Low-Cost Surface Classification System Supported by Deep Neural Models

Ignacio Sánchez, Juan M. Velasco, Juan J. Castillo, Miguel Sánchez, and Juan A. Cabrera

Presenter: Ignacio Sánchez

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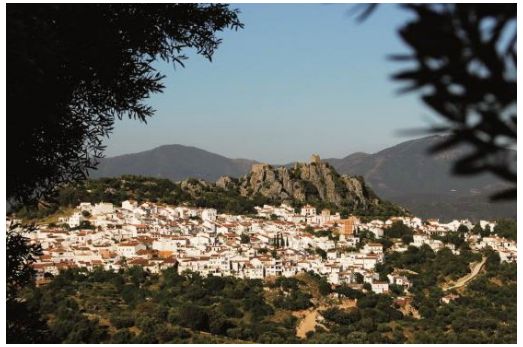

Research Group | iMMa

IAVSD 2021

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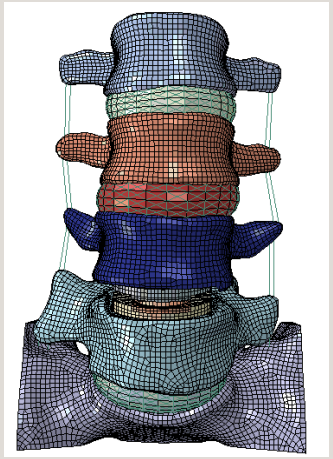
ESCUELA DE INGENIERÍAS INDUSTRIALES

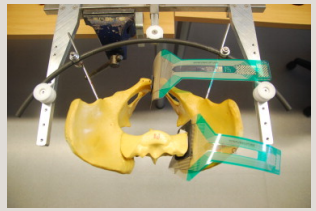
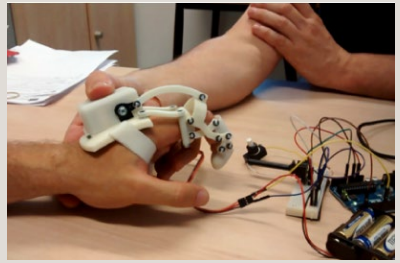
Dept. of Mechanical Engineering, Thermal Engineering and Fluid Mechanics

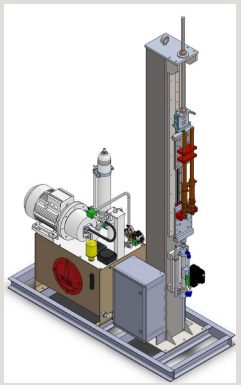
School of Industrial Engineerings
C/ Doctor Ortíz Ramos, s/n
29071 Málaga (Spain)
Telf. (+34) 951 952 372
Web: http://immf.uma.es

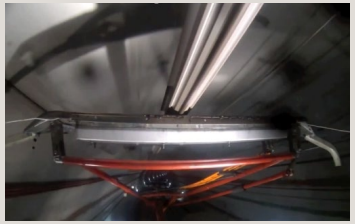
Research Group | Interests

BIOMECHANICS	MECHANISMS / MACHINES	VEHICLES
• Spinal column modeling • Knee prosthesis (modeling) • Vertebral disc prosthesis	• Simulation (Winmecc) • Synthesis • Machinery Design	• Mobile robots (RAM,AURORA) • Automobile (Tire modeling, control systems, vehicle iMMa, …) • Railway (catenary, pantograph)





Research Group | Vehicles

VEHICLE SYSTEM DYNAMICS

- Sensorized Test Vehicles
- Anti-lock Braking System (ABS)
- Traction Control System (TCS)

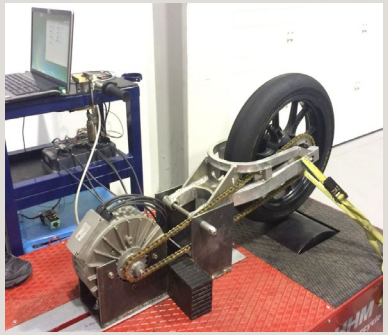
PARAMETER ESTIMATION

- Speed / Adherence / Tire Parameters / Surface
- Robust estimation by data fusion
- Applied Machine Learning and Deep Learning techniques

