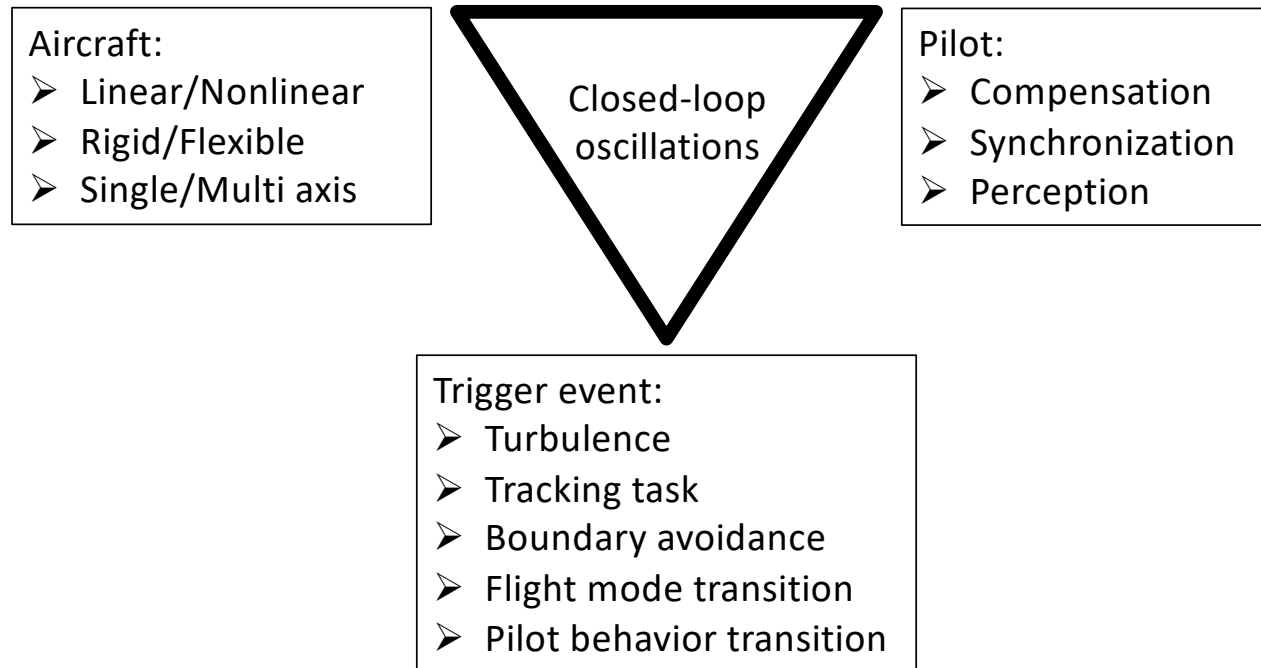


Main definition of PIO:

- MIL-STD-1797A: “sustained or uncontrollable oscillations resulting from efforts of the pilot to control the aircraft”.

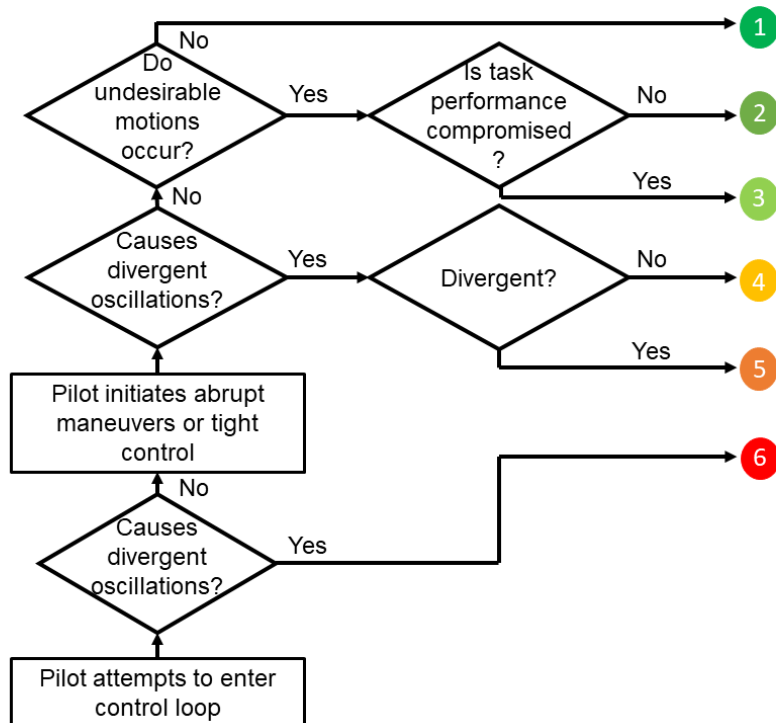
PIO definitions

PIO conditions:



PIO Identification

The PIO Rating Scale (**PIOR scale**):




No tendency for pilot to induce undesirable motion	1
Undesirable motions tend to occur when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique.	2
Undesirable motions easily induced when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated but only at sacrifice to task performance or through considerable pilot attention and effort.	3
Oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must reduce gain or abandon task to recover.	4
Divergent oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must open loop by releasing or freezing the stick.	5
Disturbance or normal pilot control may cause divergent oscillation. Pilot must open control loop by releasing or freezing the stick.	6

