A Supervised Machine Learning monitoring System for Vehicle-railway bridge Collisions

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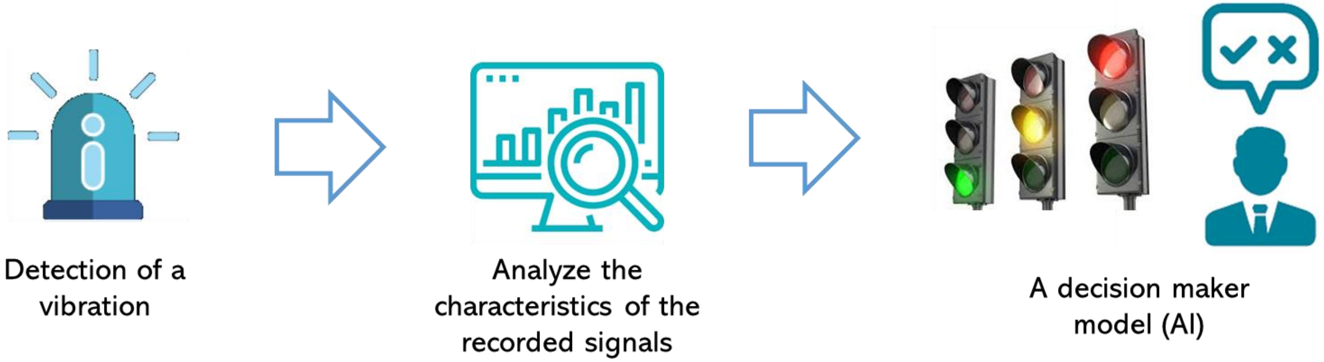
Overview of Presentation Content

Context and Project Objectives

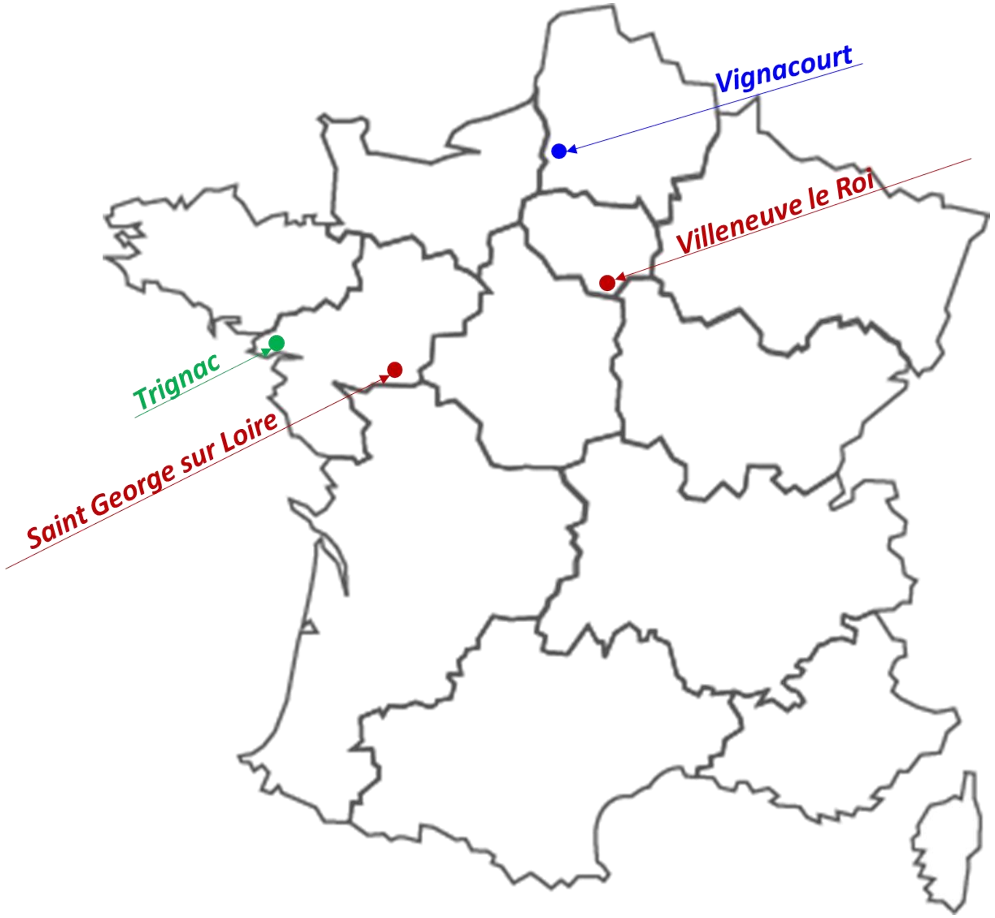
1. *Provide bridge managers with a* ***digital decision support tool*** *for evaluating bridge conditions which contributes in* ***minimizing maintenance costs****, and* ***ensuring train user safety****.*
2. *Develop a* ***generalized classification model*** *for classifying all the signals recorded by sensors connected to the bridge,* ***applicable to various bridge structures and dimensions***
3. *Evaluate and compare* ***multiple supervised ML algorithms*** *to identify the most accurate model for collision detection and categorization*



Bridges Used in the Study

- Saint Georges sur Loire (SGL)
- Trignac (TRG)
- Villeneuve-le-Roi (VLR)
- Vignacourt (VCT)

SGL TRG VLR VCT



These bridges were selected based on specific criteria:

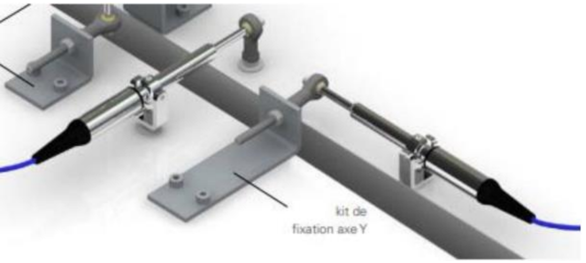
- A notable history of accidents,
- Heavy truck traffic,
- Relatively low height,
- Accessibility for installation teams.