Research Group | Vehicles

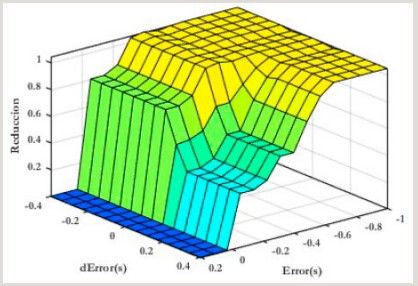
ELECTRIC VEHICLES

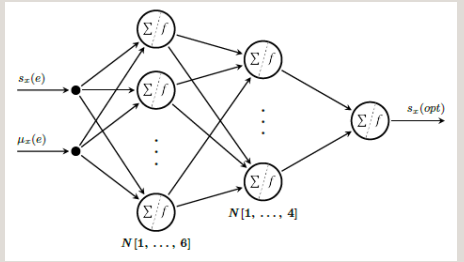
- Electric motor control
- Optimization of regeneration rate on electric motorcycle

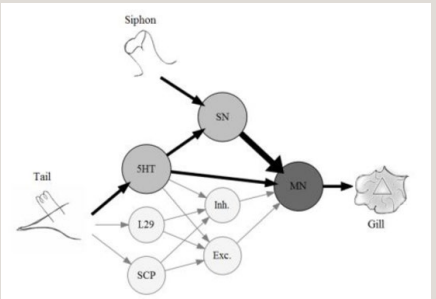


NEW CONTROL ALGORITHMS

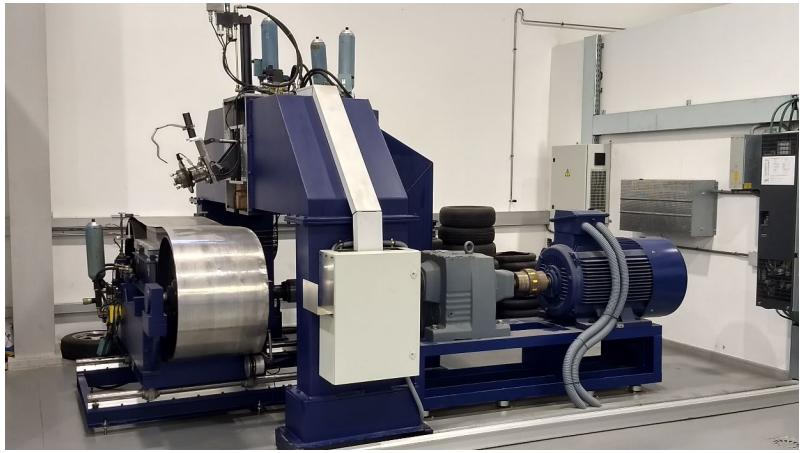
- Fuzzy systems applied to control systems
- Artificial Neural Networks (ANN, RNN, SNN) in parameter optimization

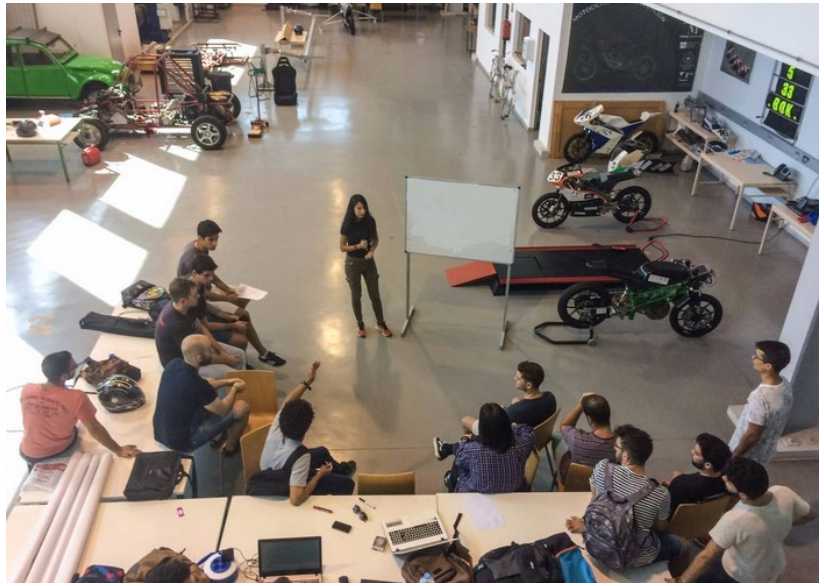






Research Group | Our facilities





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Introduction

Imagine the following situation:

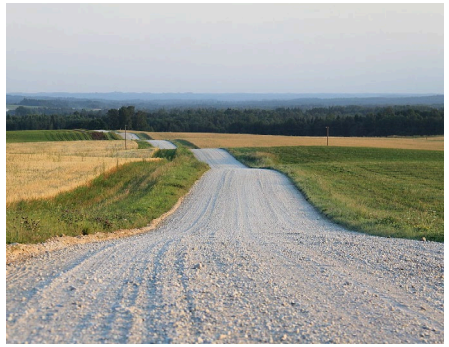
You are traveling in your car and…

Introduction

… you close your eyes!

