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Heterogeneous Information Fusion Approach for Monitoring Bearings in Harsh Environments Using an Inspection Mobile Robot

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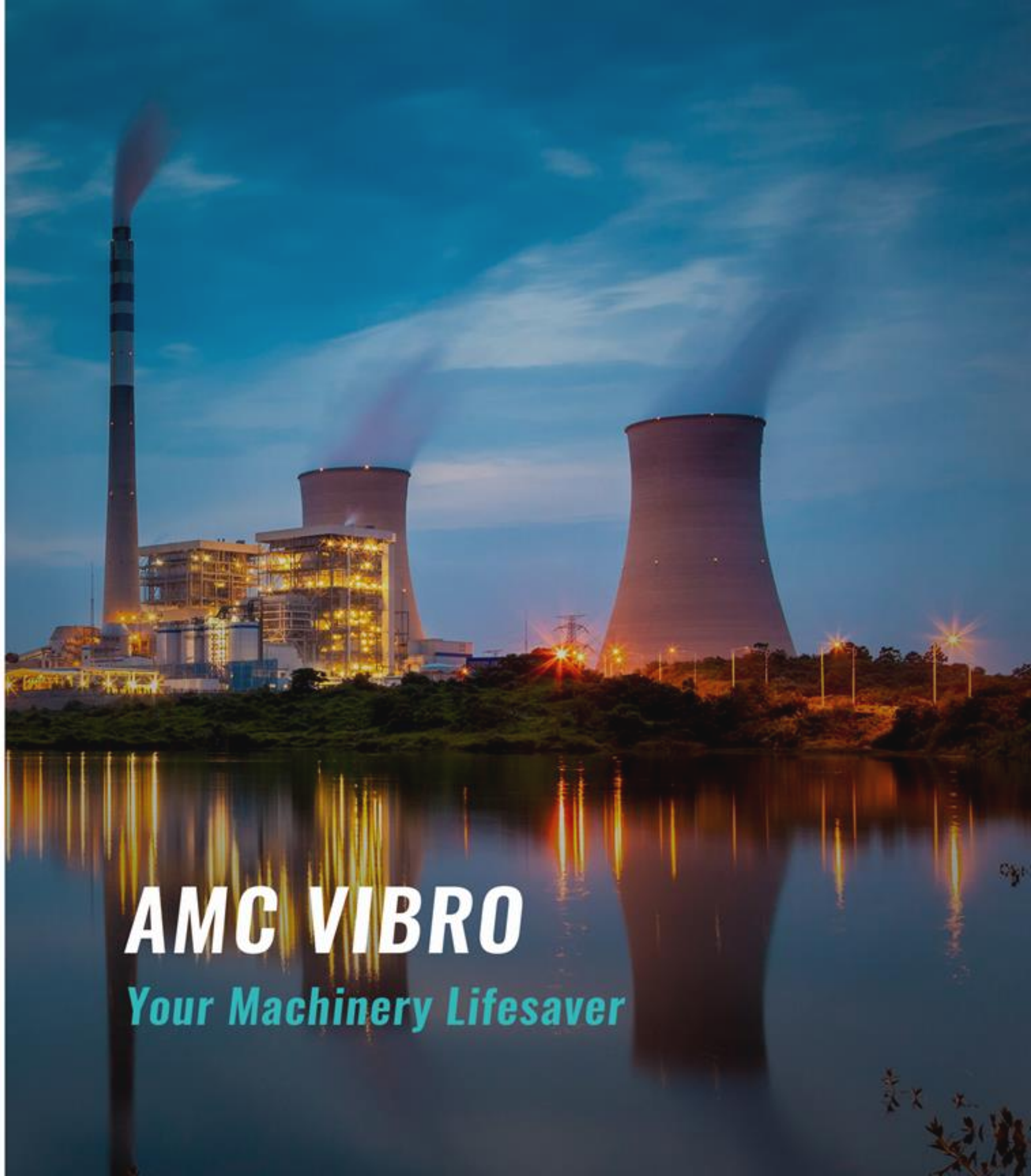