PIO severity increases

PIO Identification

The PIO Rating Scale:

- Dependent on the pilot's perception (qualitative approach).
 - Demands training to be applied.
 - Based on the amplitudes of the control input and aircraft output.
 - The PIO severity is associated with PIOR grades.
 - It is expected from the pilot to consider the phase difference during the assessment.
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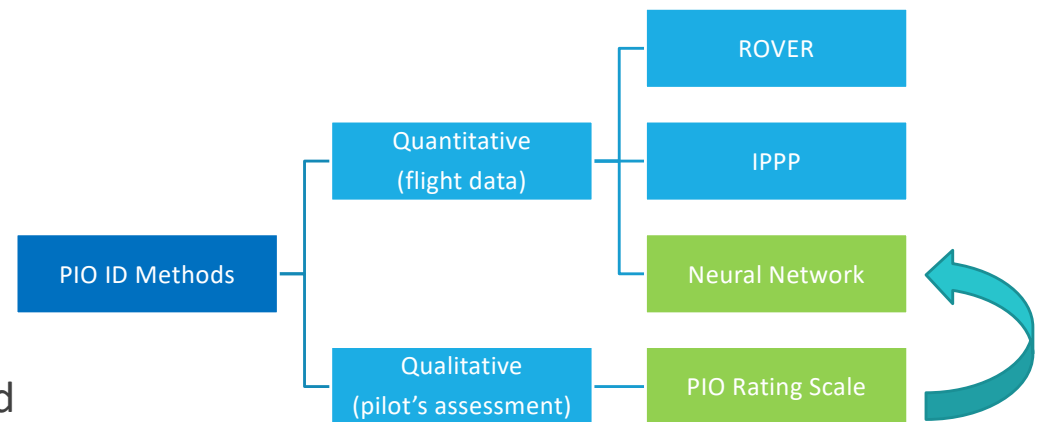
PIO Identification

Quantitative methods:


- Based on flight data processing.
- Strongly dependent on the PIO definitions.
- Arbitrary thresholds.

Qualitative methods:

- Dependent on the pilot's perception and interpretation of the PIO phenomenon.
- Largely used in the aeronautical industry (flight test and aircraft certification).



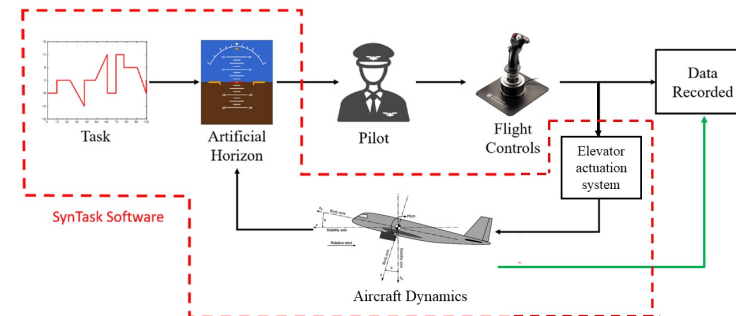
Objectives

- To build a Machine Learning-based tool to identify and quantify PIOs.
 - Hybrid approach: Quantitative flight data and PIOR labels.
 - The detection and quantification is outputted in the same framework as the PIO rating scale.
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Experimental analysis