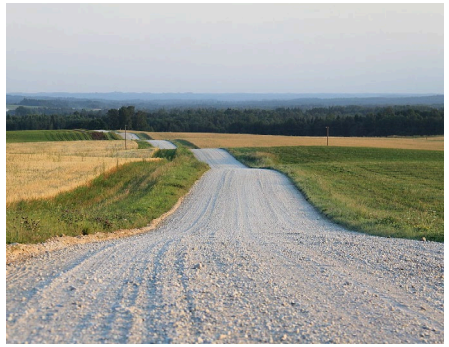
(Only if you are not driving the vehicle)

Introduction



Introduction

Would you be able to recognize the road surface you are driving on?



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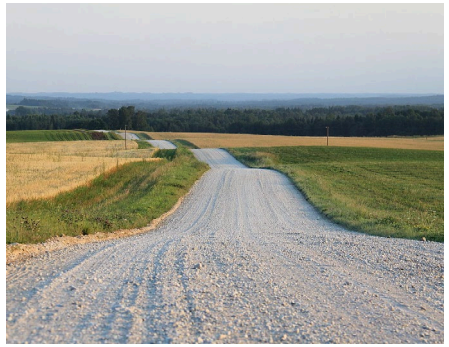

…even identify it

Introduction

What senses do you use for it?

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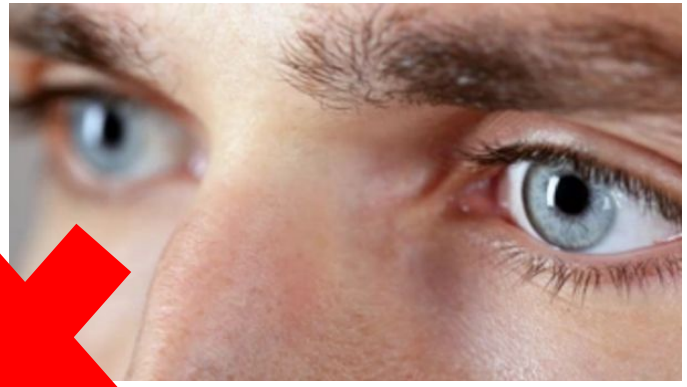

What senses do you use for it?

Introduction

PROPOSED SYSTEM ADVANTAGES

- Smaller dataset than image-based systems.
- Lower cost than camera / laser / ultrasonic sensor systems.
- Simpler and faster models to train.
- Better control of interferences than image (lights) or sound (external noises).
- Does not require sliding on the tire, avoiding or anticipating risky situations.

PROPOSED SYSTEM DISADVANTAGES

- Other systems are able to classify while the vehicle is stationary.
- Image/sound based methods allow a better transversality of use.
- Slide-based methods can provide a relationship to surface adhesion.
- Vibration-based system has difficulty to differentiate between very similar surfaces.

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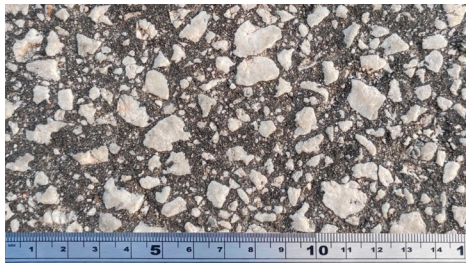
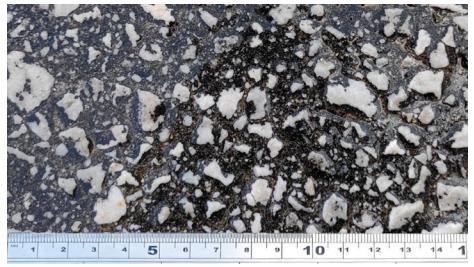
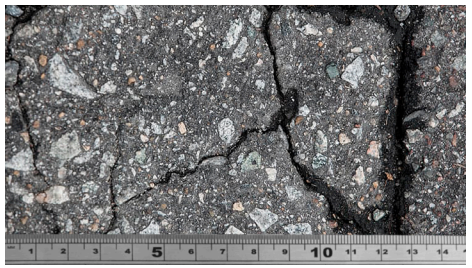
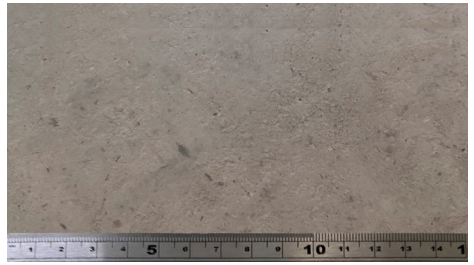
Parameter acquisition and processing