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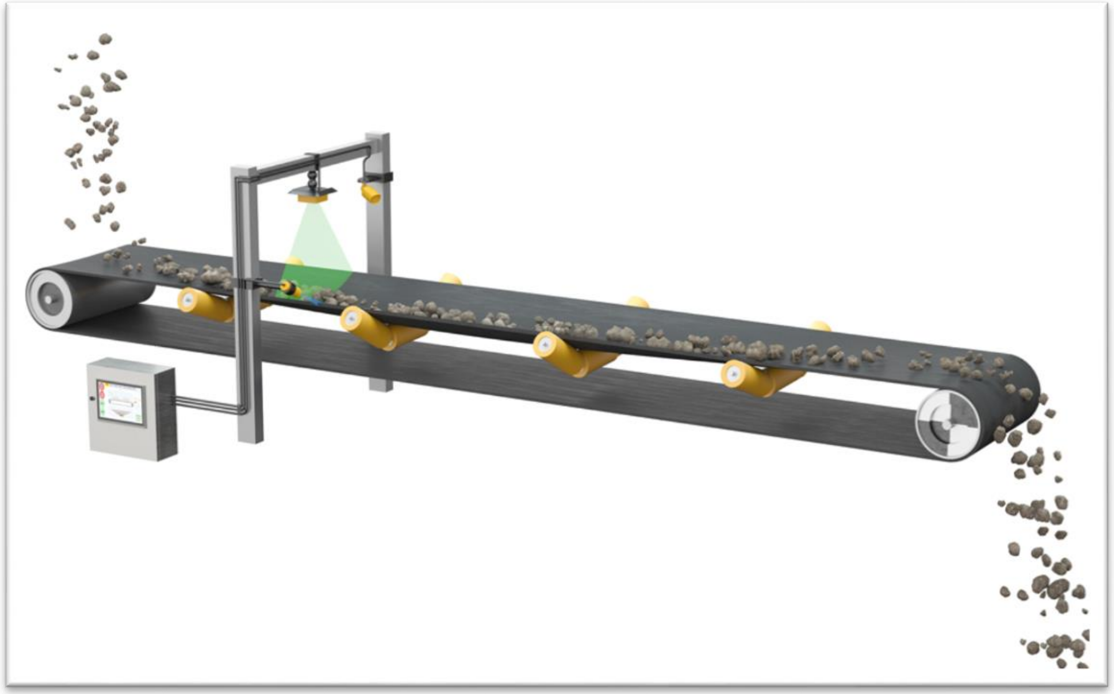
Inspection robots in atomization of underground mines

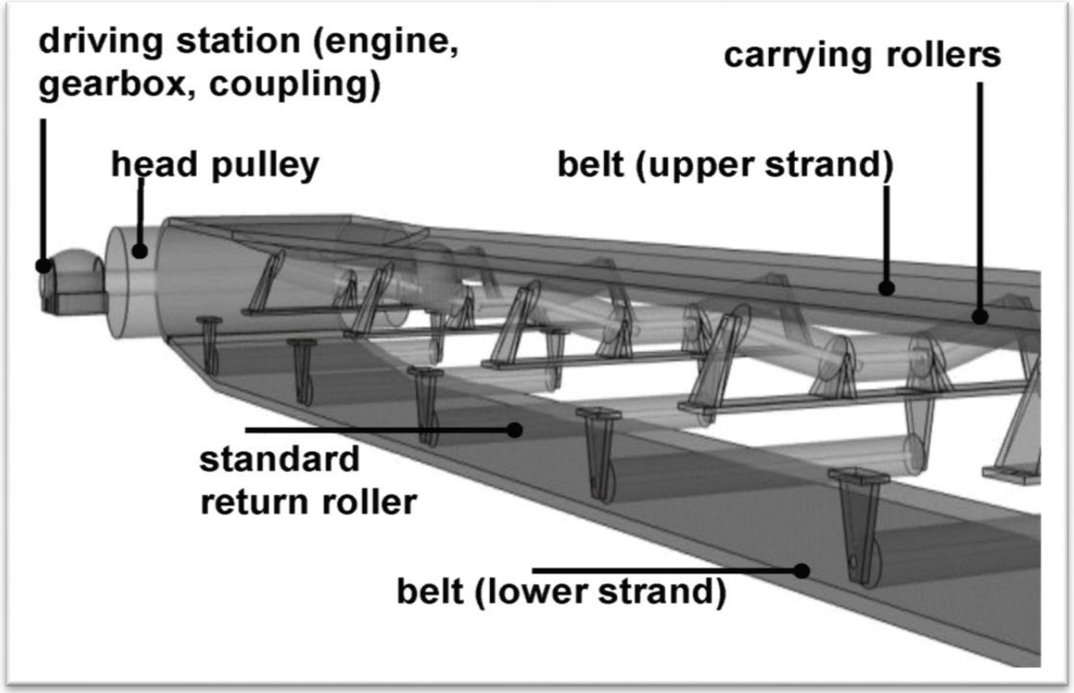
- Deep underground mines impose new challenges for mining industry when searching for new hardly accessible deposits.
- Due to a rapid development of modern technologies, as well as globalization, easy-to-mine resources have been already exploited.
- However, space, automotive, IT, etc., technologies require specific raw materials (for example, rare earth).