- VCT : Preliminary experiment for simulating shocks of increasing energy
- TRC : Neglected since no shocks occurred after 1 year of monitoring
- SGL and VLR: Considered in this study for training the ML model

Schematic representation of the instrumentation

A

Accelerometer (Velocity and frequency)



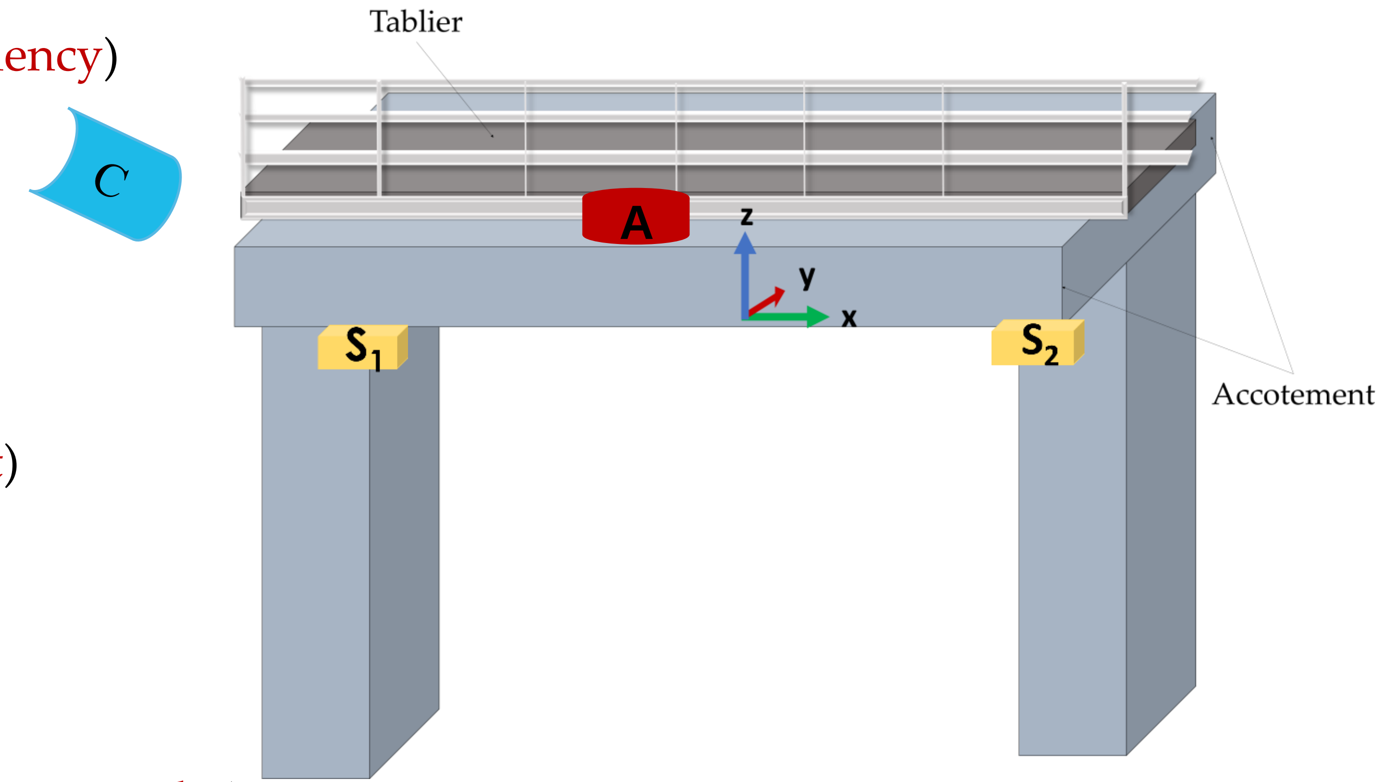
S_1

Crack meter (Displacement)

