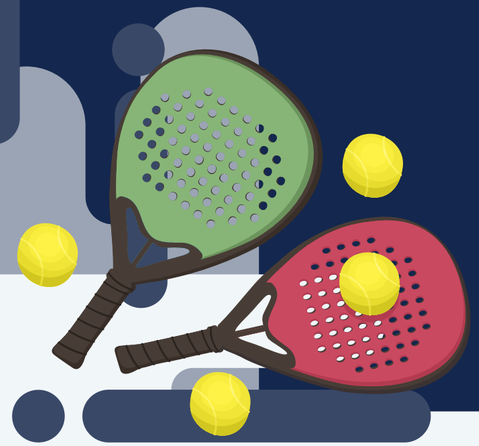
24th April 2025

CHARACTERIZATION OF PADEL BALL/RACKET IMPACT USING AI METHODS

Junia ISEN – Master 1 project under the supervision of Arthur PATÉ



ANTONIUK Pavlo
DAMERY Vincent
LAMBERT Edouard
MANY Hugo
OMS Henri
ZAKI Ilias

Summary

1) What is padel, anyways?

Video by RSPA

1)Why padel?

- Racket/bat properties (type, age) and the point of impact significantly affect athletes' biomechanics and injury risk.
- Sports like tennis, baseball, badminton, and table tennis have extensive studies on this topic.

The effects of baseball bat mass properties on swing mechanics - W. A Laughlin

Hand-arm vibration assessment in badminton athletes during three different movements - S. Nolasco

Joint Kinetics to Assess the Influence of the Racket on a Tennis Player’s Shoulder - T. Creveaux

Biomechanics of Table Tennis: A Systematic Scoping Review of Playing Levels and Maneuvers - D. Wai-Chi Wong

1)What is a Model ?

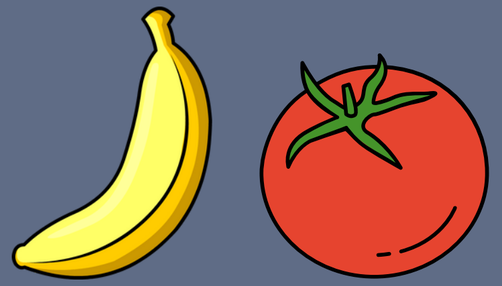
Features (Colors)

Labels

- Tomato
- Banana

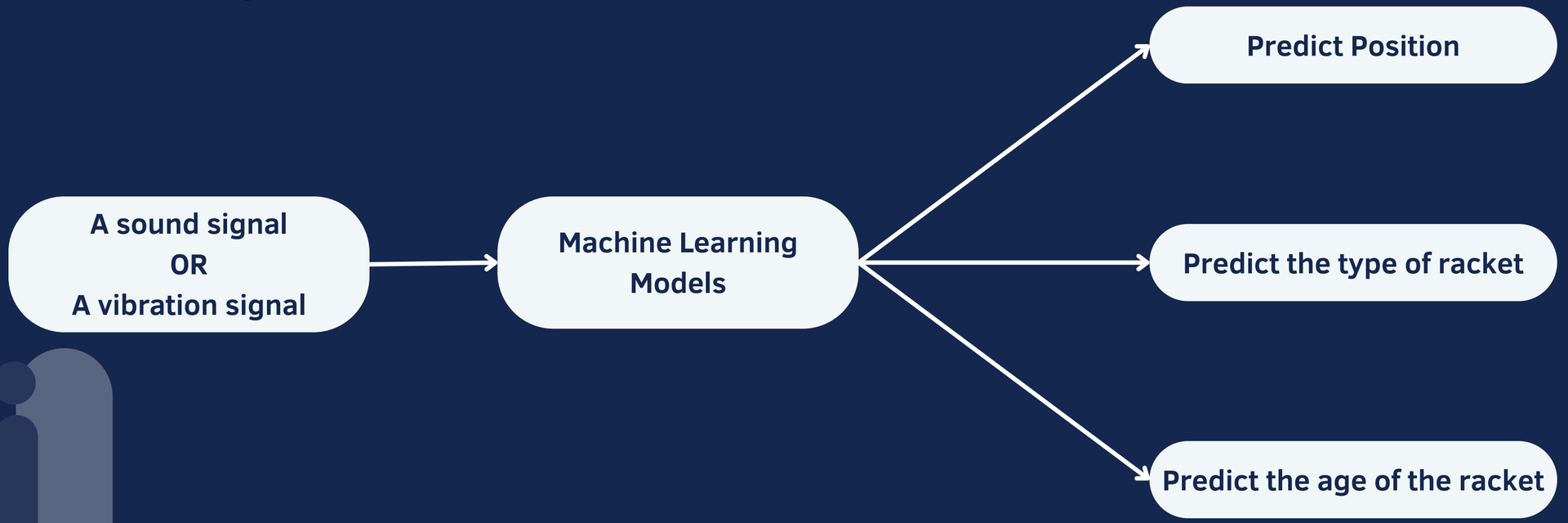
MACHINE LEARNING MODELS

Classifications



2) Objectives of the research

Characterization of padel ball/racket impact using artificial intelligence methods