Inspection robots in atomization of underground mines

- These challenges are related to locations of deposits, their geometry (thin layers), and harsh environment (dust, temperature, and humidity) including natural hazards (gas emission, water, and seismic events).
- By considering the harsh environmental conditions in underground mines, even nowadays, miners are allowed to work during shorter (6 h only) shifts.
- Therefore, There is a general tendency to minimize the presence of humans and atomization of inspection processes by intelligent robots.

Heavy duty belt conveyor (BC) systems in the mining industry





The BC systems are the main means of horizontal transport of bulk materials in mining sites

Heavy duty belt conveyor (BC) systems in the mining industry

A general view of the belt conveyor in mining sites

Traditional idler inspection

Application of mobile robots for performing CM tasks

- Inspection mobile robots can capture various types of data including RGB images, IR images, sound, lidar data
  - Vibro-diagnostics of conveyor gearbox
  - Infrared thermography of conveyor gearbox
  - General inspection for belt conveyor image analysis
  - Acoustic based CM methods

Lidar

RGB CAMERA

Microphone

Thermal Camera

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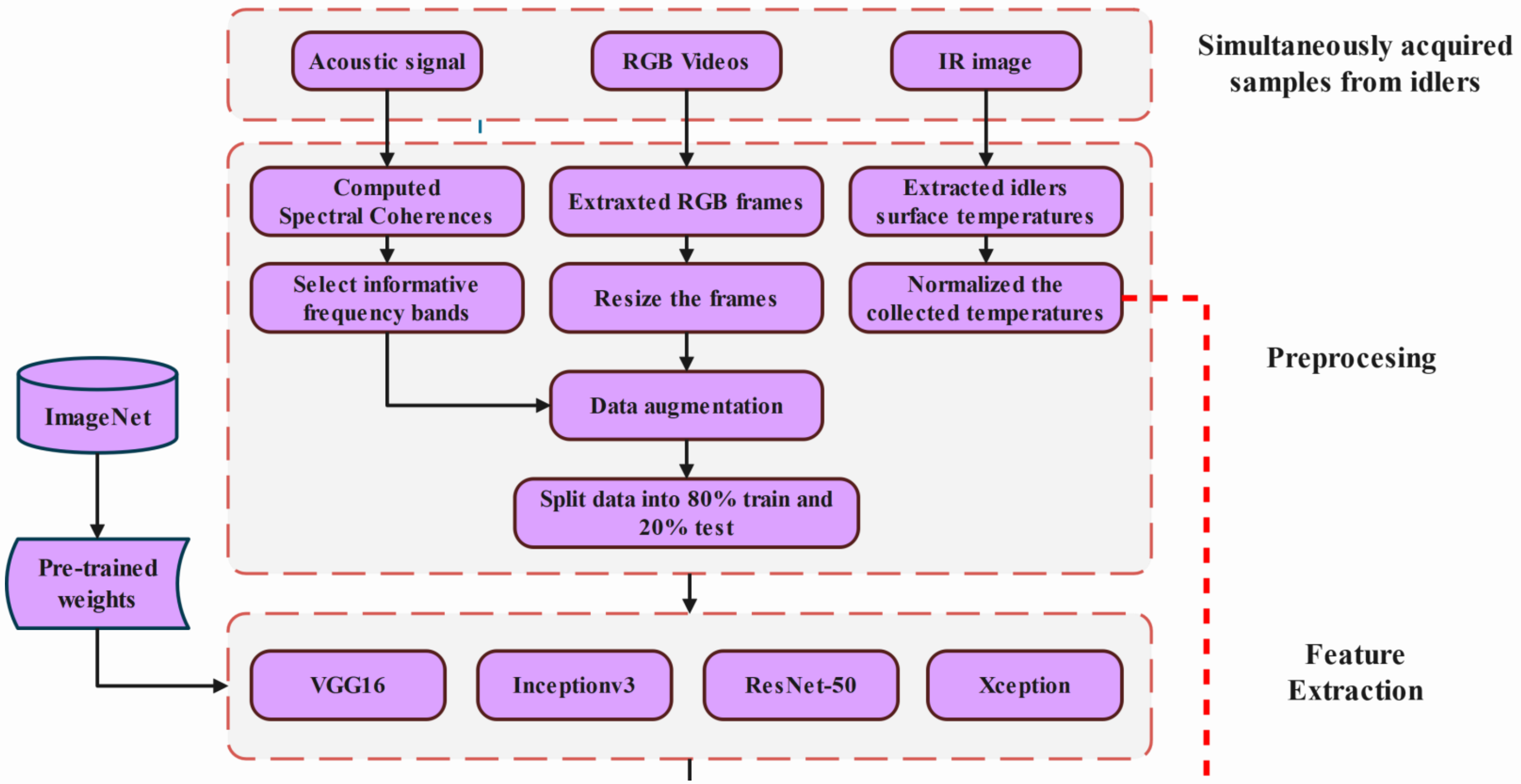
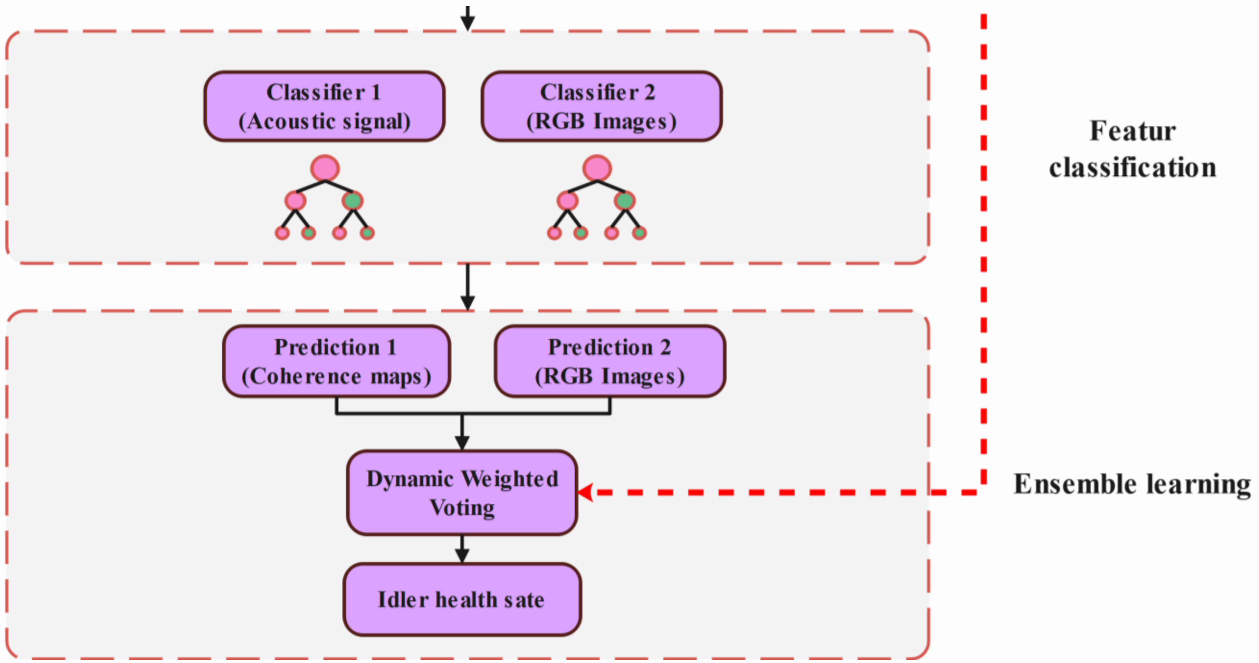
Different information fusion methods