S_2

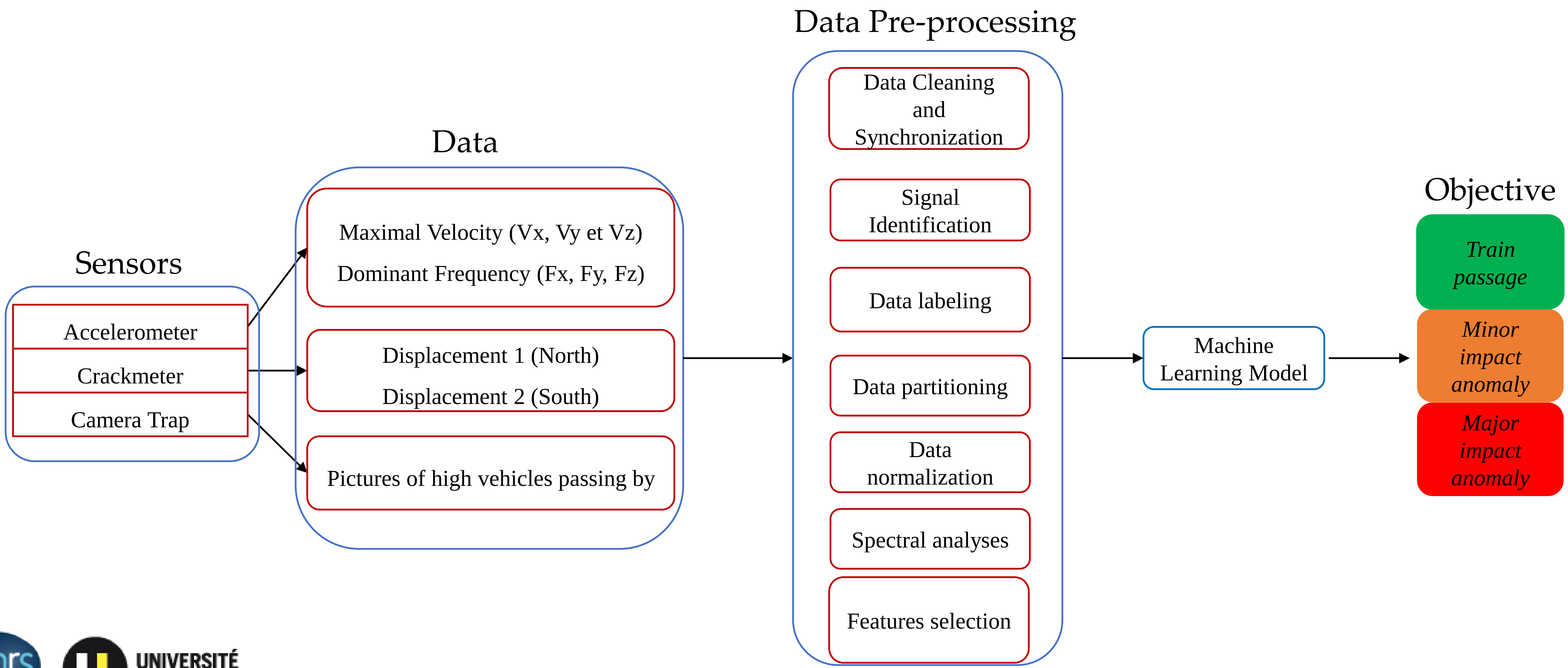
C

Camera trap (Pictures of high vehicles passing by)



- X = direction of train
- Y = direction of vehicle
- Z = vertical to the bridge

Methodology



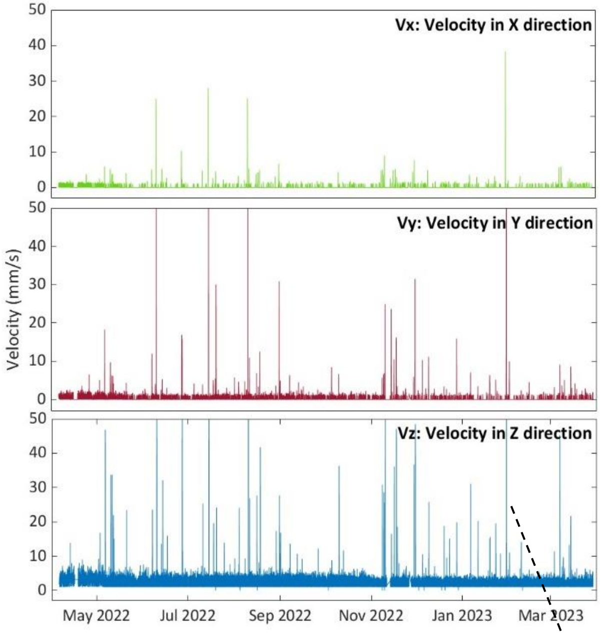
Recorded Data

Accelerometer (VLR et SGL)