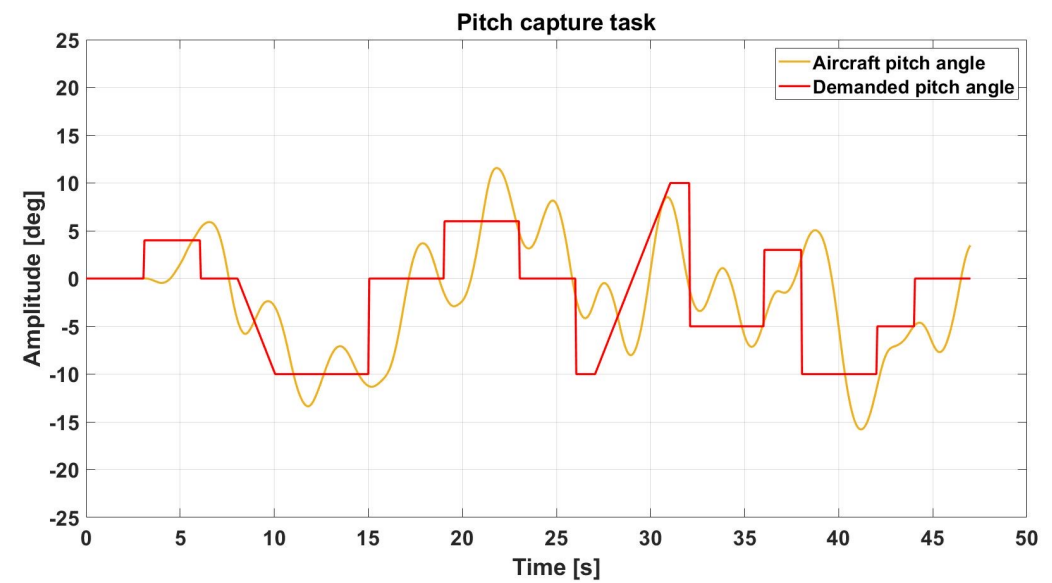
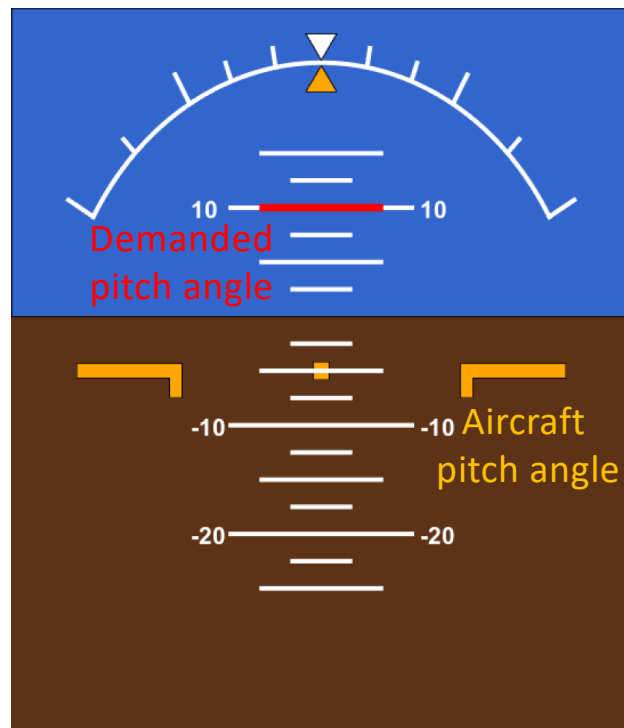
Data acquisition:

- A dataset was created using the Syntask Software of University of São Paulo.
- Ten trained test pilots participated in the simulated flight tests.
- Six variations of the commercial airliner linear longitudinal model were used (the $C_{m\dot{\alpha}}$ derivative was artificially modified).
- Eight task profiles were used.
- Data from 480 test flights were recorded with PIOR grades (***labelled dataset***).



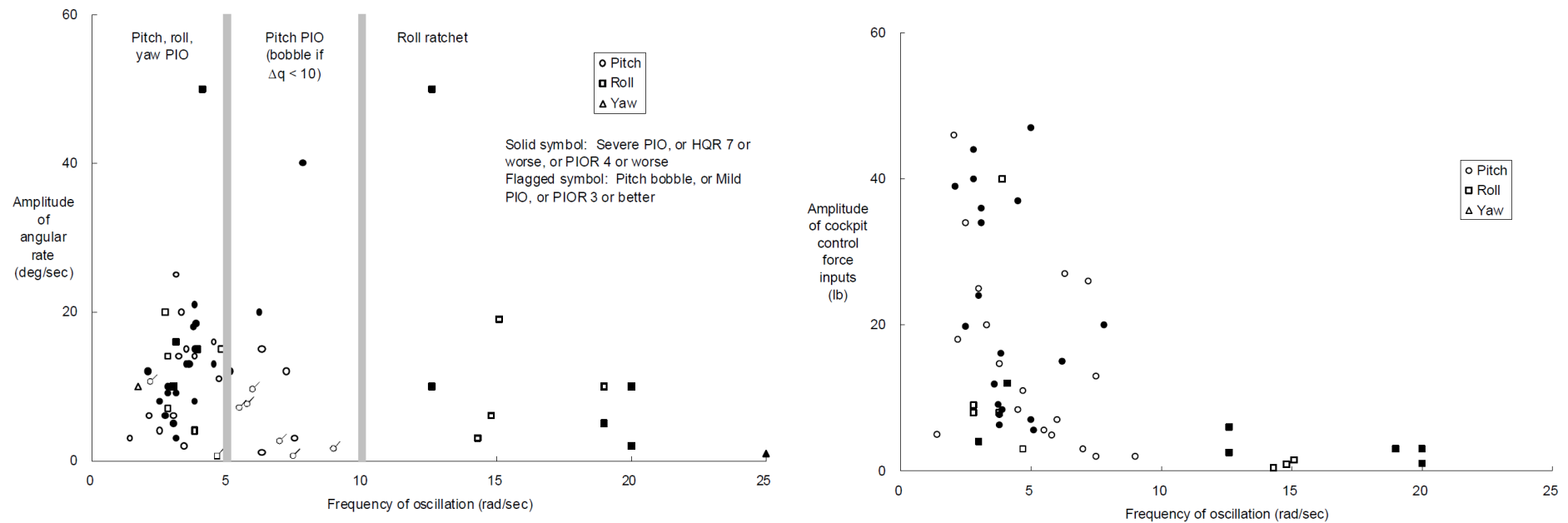
Experimental analysis

The Syntask Software:



Data preprocessing

Angular rates and pilot's input for several real PIO cases.