- The information fusion method for processing the multi-sensor CM systems can be categorized into three different groups, including the data-level, feature-level, and decision-level fusion methods.
  - In **data-level fusion**, raw data from each sensors are fused to be represented as a single data unit without going through any feature extraction.
  - In **feature-level fusion**, the extracted features from each sensor are individually processed and integrated into a feature vector using a certain approach.
  - In **decision-level fusion**, the corresponding data from each sensor is separately processed, and the obtained results that represent the monitored equipment are separately stored.

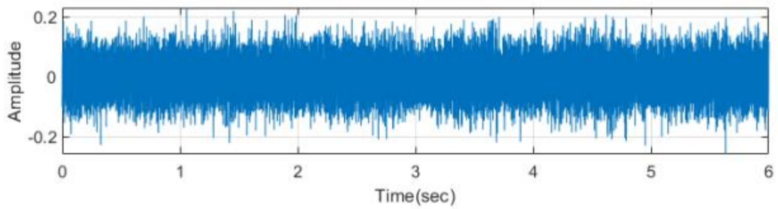
Proposed fusion approach (part 1)



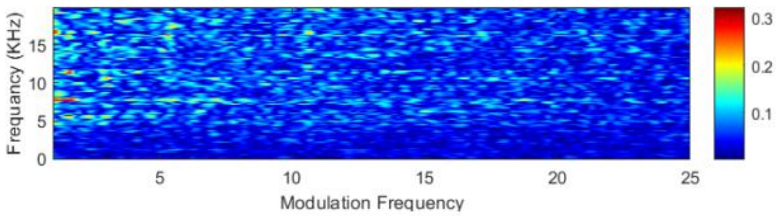
Proposed fusion approach (part 2)



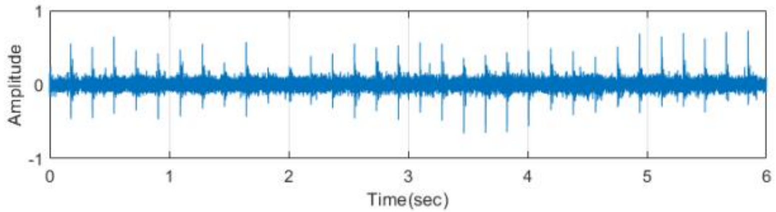
Comparison of the common energy patterns in Spectral Coherences for a faulty and healthy idlers