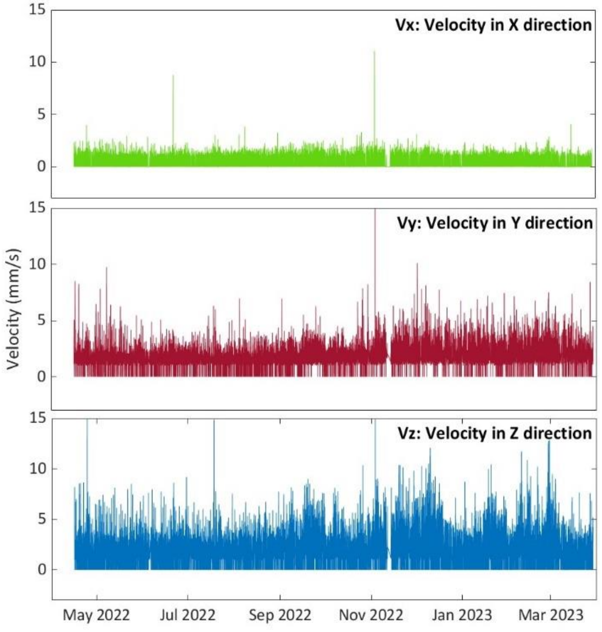
April 2022 – April 2023

Velocity

VLR

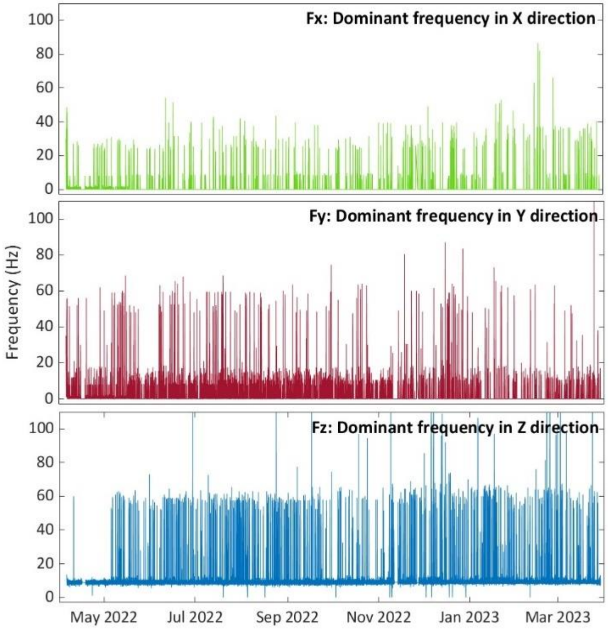


SGL

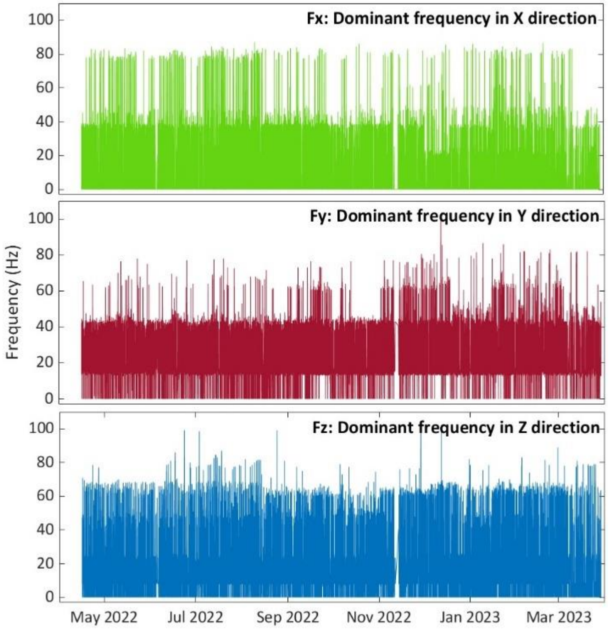


Frequency

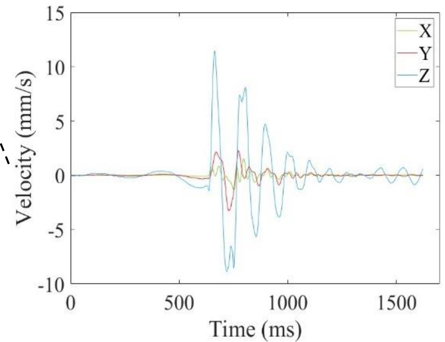
VLR



SGL



Click on the bar

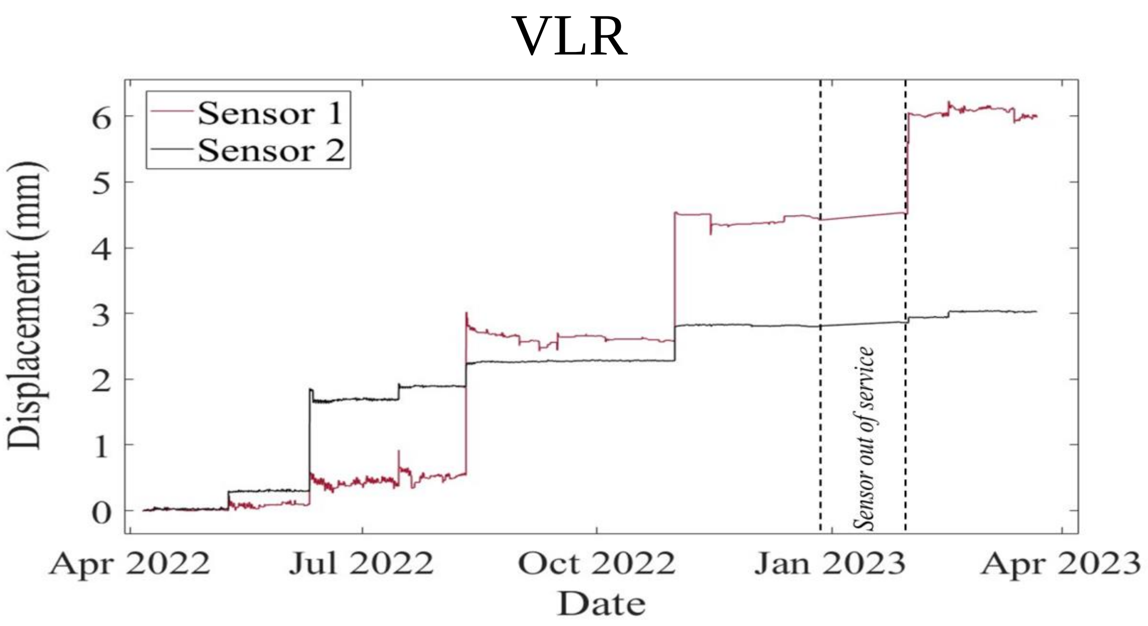


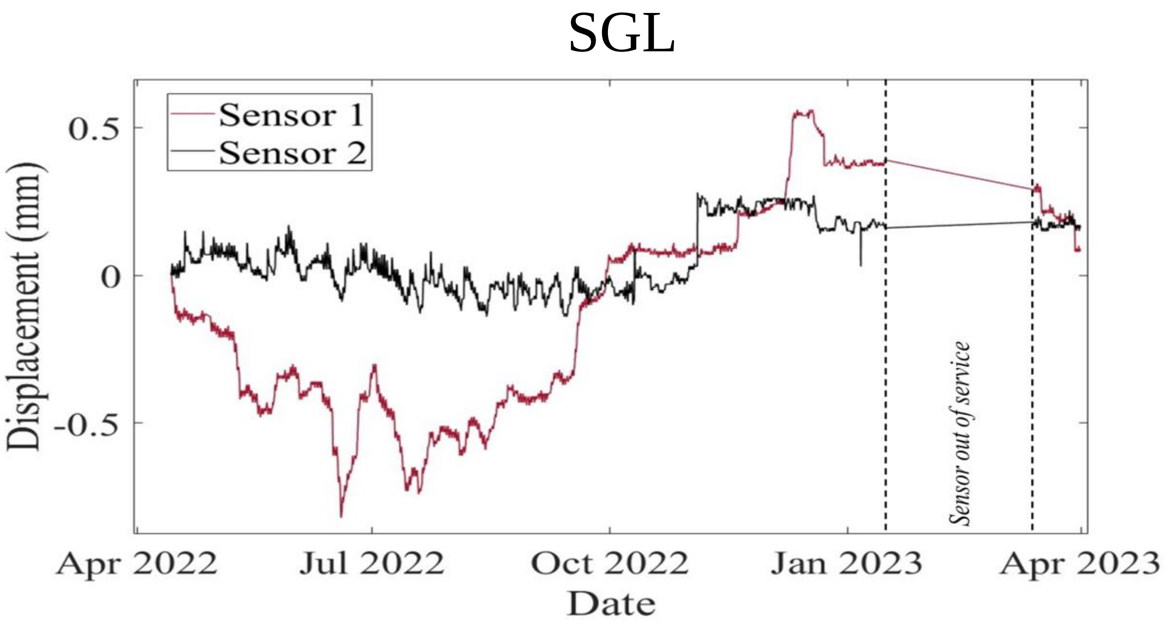
- X = direction of train
- Y = direction of vehicle
- Z = vertical to the bridge