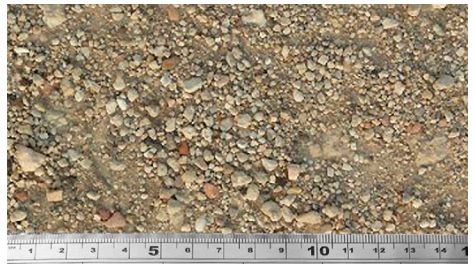

Dry asphalt


Wet asphalt

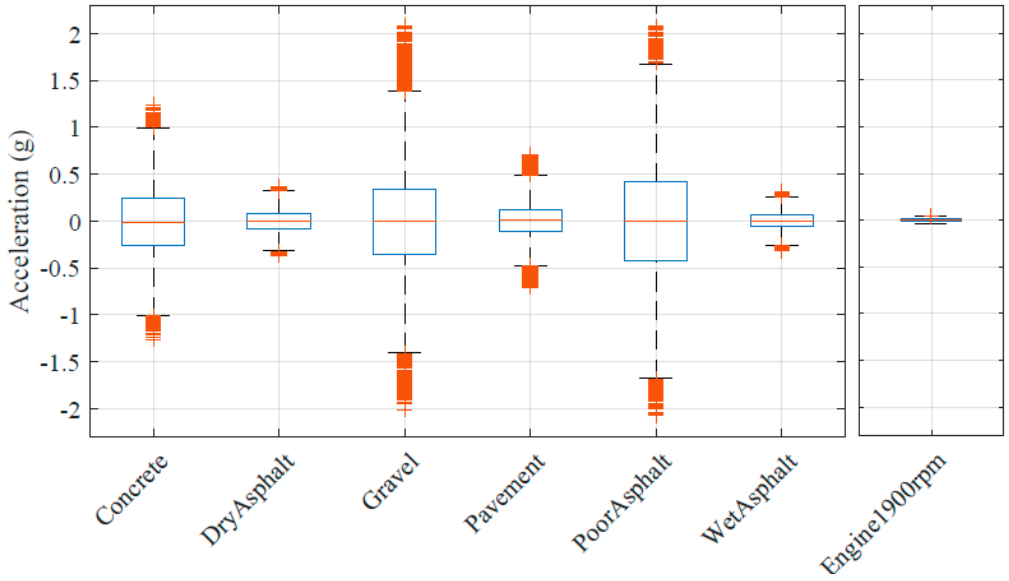

Poor asphalt


Pavement

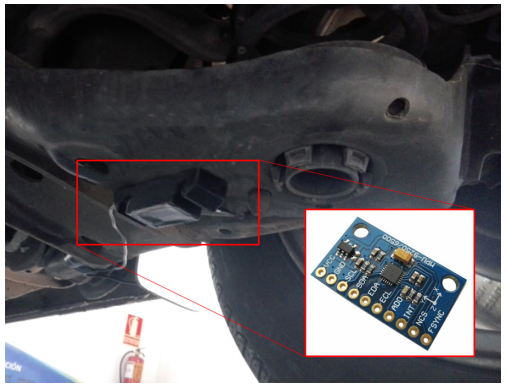

Concrete

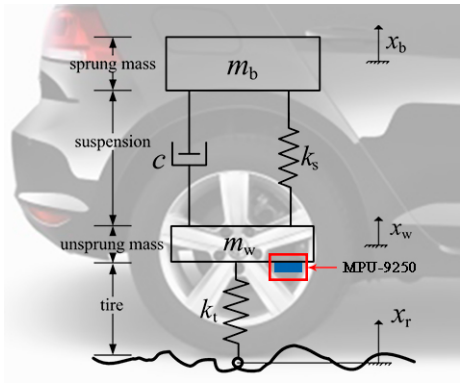

Gravel

Texture	Wavelength (mm)
Mega-Texture	50-500
Macro-Texture	0.5-50
Micro-Texture	0.0-0.5