3) Technical Part

a) Database and Features

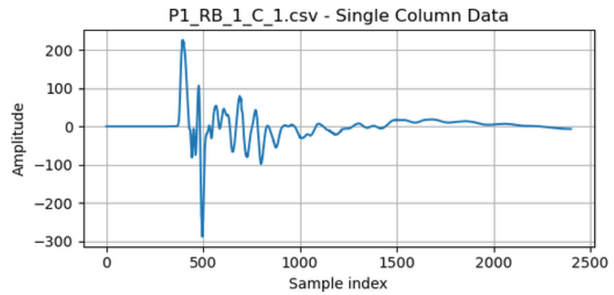
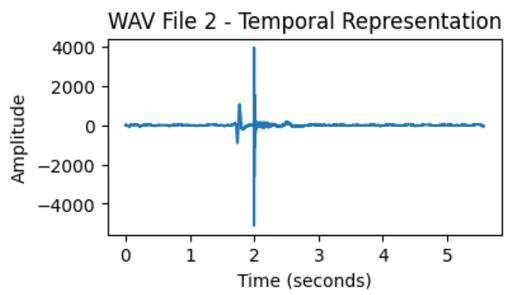
b) Models

c) Tools

d) Results

3) Technical Part

a) Database and Features : Data

Vibration	Sound
	

Time domain → Frequency domain

795 Impact

Data from PHD student : Thomas Daney

3) Technical Part

a) Database and Features : Data cleaning

.wav → single_impact.wav

i) Sound

ii) Vibration

.mat → single_impact.mat

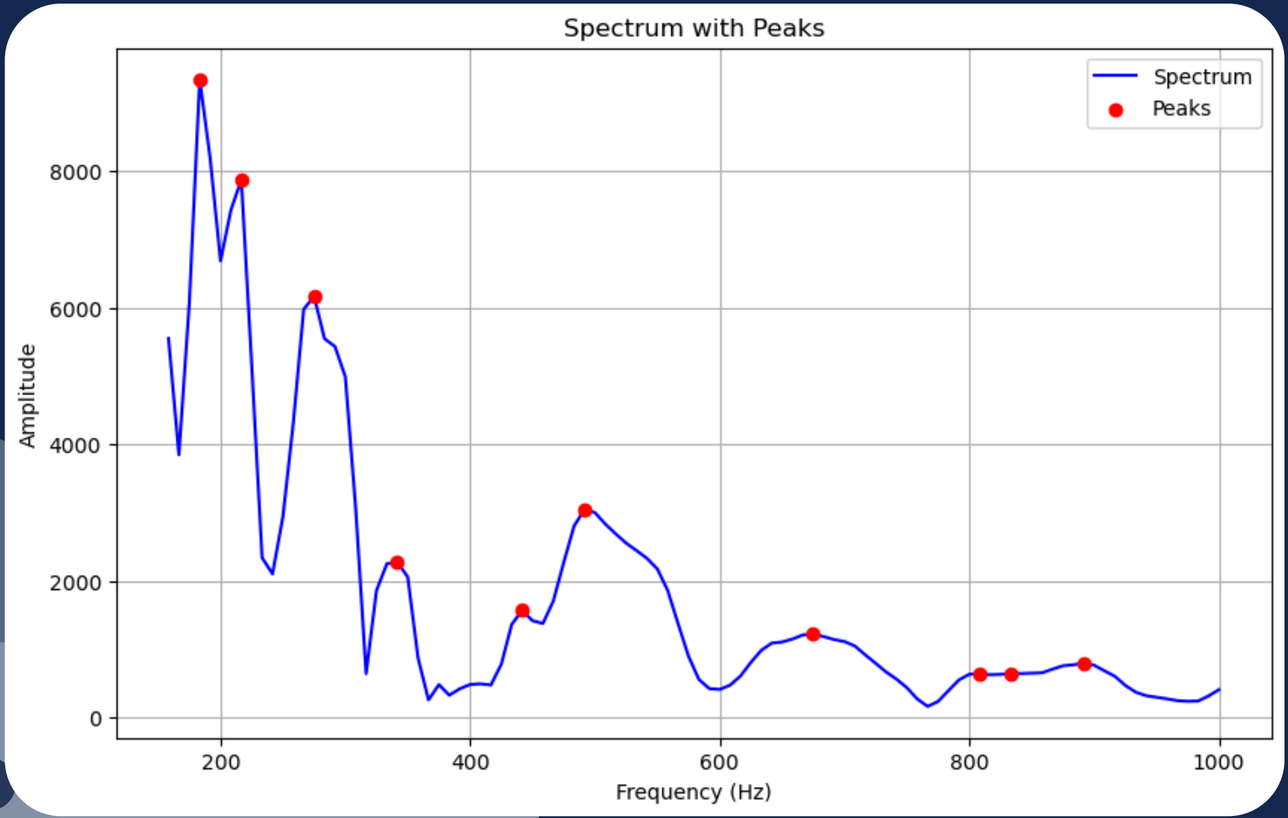
single_impact.mat → single_impact.csv

single_impact.csv → all_impact.csv

3) Technical Part

a) Database and Features :