Recorded Data

Displacement

April 2022 – April 2023



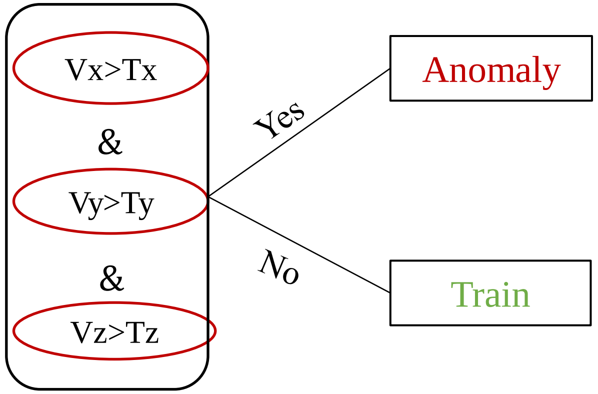


Data Preprocessing

- *Determination of the threshold for anomaly detection,*
- *signal pattern identification,*
- *data labeling,*
- *features extraction,*
- *data partitioning for training and testing the learning model.*

Data Pre-processing

Determination of the threshold



- X = direction de train
- Y = direction des véhicules
- Z = vertical du pont

1. A reference sample of 200 train signals without anomalies was manually selected
2. The threshold value was determined by adding the standard deviation to the maximum velocity observed in the reference sample

$T_x = \max(V_x) + \mathrm{std}(V_x)$
$T_y = \max(V_y) + \mathrm{std}(V_y)$
$T_z = \max(V_z) + \mathrm{std}(V_z)$

VLR: $T_x = 1.9$ $T_y = 2.9$ $T_z = 9.1$ mm/s

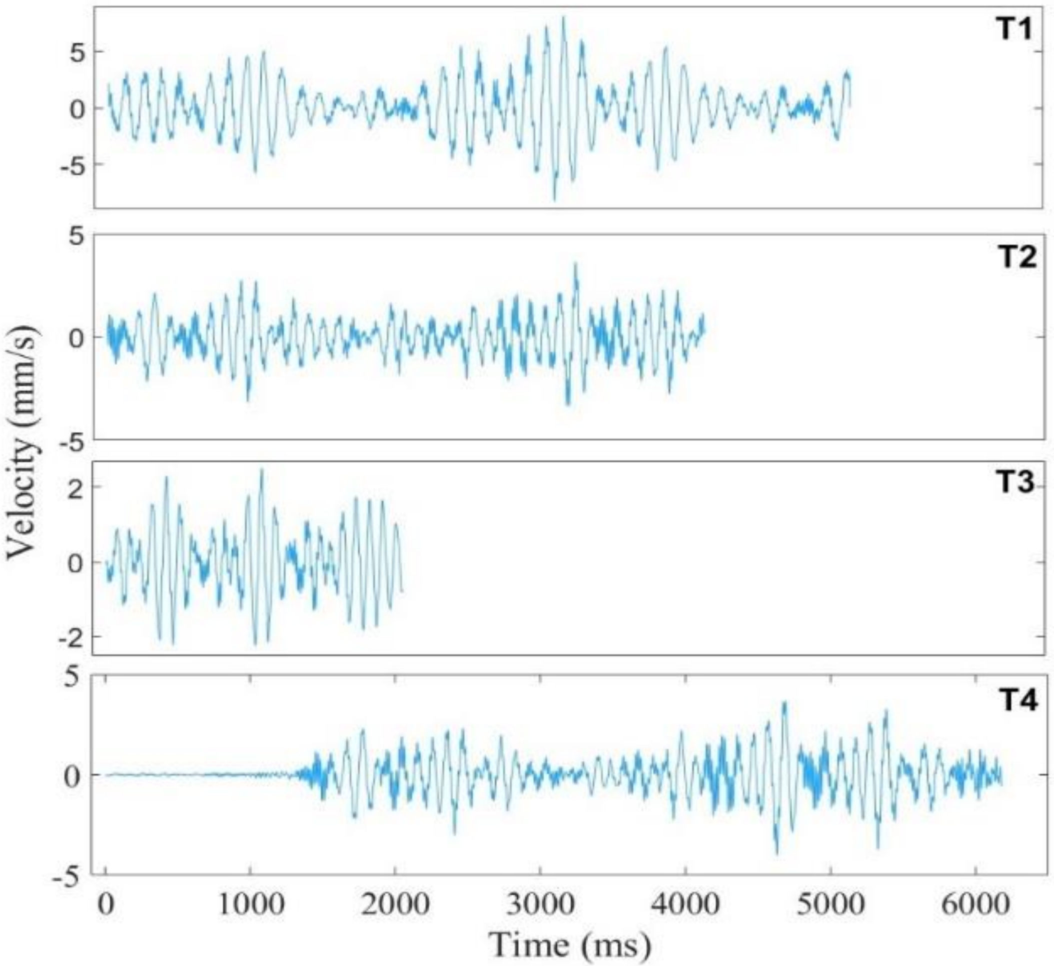
SGL: $T_x = 2.1$ $T_y = 6.1$ $T_z = 7.2$ mm/s

Data Preprocessing

Signal pattern identification

Train Passage

- The VLR bridge was closely monitored during 4 hours by a technical team.
- This experiment was performed to study the signals recorded as the trains were crossing the bridge.