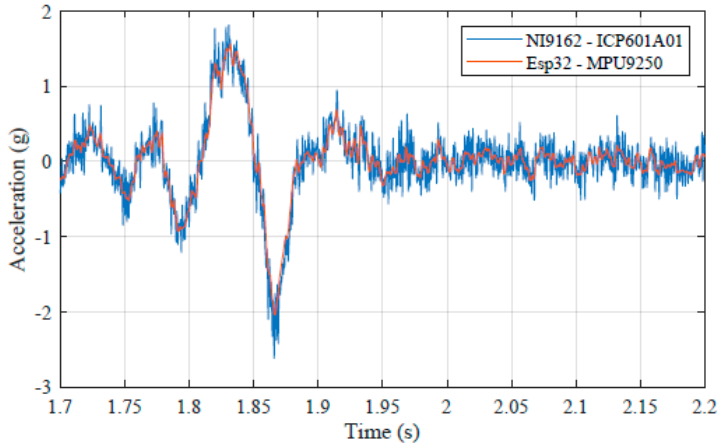


Parameter acquisition and processing



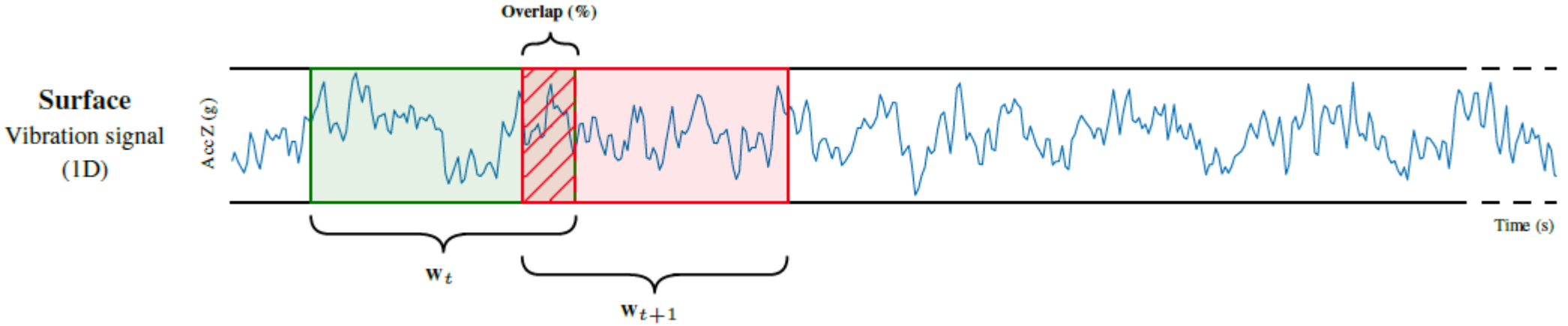


- Ideal interest range: 0 - 1 kHz
(Observed with 10 kHz accelerometer)
- Acquisition Frequency: 1 kHz (máx.)
- Amplitude: ± 4 G
- Real Time Communication (ISR Timing)



Validation Test

Parameter acquisition and processing



Requirements	Values
Speed	50±3 km/h
Tire pressure	2.2±0.1 bar
Vehicle load	2 occupants / full tank
Road	Straight sections

Data recording — Invariant test conditions

Signal Processing — Clean signal: outliers, continuous components...

Segmentation — Create Windows (0.1 s) suitable for real-time systems

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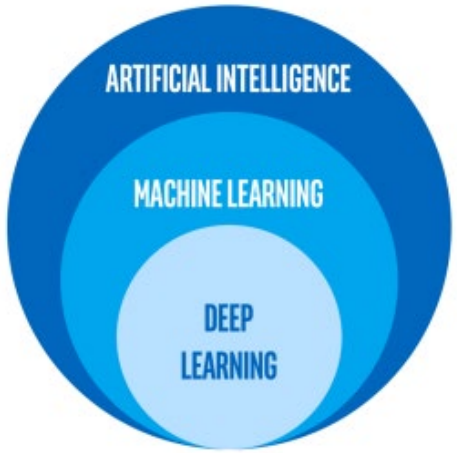
Methodology for surface classification (LSTM)

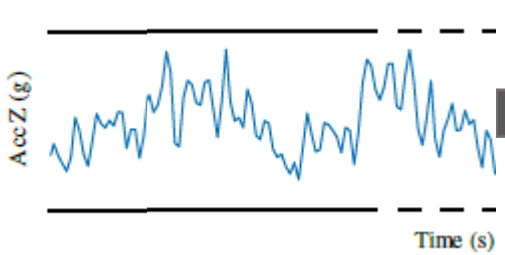
Time Series

What methodology to use?