Features : N-best peaks

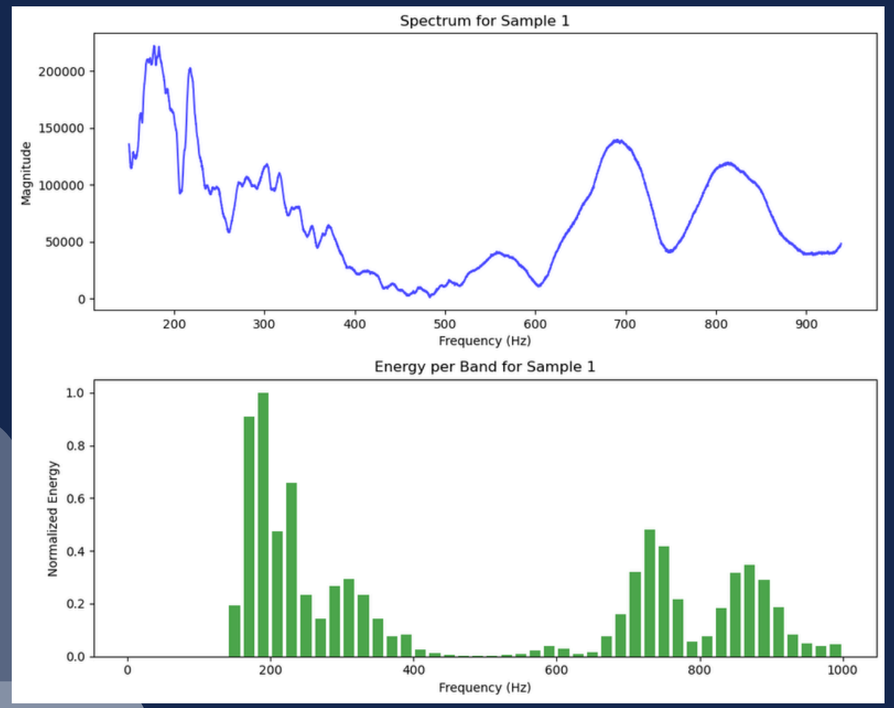


frequence1	amplitude_gauche1	frequence2	amplitude_gauche2
200,7908841	166765,9842	201,3296789	166188,6153
200,6104688	153737,9711	201,1492615	153057,504
201,328859	161246,1712	202,5860419	158727,8944
220,5621597	186169,0246	220,8415291	189794,7325
221,7478858	176902,8587	222,9886813	178374,2777
200,9937238	157631,6914	223,3995816	192872,1006
221,0317353	191445,8593	222,0526671	196130,1676

3) Technical Part

a) Database and Features :

Features : Energy per band



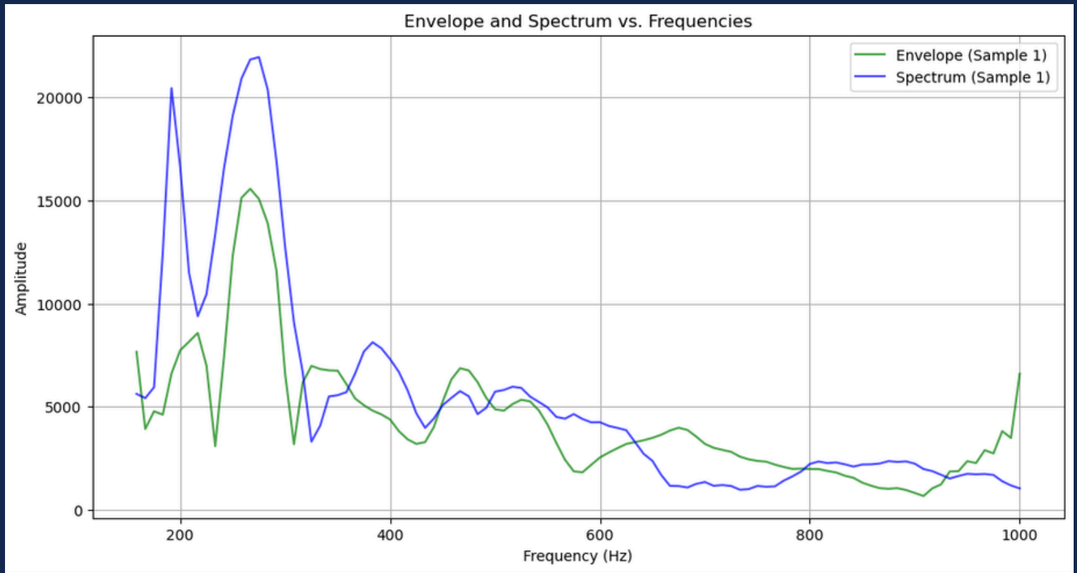
For sound and band = 20HZ

- Splits signal into frequency bands
- Measures energy in each band
- Highlights spectral distribution
- Useful for audio & speech analysis
- Robust to noise

3) Technical Part

a) Database and Features :

Features : Envelope on a spectrum

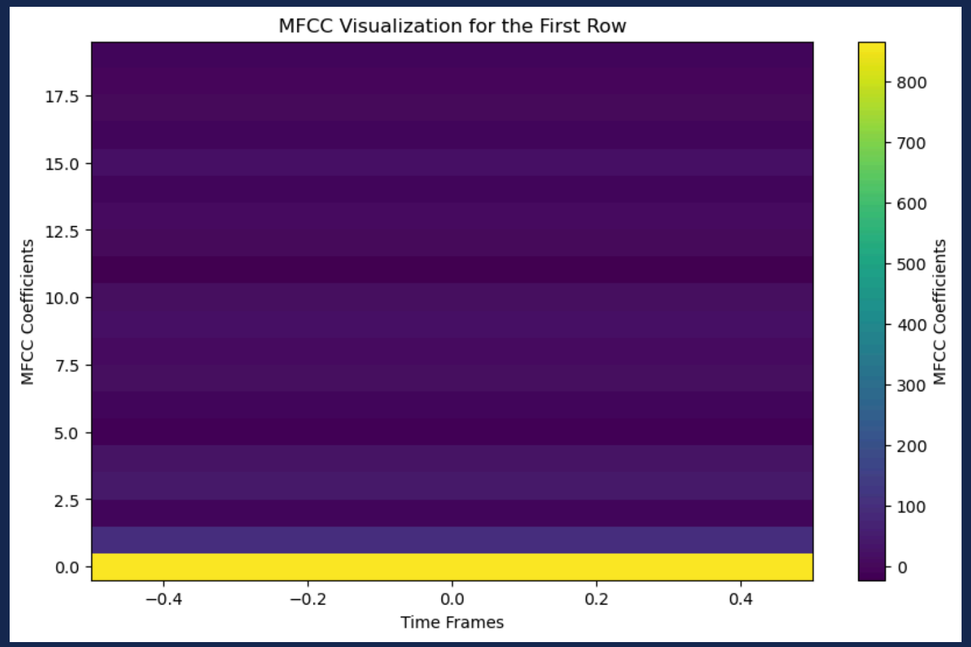


- Captures the shape of the spectral curve
- Highlights amplitude variations over frequency
- Smooths out fine spectral details

3) Technical Part

a) Database and Features :

Feature: Mel-frequency cepstral coefficients (MFCC’s)



- Biologically Inspired
- Dimensionality Reduction
- Robust to noise
- Efficient and Fast to Compute