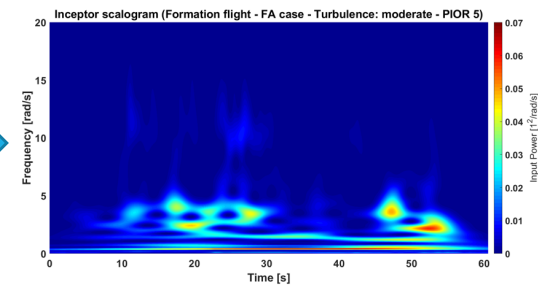
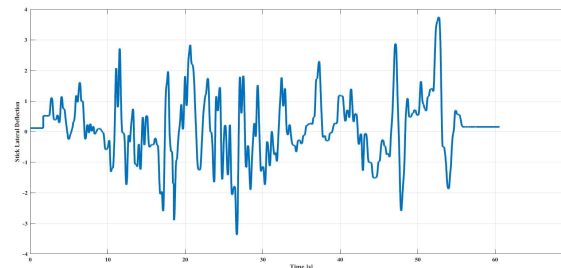
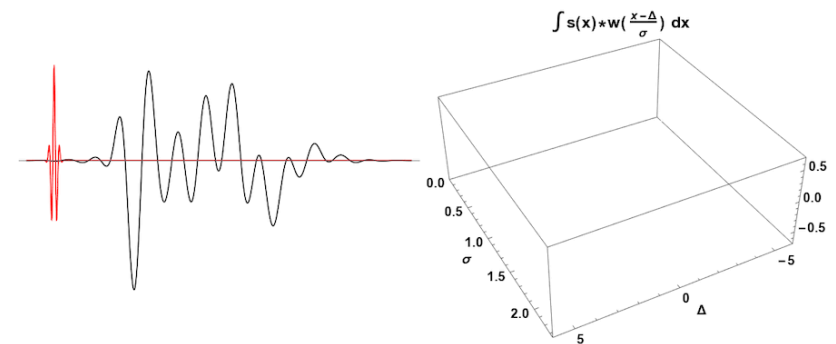


Source: Mitchell, Arencibia, and Muñoz (2004)

Data preprocessing

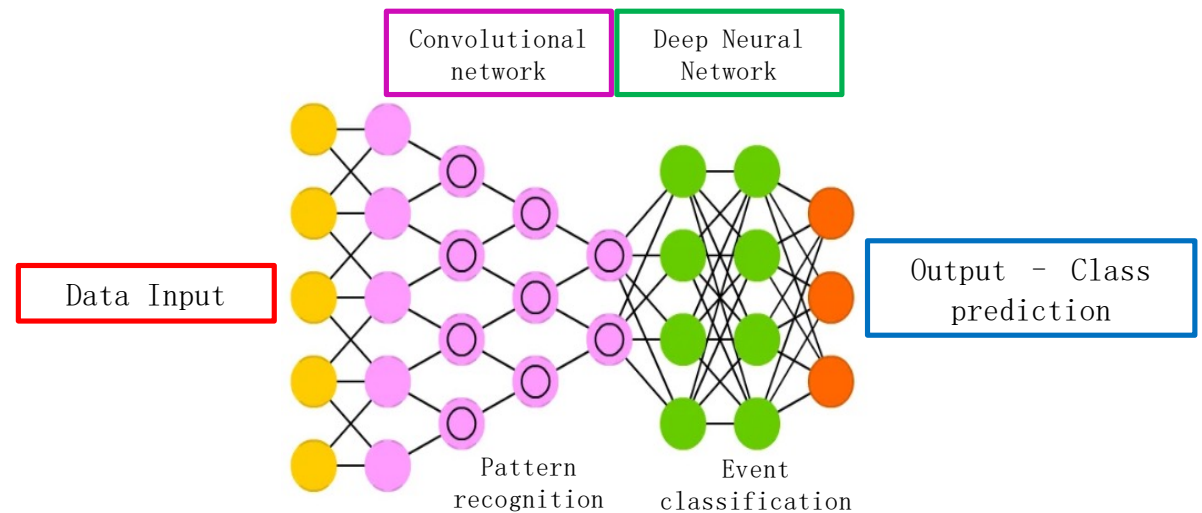
The Wavelet Transform:

- Time-frequency transform.
- Useful to non-stationary (frequency varying) signal analysis.
- Power density is a function of both time and frequency.
- Capable of highlighting PIO traces in measured flight data.
- Applied to the **pilot's input and the pitch rate response.**