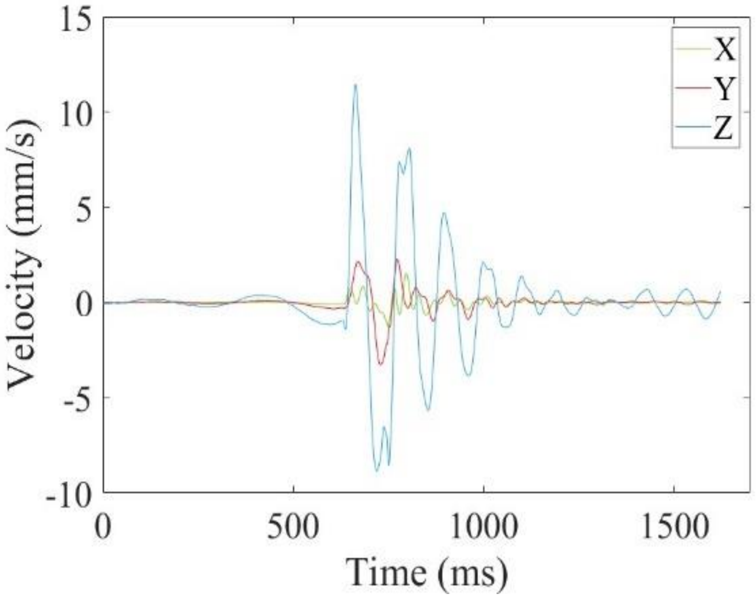
- Period of these signals ranges between **30 to 100 ms**
- Maximum displacement **= 0.03 mm**
- **Vx<Tx Vy<Ty Vz<Tz**

Data Preprocessing

Signal pattern identification

Minor Impact Anomaly

During the monitoring of the VLR bridge (4 hours), an unexplained signal with high intensity exceeding 11 mm/s was detected, while there was neither train passage nor any serious anomaly.



- Period ranges between **140 to 200 ms**
- Displacement **< 0.1 mm**
- Vx>Tx Vy>Ty Vz>Tz

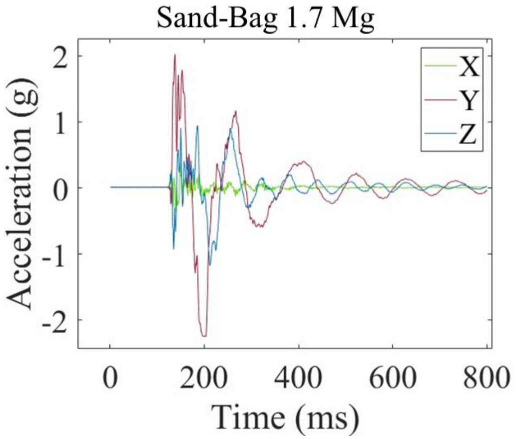
The reason behind these signals may be:

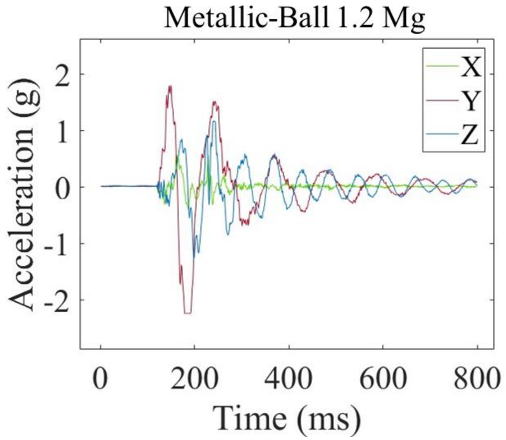
- Unusual train configuration,
- a light vehicle friction with the bridge,
- nearby construction activities surrounding the bridge,
- other environmental conditions,

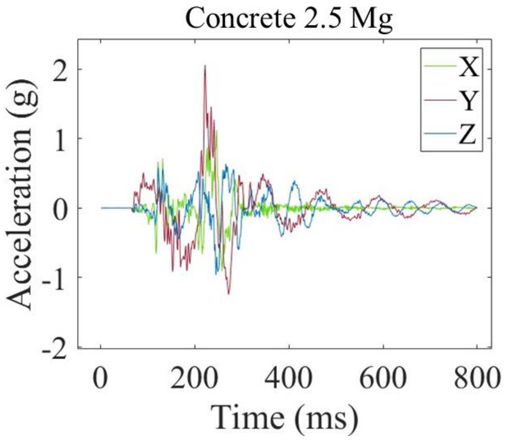
Data Preprocessing

Signal pattern identification

Major Impact Anomaly (Vignacourt bridge)