3) Technical Part

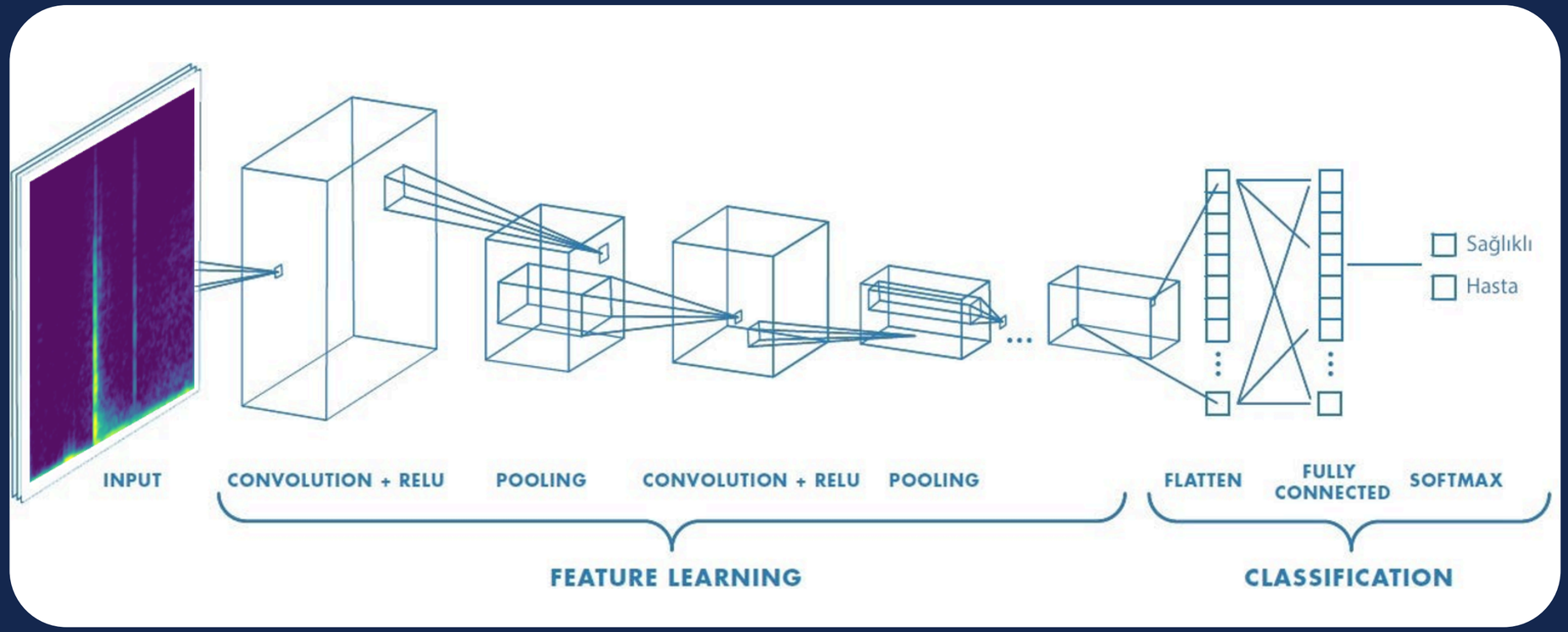
Other features

Feature	Description
Spectral Centroid	Represents the "center" of the spectrum, indicating energy focus.
Log Attack Time	Measures how quickly a sound reaches its peak after attack.
Inharmonicity	Describes the deviation of harmonics from ideal values.

3) Technical Part

b) Models

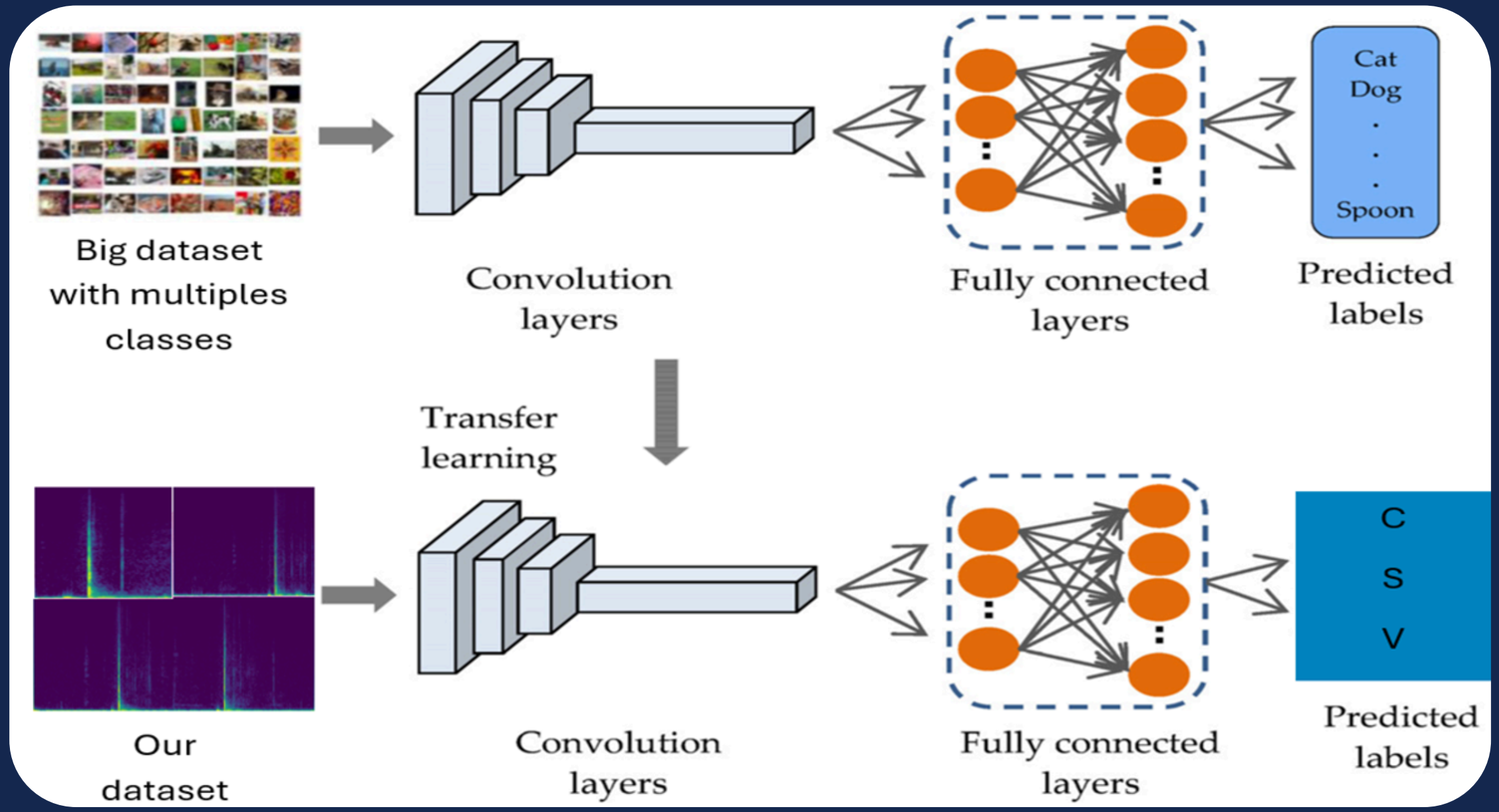
CNN (Convolutional Neural Network)