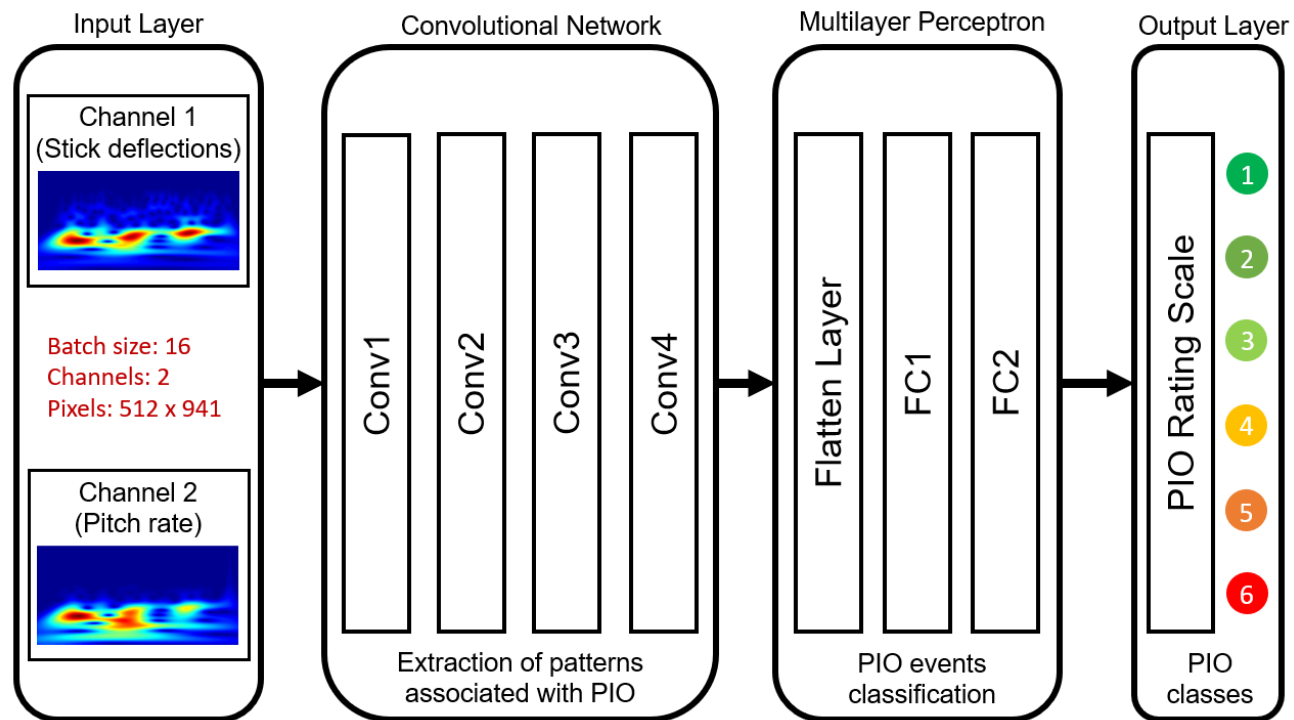


Convolutional Neural Network

- Uses simple flight measurements as multi-channel input.
- Pattern recognition in the flight data.
- Can handle data in image format (wavelet transform).
- Can provide an output in the PIOR format (PIO severity information).
- Supervised learning: PIOR labels can be used in the training process.



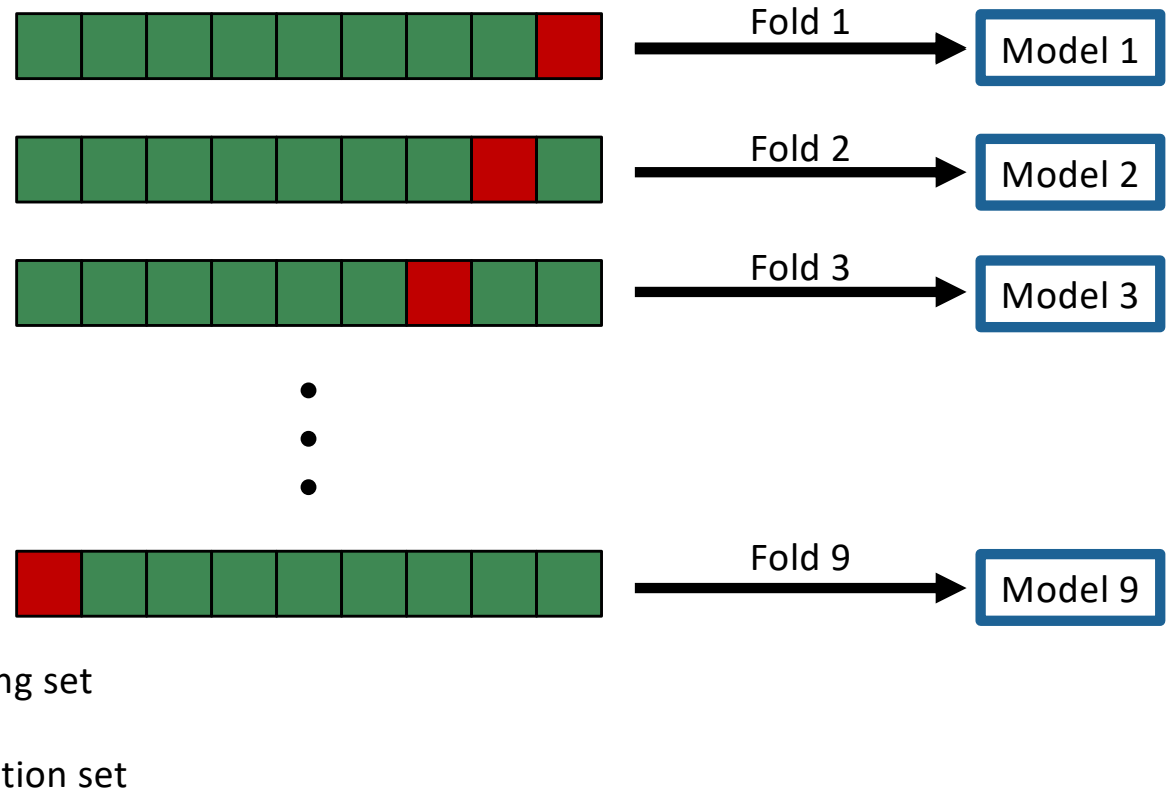
CNN architecture



Training and Validation

K-fold method:

