Classification of damage mechanisms in CFRP using CWT-based features and Deep Learning

Background:

Acoustic Emission (AE) is a non-destructive testing method to apply in-situ monitoring. When a damage in carbon fiber reinforced plastic occurs, energy is released. A fraction of this energy is transformed into ultrasonic waves. The ultrasonic waves can be measured using piezoelectric transducers mounted on the surface of the monitored structure/material. Each damage causes a specific signal characteristic in time, frequency, and time-frequency domain.

Data set description:

The data set consist of 1600 samples of damages and noise. Each sample is described by 53 predictors. These 53 predictors correspond to the Continuous Wavelet Transform (CWT) coefficients in the frequency range of 10 to 500 kHz. The data set is split into 1280 samples for training and 320 samples for test. The samples are separated into five classes, delamination, debonding, matrix crack, fiber breakage, and noise (no damage).

Task:

The goal is to classify different damage mechanisms, represented by features extracted from the Fourier-transformed signal, using Deep Learning techniques. Two classification approaches are to be designed, implemented, and compared.

<u>Approach 1: Two-Stage Classification</u>

This approach separates the task into two consecutive steps:

1. Damage Detection (Binary Classification):
   - A model is trained to distinguish between noise (no damage) and any form of damage.
   - All four damage types — *delamination, debonding, matrix crack, and fiber breakage* — are grouped into a single "damage" class.
   - The model outputs one of two classes: "No Damage" or "Damage".
2. Damage Classification (Multi-Class Classification):
   - Only the signals identified as "damage" in the first step are passed to a second model.
   - This model is trained to classify the type of damage into one of four categories: Delamination, Debonding, Matrix Crack, or Fiber Breakage.

<u>Approach 2: Single-Stage Classification</u>

In this approach, damage detection and classification are performed in a single step:

- A single model is trained to directly classify each signal into one of five classes: Noise (no damage), Delamination, Debonding, Matrix Crack, or Fiber Breakage.

<u>Evaluation and Comparison:</u>

- Both approaches must be evaluated using appropriate classification metrics
- For a fair comparison, the results of the two stages in Approach 1 must be combined to match the output structure of Approach 2.
- The comparison should assess overall classification performance, as well as the strengths and weaknesses of the two-step versus one-step strategies.