3) Technical Part

b) Models

Transfer Learning

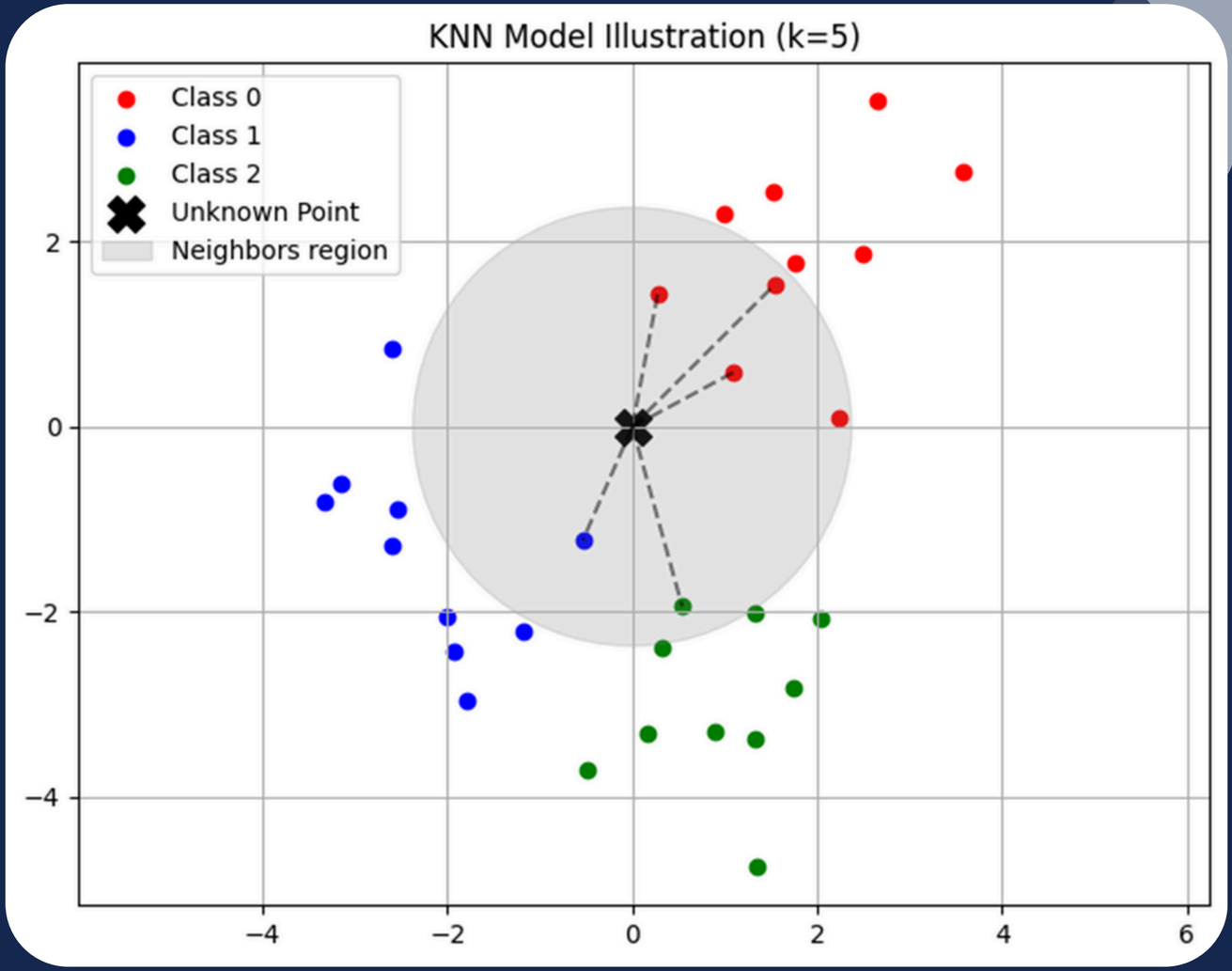


3) Technical Part

b) Models

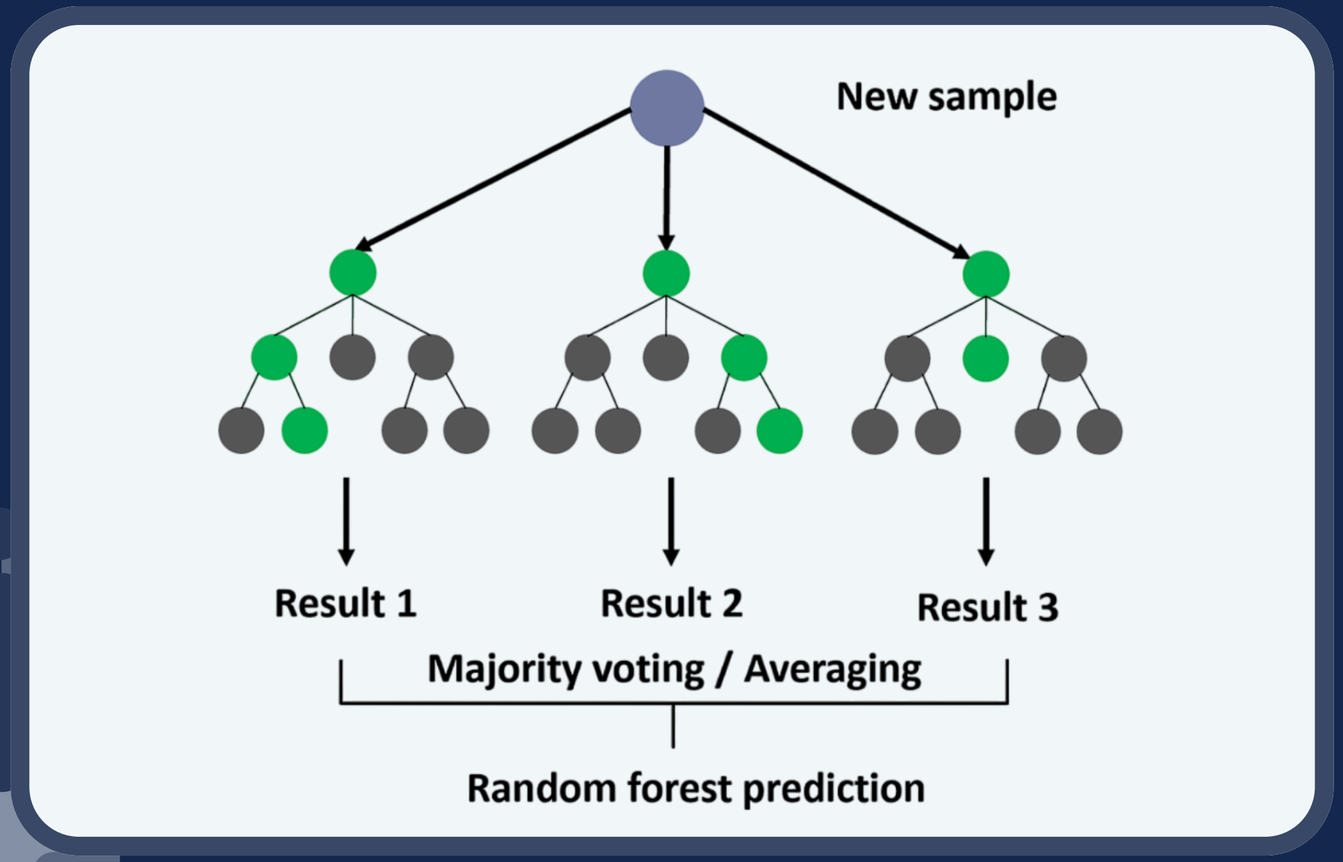