- The dataset was split into nine parts.
- The training procedure was executed nine times.
- Adaptive Weighted Momentum (AdamW) optimization algorithm.
- Cross entropy loss function with label smoothing.



Training and Validation

- Training process presented some degree of overfitting.
- Maximum validation accuracy is 63.1% (Fold 6).

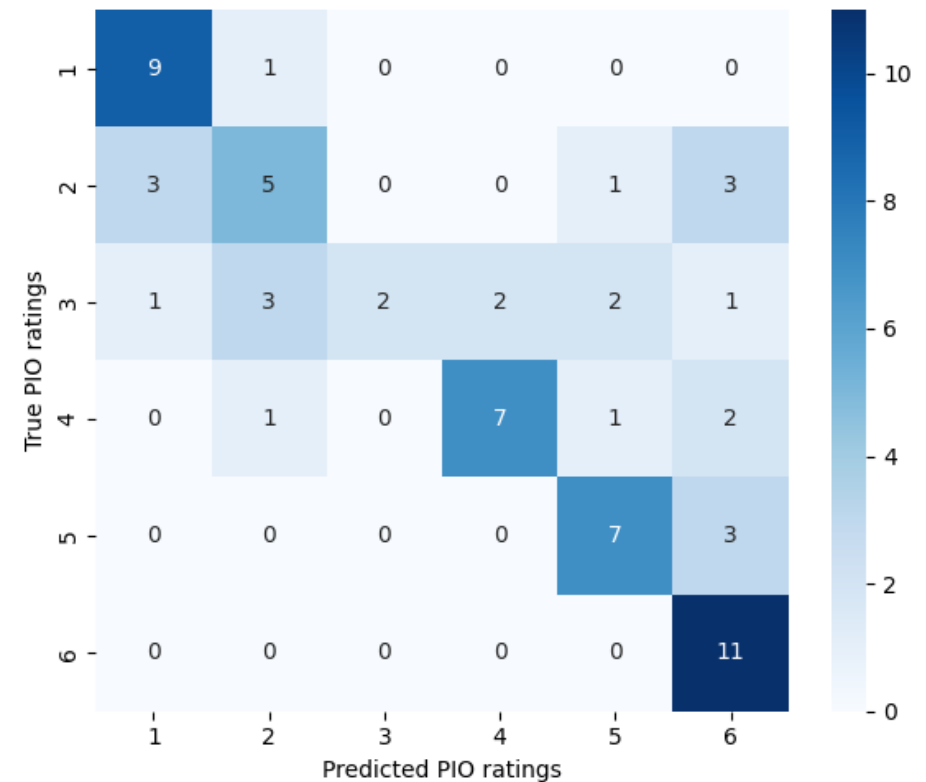
Fold	Training Accuracy■	Validation Accuracy■
1	51.7%	39.4%
2	98.1%	63.1%
3	98.5%	61.5%
4	98.5%	58.5%
5	93.7%	50.8%
6	99.8%	63.1%
7	98.8%	50.8%
8	99.0%	60.0%
9	25.3%	27.7%

Training and Validation

Confusion matrix and performance of Fold 6: ■

- Poor classification of PIORs 2 and 3.
- Several events that belongs to classes 2 to 5 being classified as PIOR 6.

PIOR	Precision	Recall	F1-score
1	69.2%	90.0%	78.2%
2	50.0%	41.7%	45.4%
3	100.0%	18.2%	30.8%
4	77.8%	63.6%	70.0%
5	63.6%	70.0%	66.7%
6	55.0%	100.0%	71.0%