Six-surface experiment output



Methodology for surface classification (LSTM)



Time Series

?

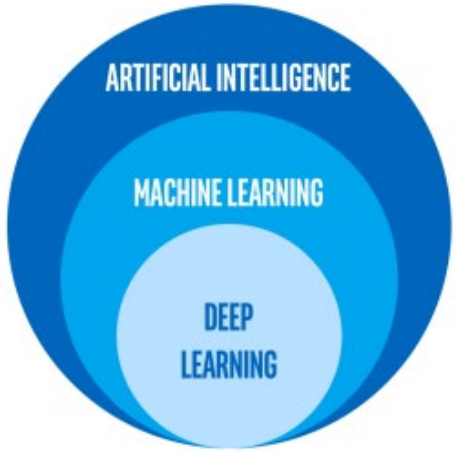
What methodology to use?

SURFACE

Output label

Artificial Intelligence

Classification problem

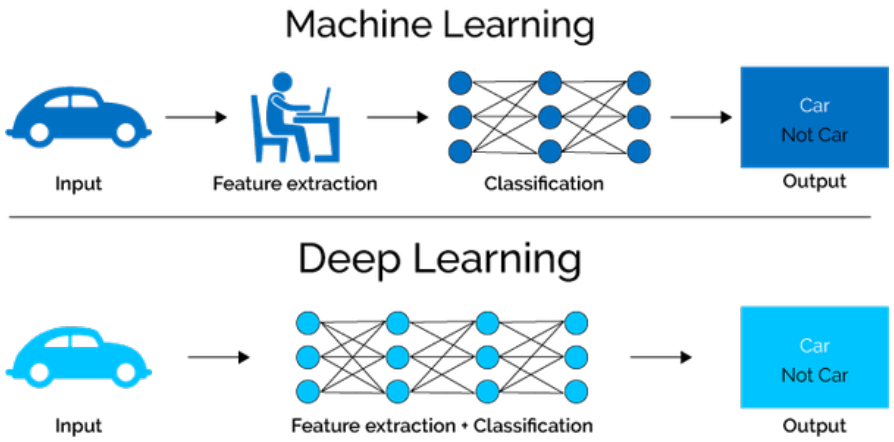


Neural Networks

Supervised Learning

Methodology for surface classification (LSTM)

Time Series | What methodology to use? | Output label



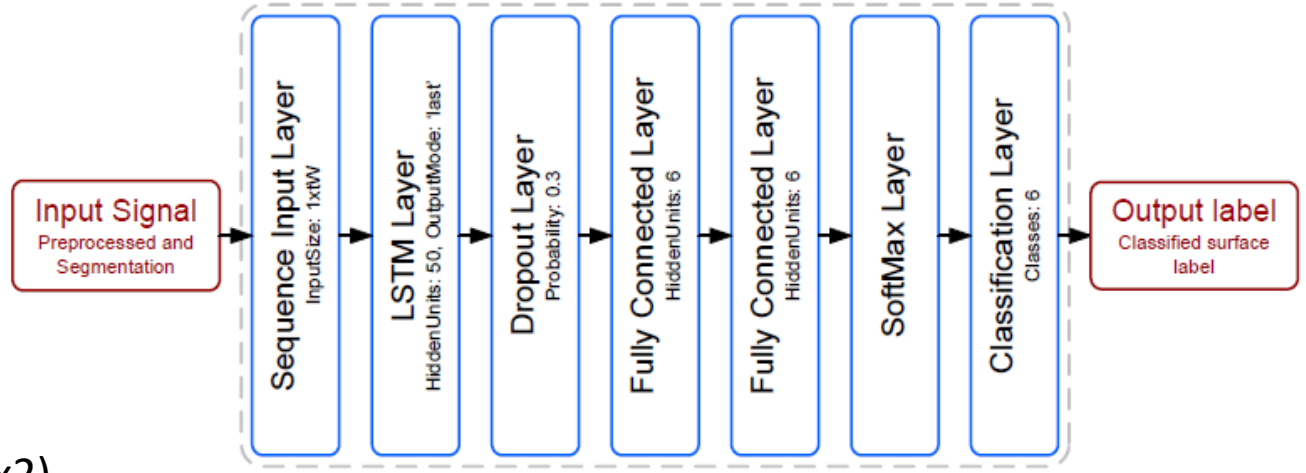
- Deep Learning: Feature extraction + Classification
- Selecting an efficient architecture (LSTM)
- Hyperparameter tuning (Training)
- Limited data (large dataset required)
- Long training time