KNN (k-nearest neighbors)

Test accuracy : 88,38%



3) Technical Part

b) Models : Random Forest Classifier



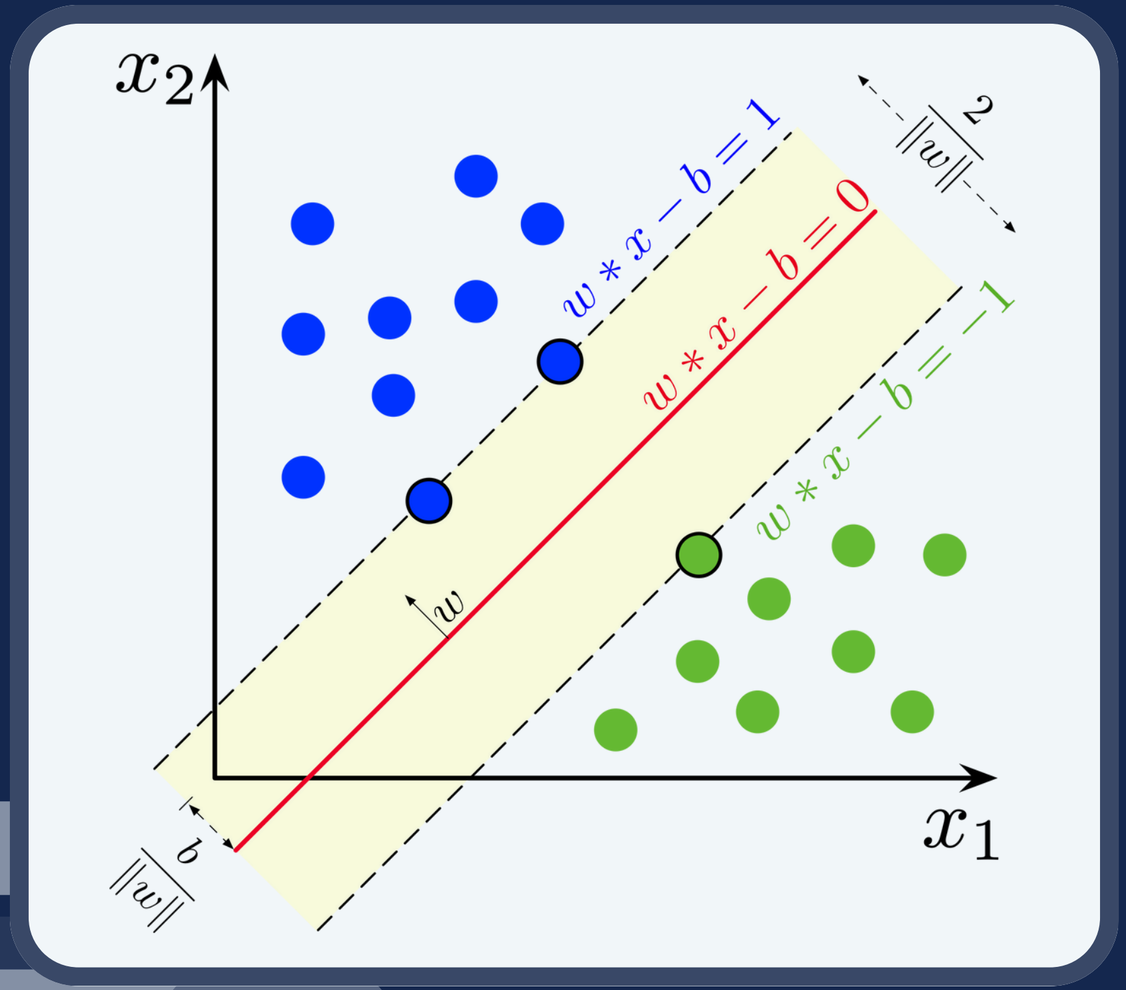
Hyperparameters :