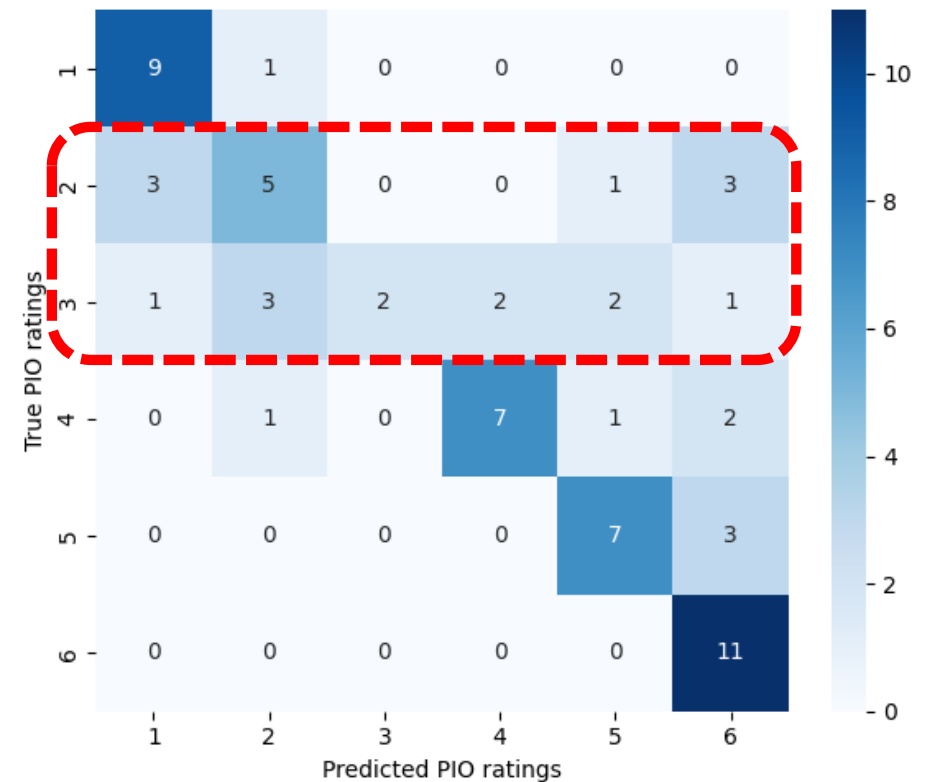


Training and Validation

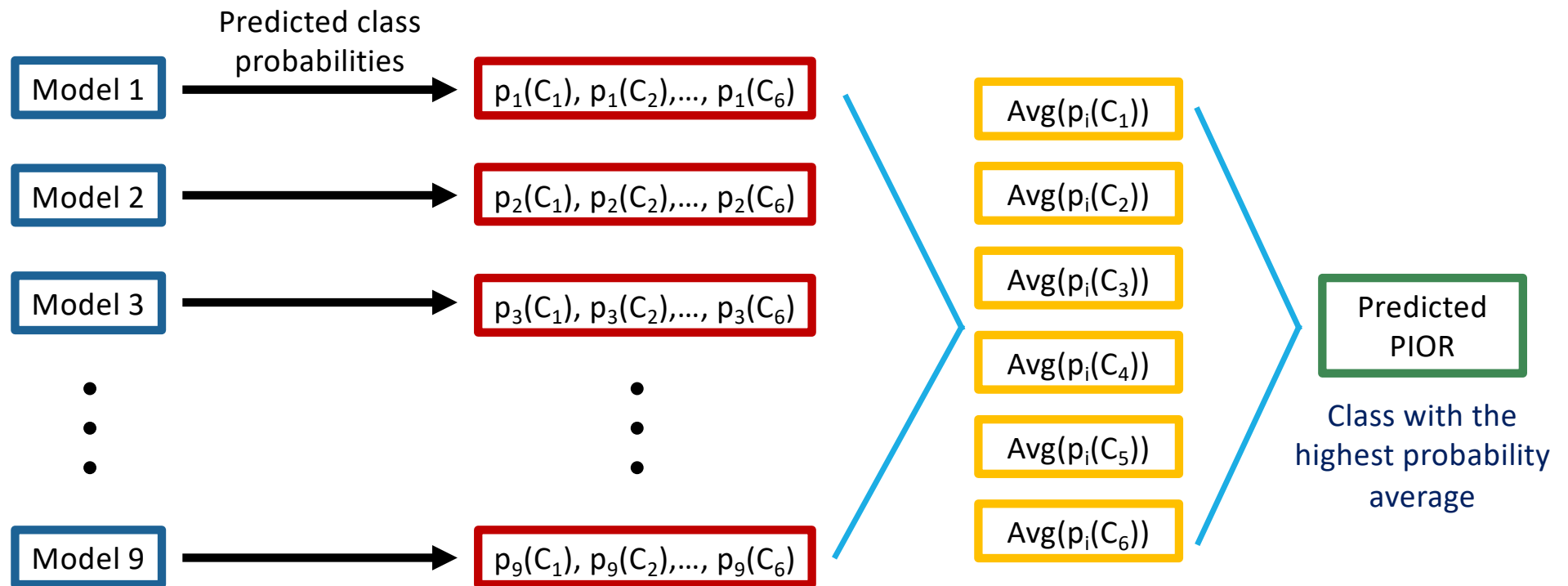
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Soft Voting Ensemble Method