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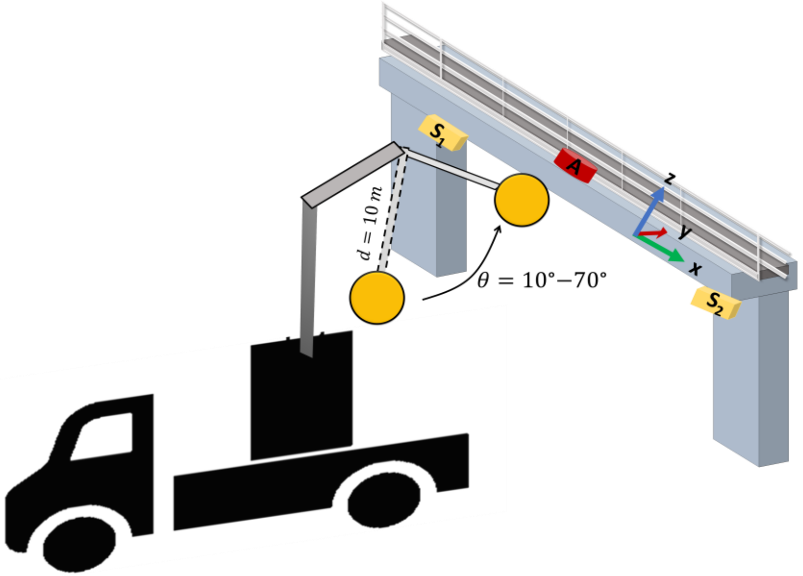
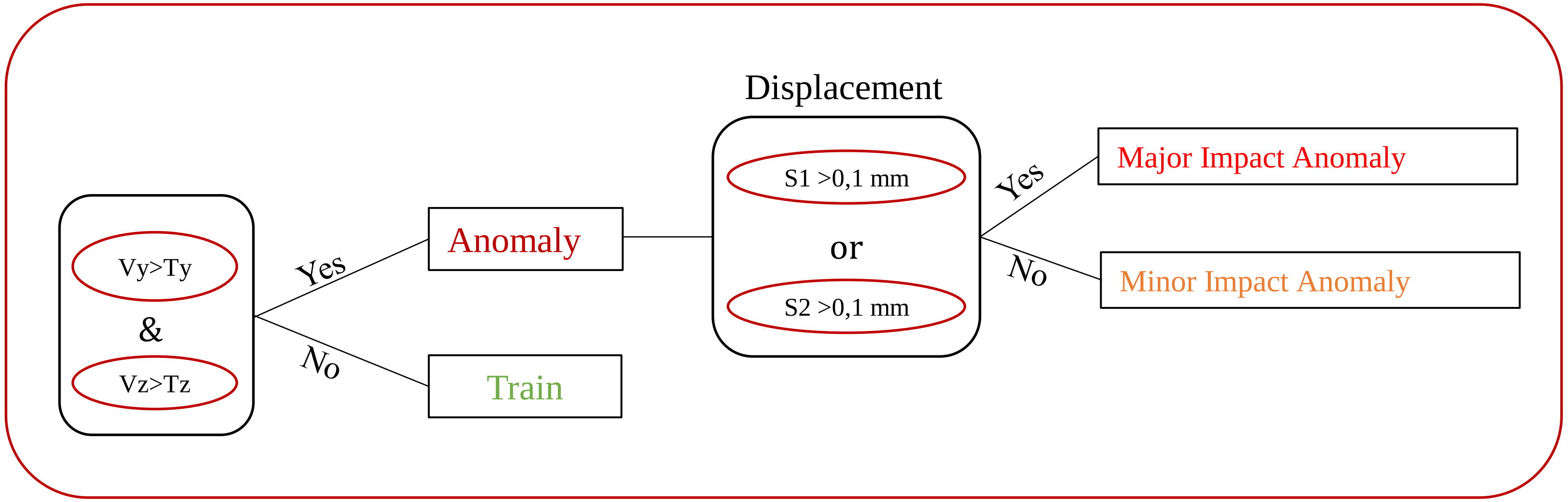


- Period ranges between **140 to 200 ms**
- Displacement **> 0.19 mm**

Material	Sensor 1 (mm)	Sensor 2 (mm)
Sand Bag -1.7 Mg	0.26	0.19
Metallic ball -1.2 Mg	0.55	0.69
Concrete – 2.5 Mg	0.87	1.24

Data Preprocessing

Data Labeling



(VLR et SGL)

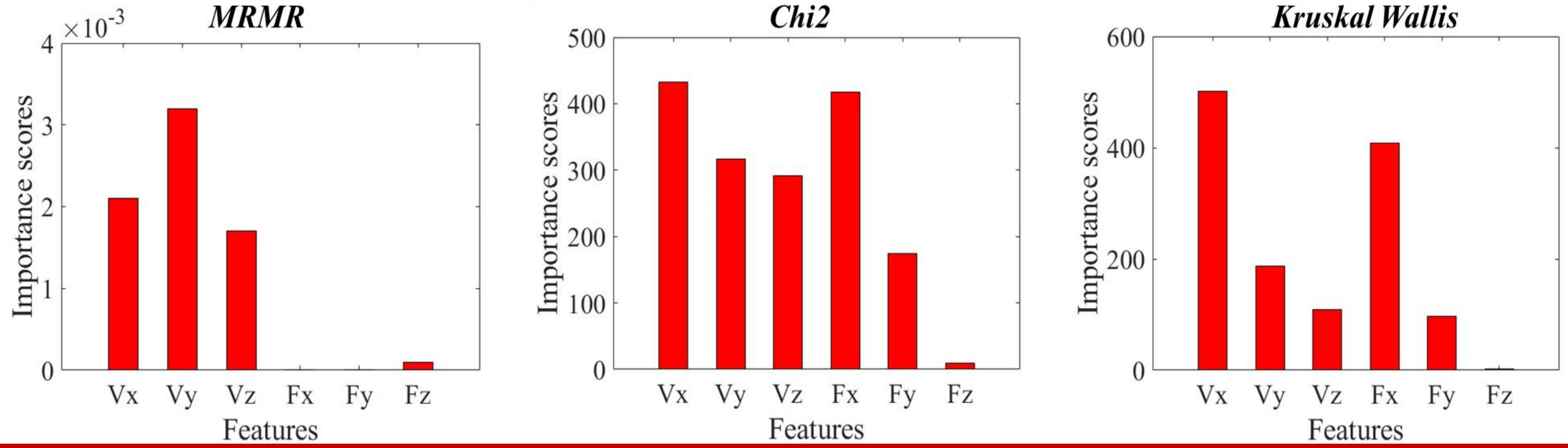
April 2022 – April 2023

Bridge	Passage de train	Major Impact Anomaly	Minor Impact Anomaly
VLR	100788	7	58
SGL	27295	1	7
Total	128083	8	65

Data Preprocessing

Features extraction

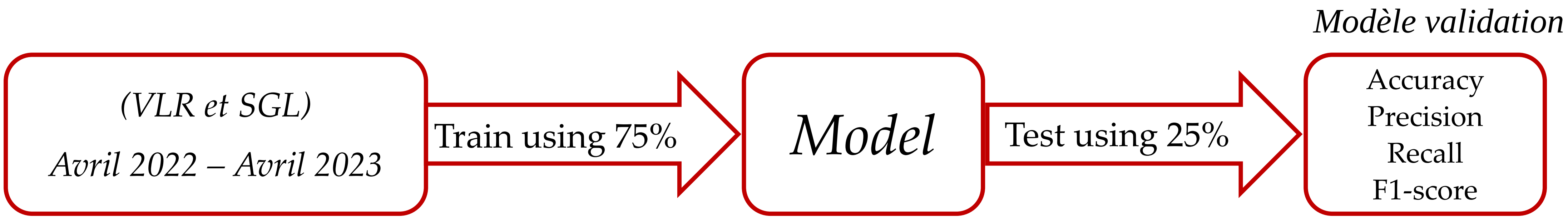
1. ***MRMR*** assesses feature relevance and redundancy through mutual information calculations with the target variable and between features.
2. ***Chi2*** tests variable independence, distinguishing between statistical dependency and independence.
3. ***Kruskal-Wallis*** identifies significant variations in numerical variable distributions among different groups.