- **Number of trees**
- **Depth Range**
- **Splite Range**

Test accuracy : 88,83%

3) Technical Part

b) Models : SVM



- Uses a hyperplane to separate classes
- Inherently binary, but can be used for multiclass clasification

3) Technical Part

c)Tools

Functions

- Consistency across all notebooks and models
- Harmonized results and interpretations
- Cleaner, more maintainable codebase
- Easier debugging and updates

🛠️ Tools and Functions

Signal Processing Functions

- `readWavFolder(folderPath)`
  > Reads all `.wav` files from a folder and returns their sample rates, data arrays, and filenames.
- `spectrumFromWav(wavFile)`
  > Computes the FFT magnitude spectrum of the **first audio channel** of a WAV file.
- `spectrumFromSignal(signal, sample_rate)`
  > Computes the FFT magnitude spectrum and filters it between 150 Hz and 1000 Hz.
- `energy_per_frequency_band_from_spectrum(spectrum, freqs, band_width)`
  > Divides the frequency spectrum into bands and computes the energy (sum of squares) in each.
- `envelope_from_signal(signal)`
  > Computes the **amplitude envelope** of a 1D signal using the Hilbert transform.
- `extractPeakFromSignal(signal, smoothing=1, num_peaks=None)`
  > Extracts the most prominent peaks from a 1D signal, with optional smoothing and limit on number of peaks.
- `plot_spectrum_with_freq(signal, freqs, title="Spectrum Plot")`
  > Displays the magnitude of a frequency spectrum against its corresponding frequencies.

3) Technical Part

c)Tools

Library	Main Use
NumPy	Numerical arrays and mathematical operations
Pandas	Read and manipulate .csv and tabular data
Matplotlib / Seaborn	Visualization of signals and spectra
SciPy	Signal processing, including Hilbert transform
LibROSA	MFCC and audio feature extraction
scikit-learn	Machine learning models and data preprocessing
TensorFlow / Keras	Neural networks and transfer learning

3) Results

d) Results

Top 50 models selected

30,014 models trained in total

24 models above 95%

Vibration improves accuracy by 9% in average compared to sound.

Best features: Energy/Envelope

Best Models: KNN/RTF

Type of Signal	ML Model t...	Objectives	Dataset	Features	Training ...	Test Accu...
Sound	KNN	Position	P1	Energy	100%	100%
Sound	RTF	Position	P1	Energy	100%	100%
Sound	RTF	Position	P1	Envelope	100%	100%
Sound	RTF	Position	P1	MFCC	100%	100%
Sound	RTF	Position	P1	Peaks	100%	100%
Sound	SVM	Position	P1	Envelope	100%	100%
Sound	XGBoost	Position	P1	Energy	100%	100%
Vibration	KNN	Position	P1	Envelope	99%	100%
Vibration	KNN	Position	P1	MFCC	100%	100%
Vibration	KNN	Racket Type	P1.P2.P3	Energy	100%	100%
Vibration	KNN	Racket Type	P1.P2.P3	Envelope	100%	100%
Vibration	KNN	Racket Type	P1.P2.P3	MFCC	100%	100%
Sound	KNN	Racket Type	P1.P2.P3	Energy	96%	99%
Vibration	RTF	Racket Type	P1.P2.P3	Energy	100%	99%
Vibration	RTF	Racket Type	P1.P2.P3	MFCC	100%	99%