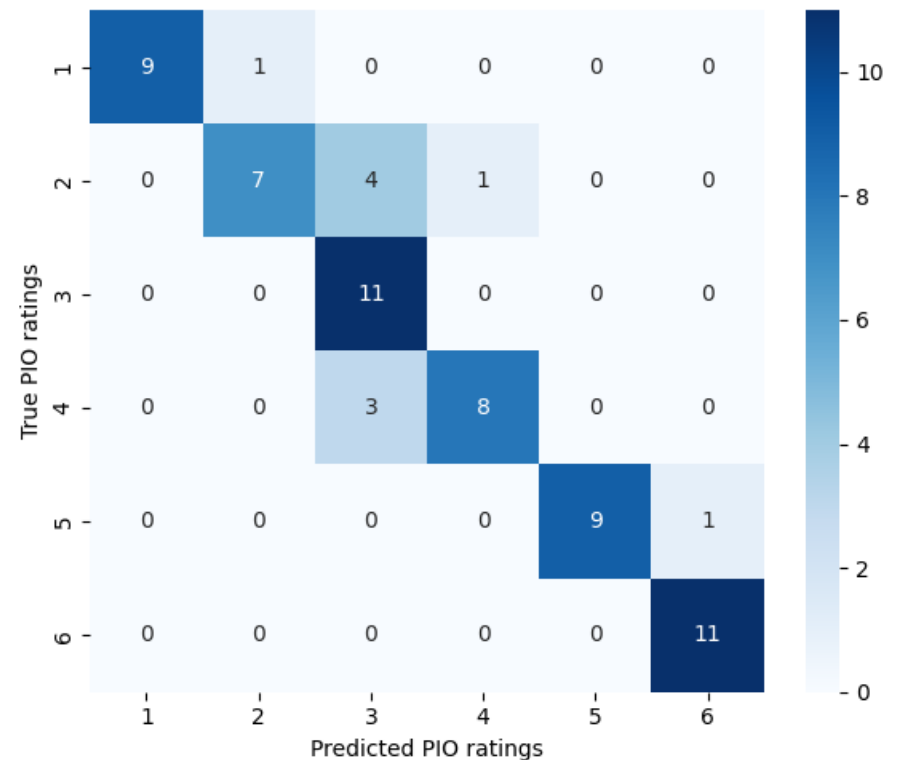


Soft Voting Ensemble Method

Confusion matrix of the ensemble model:

- PIORs 2 and 3 classification improved.
- PIOR 6 precision had a great improvement.
- 84.6% overall accuracy.

PIOR	Precision	Recall	F1-score
1	100.0%	90.0%	94.7%
2	87.5%	58.3%	70.0%
3	61.1%	100.0%	75.9%
4	88.9%	72.7%	80.0%
5	100.0%	90.0%	94.7%
6	91.7%	100.0%	95.7%

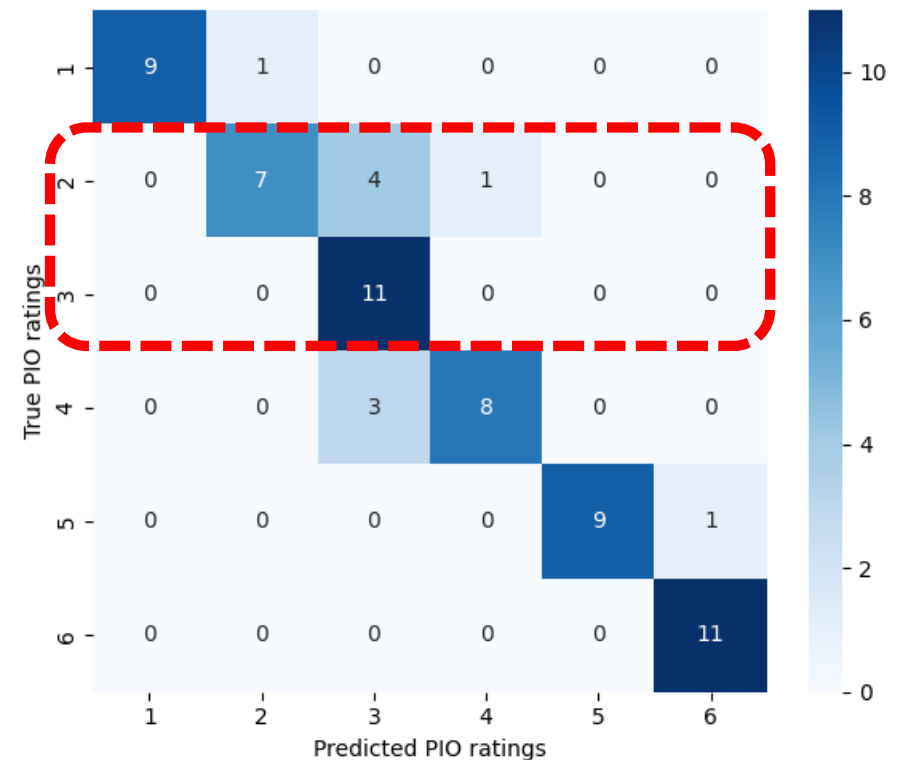


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4	88.9%	72.7%	80.0%
5	100.0%	90.0%	94.7%
6	91.7%	100.0%	95.7%



Conclusion

- This work presents a contribution to the PIO identification field:
 - Hybrid method that combines machine learning and the PIO rating scale.
 - Application of the Wavelet transform to expand flight data information.
- This approach has relevance to the areas of flight testing and aircraft certification:
 - The developed tool presents an alternative to be compared with real pilot's assessment.
- In the future, the tool can be improved for:
 - Better accuracy.
 - Real-time detection.
 - PIO suppression control law.