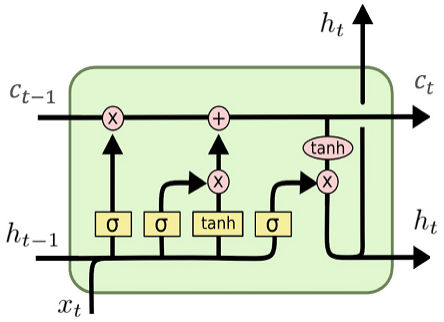
Methodology for surface classification (LSTM)

Internal structure of the Neural Network employed:

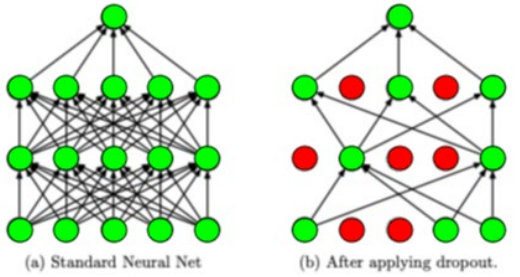
7-Layer Neural Network

- Feature extraction:
  - Single **LSTM** Layer (50 units)
- Classification:
  - **Dropout** Layer (0.3)
  - **Fully Connected** Layer (6 units) (x2)





LSTM



Dropout effect

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Experiments and results

Measures against the occurrence of **Overffiting**:

- **Balanced Datasets** for each surface:
  - 726 total Dataset (6 surfaces)
  - 121 segments per surface

- **Randomly** selected surface samples for training, validation and test.

	Dataset		
	Training		Testing
%	60 % (Train)	10 % (Validation)	30 % (Test)
n	76	9	36

Software for model training and execution:

Training conditions:

- Minibatch size: 100
- Max epochs: 2000
- Initial Learning Rate: 0.02
- Learning Rate Update: 0.5 every 500 epochs
- Validation Frequency: 50 epochs
- Solver: Adam
- Execution Environment: single GPU

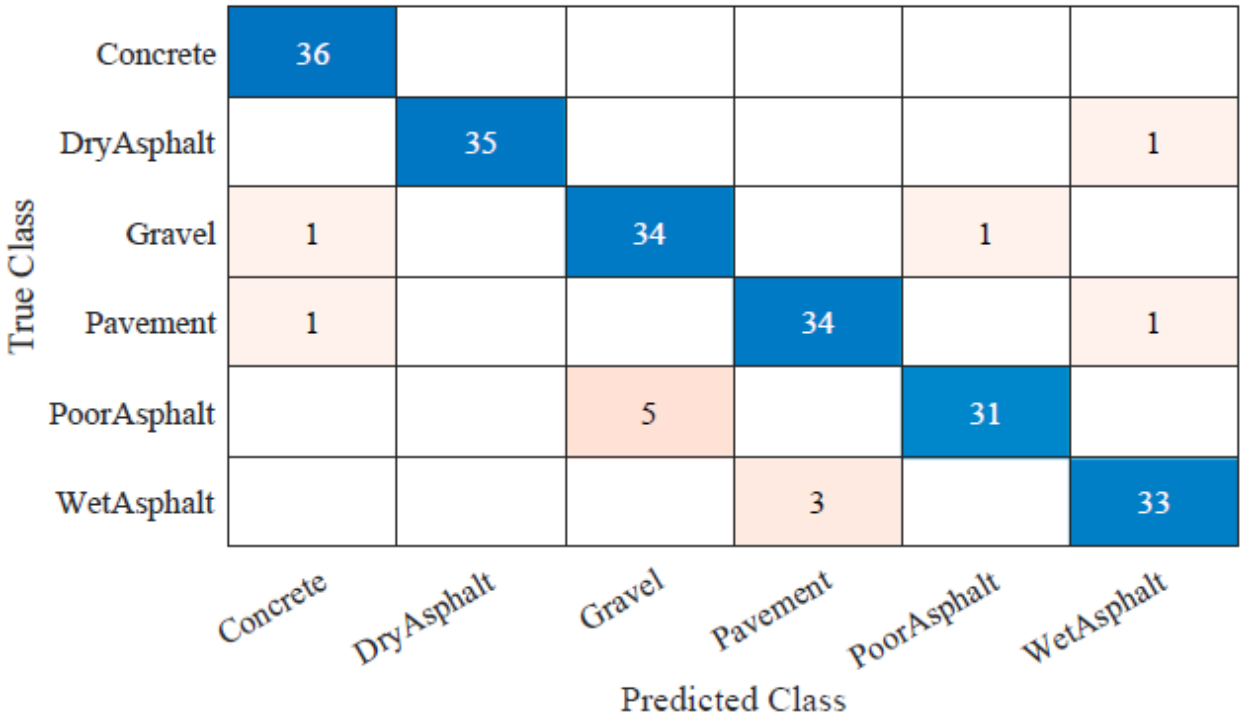
Experiments and results

Main objectives during the training process:

- Search for a reduced and simple network architecture (**efficient** network design, shorter training time and faster classification execution).

  LSTM / BiLSTM / Dropout / tW / LR / ...

- Evaluation of results (**Confusion Matrix**). Control and guarantee the correct convergence of results.



Experiments and results

Statistical analysis of the classification results:

Surfaces	Predictions				Metrics		
	TP	FP	TN	FN	P	R	F1
Concrete	36	2	178	0	94,7	100,0	97,3
DryAsphalt	35	0	180	1	100,0	97,2	98,6
Gravel	34	5	175	2	87,2	94,4	90,7
Pavement	34	3	177	2	91,9	94,4	93,2
PoorAsphalt	31	1	179	5	96,9	86,1	91,2
WetAsphalt	33	2	178	3	94,3	91,7	93,0
Averages	-	-	-	-	94,2	94,0	94,0

$$P = TP / (TP + FP)$$

$$R = TP / (TP + FN)$$

$$F1 = 2 (P \cdot R / (P + R))$$

Classification ratio (F1) higher than 90 % on any of the tested surfaces, **average result of 94 %.**

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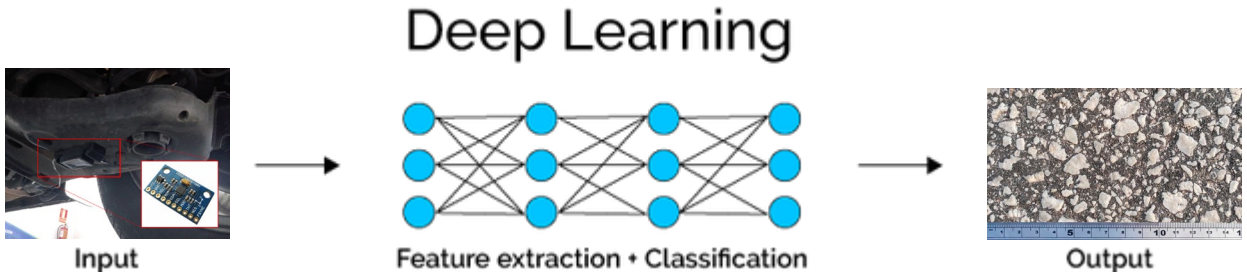
Conclusions and future works

Road surface classification has been studied from an approach based on the analysis of the vibration generated by the road surface, using a low-cost accelerometer system and Deep Learning techniques applied to the classification task.



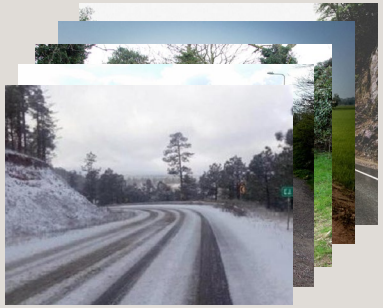
CONCLUSIONS

- An average rating of 94 % is achieved on the proposed task and always above 90 % on each individual surface.
- A reduced detection-execution time (0.1 s) has been achieved.
- An economical and simple system has been successfully developed.
- System with stable response even in cases of confusion.

Conclusions and future works

FUTURE WORKS

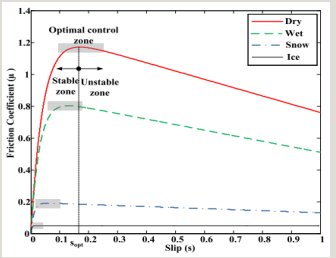
- Increase the Dataset:
  - More surfaces
  - Longer test duration
  - Different speeds



- Search for new and more efficient network architectures with improved capabilities.

- Validate the model in tests with different types of vehicles.

- In the near future, perform data fusion to estimate the Adhesion Coefficient (μ) of the surface (estimated surface, tire temperature, pressure, wear, ...).



Thank you for your attention

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