Exclude F_Z

Data Preprocessing

Data partitioning



Data Preprocessing

Model Training

RF

True class \ Predicted Class	Train	Minor Impact	Major Impact
Train	32019		
Minor Impact		16	2
Major Impact			2

KNN

True class \ Predicted Class	Train	Minor Impact	Major Impact
Train	32019		
Minor Impact	1	15	2
Major Impact			2

ANN

True class \ Predicted Class	Train	Minor Impact	Major Impact
Train	32018	1	
Minor Impact	1	15	2
Major Impact		1	1

SVM

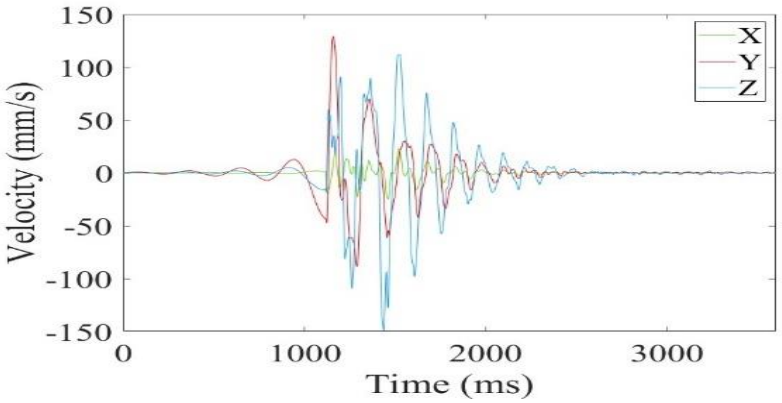
True class \ Predicted Class	Train	Minor Impact	Major Impact
Train	32018	1	
Minor Impact	2	14	2
Major Impact	2		

Method	Accuracy (%)	Precision (%)	Recall (%)	F1-score (%)
Random Forest (RF)	99.3	99.7	99.4	99.5
Kth Nearest Neighbor (KNN)	99.0	98.6	99.0	98.8
Artificial Neural Network (ANN)	97.7	97.9	97.7	97.8
Support Vector Machine (SVM)	97.1	98.0	97.1	97.5

AdSignum

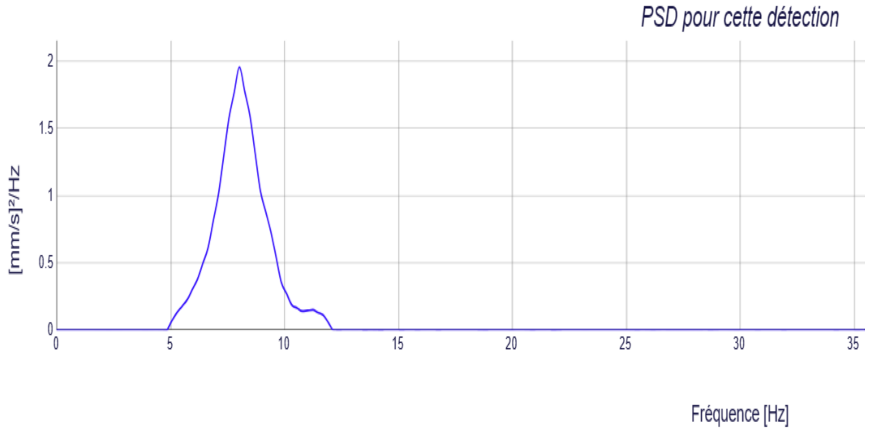
OMNIDOTS

- Maximal velocity in three directions
- Dominant frequency in three direction
- Temporal velocity in three direction



AdSignum

- Maximal velocity in three directions
- Dominant frequency in three direction
- PSD (Power Spectral Density) in three direction



Test Model (AdSignum)
March 2023 – July 2023

- *The model was trained using April 2022 – April 2023 (VLR and SGL). Now we test the model using March 2023 – July 2023 (VLR)*

Passage of a train	Major Impact Anomaly	Minor Impact Anomaly
10681	10	32

Major Impact Anomaly	Displacement 1	Displacement 2	Validation
'13/03/2023 09:02:33'	0.21	0.02	Police
'28/03/2023 09:50:39'	0.36	0.11	Police
'28/03/2023 10:05:13'	0.46	0.25	Police
'04/04/2023 07:05:27'	0.04	0.01	Displacement
'19/05/2023 14:05:12'	0.09	0	Displacement
'26/05/2023 10:34:14'	0.04	0.02	Displacement
'15/06/2023 05:43:22'	0.18	0	Displacement
'16/06/2023 15:17:38'	0.04	0.14	Camera
'26/06/2023 13:07:55'	0.05	0	Camera
'27/06/2023 05:45:49'	0.11	0.17	Camera

Conclusions and perspectives

Conclusions

1. *Extensive data preprocessing was performed.*
2. *Random Forest outperformed other ML models in signal classification.*
3. *The model is applicable to various bridge structures and designs*
4. *High performance of the model prediction → informed decisions for necessary maintenance and protective measures*

Perspectives

1. *Improve the instrumentation in future studies for precise data labeling.*
2. *Explore unsupervised ML methods for classification (k-means, hierarchical)*
3. *Incorporate additional features such as Spectral Analysis (PSD)*
4. *Extend testing to diverse bridge structures.*

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Merci

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