4) Project Management

a) Organize and conduct meetings

b) README

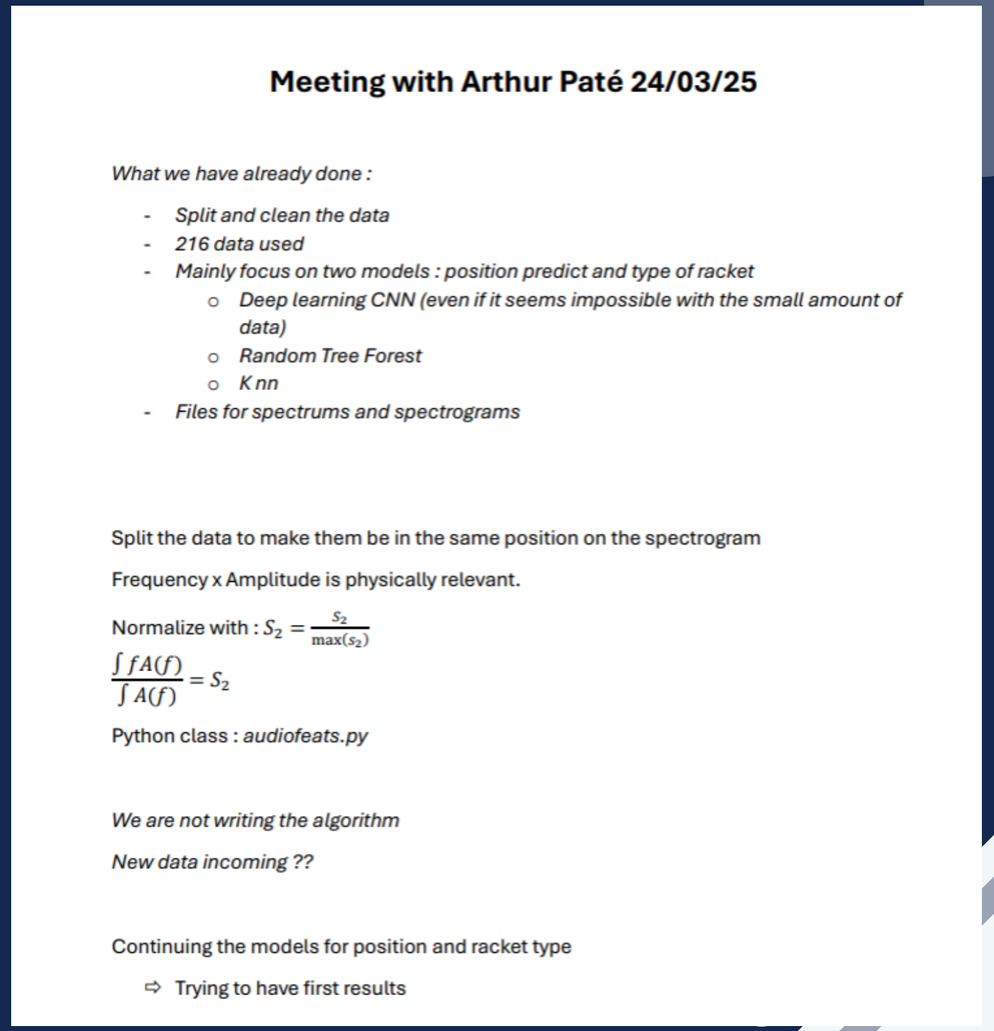
4) Project Management

a) Organize and conduct meetings

📍 Location: IC1 205
🕐 Frequency: Every Monday
⏳ Duration: 1 hour

🎯 Meeting Goals:

- Review project progress
- Assign weekly tasks
- Solve potential issues
- Encourage idea sharing



Meeting with Arthur Paté 24/03/25

What we have already done :

- *Split and clean the data*
- *216 data used*
- *Mainly focus on two models : position predict and type of racket*
  - *Deep learning CNN (even if it seems impossible with the small amount of data)*
  - *Random Tree Forest*
  - *K nn*
- *Files for spectrums and spectrograms*

Split the data to make them be in the same position on the spectrogram

Frequency x Amplitude is physically relevant.

Normalize with : $S_2 = \frac{S_2}{\max(S_2)}$

$\frac{\int fA(f)}{\int A(f)} = S_2$

Python class : *audiofeats.py*

We are not writing the algorithm

New data incoming ??

Continuing the models for position and racket type

⇨ Trying to have first results

4) Project Management

b) README.md

🎯 Project Objective

Predict the impact zone, racket type, and racket age using audio and vibration signals.

✨ Features

MFCC, Energy, Peaks, Envelope, and Attack Time

🤖 Machine Learning

KNN, Random Forest, SVM, and XGBoost

📊 Data

Recordings of padel ball impacts using 4 rackets, 3 impact zones, and 3 usage levels.

📁 Project Structure

Organized codebase: separate folders for Audio Models, Vibration Models, and Data.

🛠️ Tools and Functions

Custom Python functions for signal processing, feature extraction, and visualization.

5) Conclusion

- AI successfully predicts impact zone, racket type, and age using sound and vibration data.
- Vibration data improves accuracy by up to 9% in average compared to sound.
- 30,000+ models tested – best results from Random Forest and KNN.
- Top features: Energy bands and envelope.
- Strong potential for sports analytics and racket design innovation.

6) Perspectives & recommendation

Future Perspectives

- Deep learning with more data → handles more variety & player styles
- Interactive UI to visualize key features (impact point, racket type)

Applications:

- Consistent racket manufacturing
- Impact detection during training (for coaches)
- Help players choose the right racket
- Create signature rackets for athletes

Momo González Signature PUMA 2025

Padel racket manufacturers

THANK YOU

FINAL RECAP – KEY TAKEAWAYS

🎯 Goal	Predict impact position, racket type, age
📊 Data	**795** impacts – Sound & Vibration signals
✨ Features	MFCC, Energy bands, Envelope, Peaks,
🤖 Models	**30,014** tested – Best: KNN,RTF
⚡ Insight	**+9%** accuracy with vibration vs sound
🚀 Next Steps	Real-time detection, player feedback, racket design

Summary

Hugo
Ilias
Henri
Pavlo

Tiltle Slide => Edouard
Summary => Edouard

1. Introduction & Context
2. Objectives of the research
3. Technical Part
    a. Database and Features
        i. Data: sound, vibration & cleaning
        ii. Features (N_peak, Energy band,...MFCC, and other)
            1. N_peak
            2. Energy band
            3. Envelope
            4. MFCC
            5. other
    b. Models
        i. CNN + Transfer learning part (+ and -)
        ii. Random tree forest part (+ and -)
        iii. KNN part (+ and -)
        iv. Other model (XGBOOST,SVM) (+ and -)
    c. Tools
        i. Libraries
        ii. Functions
    d. Results (best models per Classification type with best Features for the better train accurancy)
4. Project Management
    a. Organize and conduct meetings
    b. READNE.md
5. Conclusion
6. Perspectives and recommandations