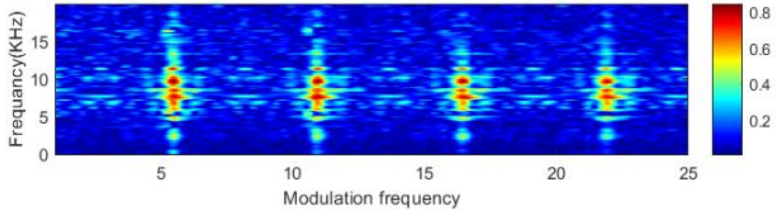
(a) Raw input signal: healthy case



(b) Spectral Coherence : healthy case



(c) Raw input signal: faulty case



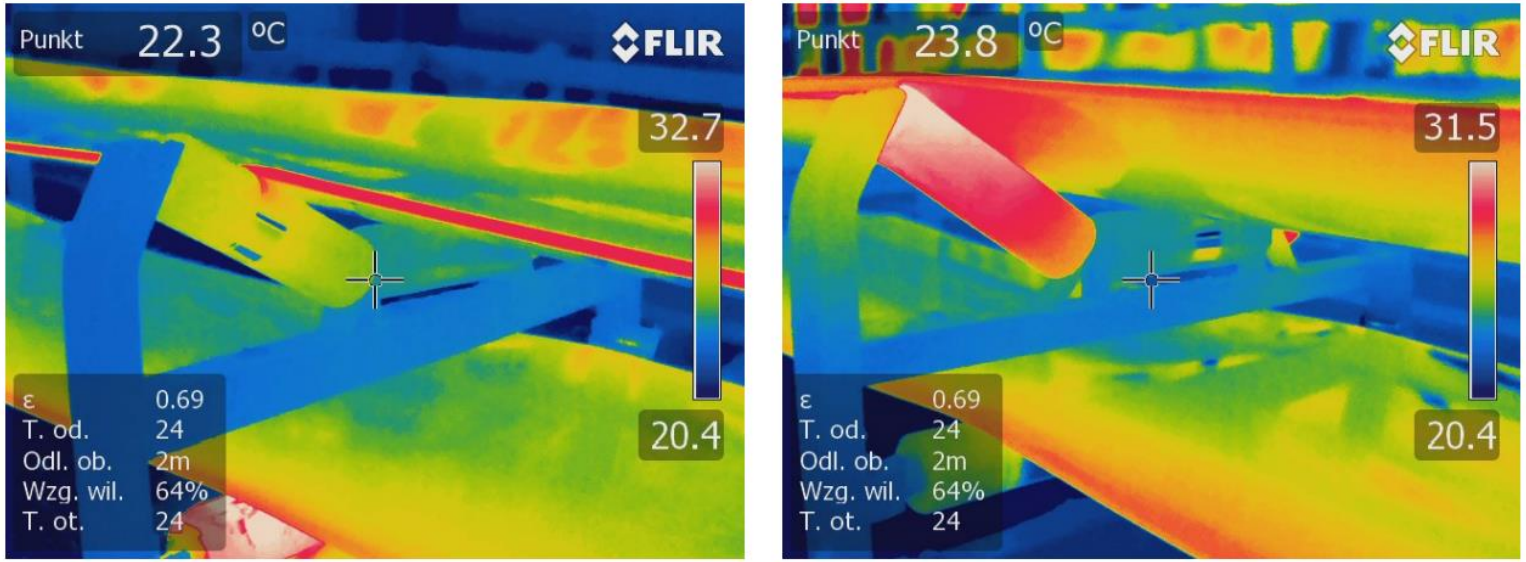
(d) Spectral Coherence : faulty case

Comparison of RGB images captured from a moving and stuck idler

(a) Rotating idler: healthy

(b) Stuck idler: faulty

Comparison of IR image from a cold (moving idler) and overheated (stuck idler)

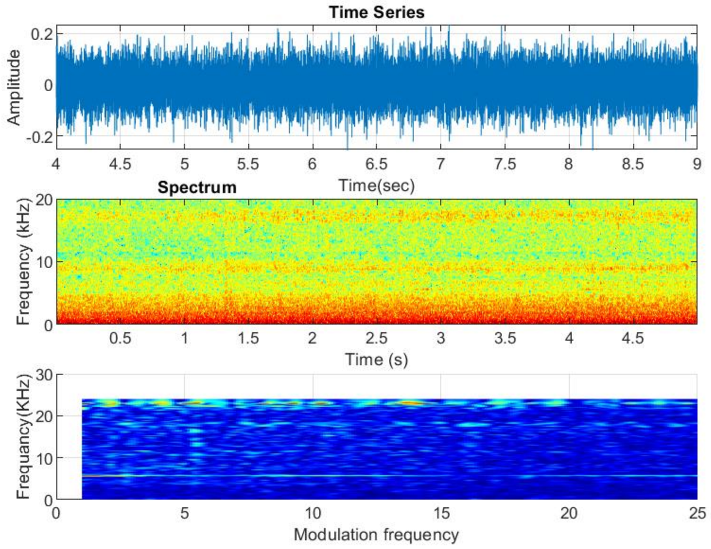


(a) Cold idler: healthy

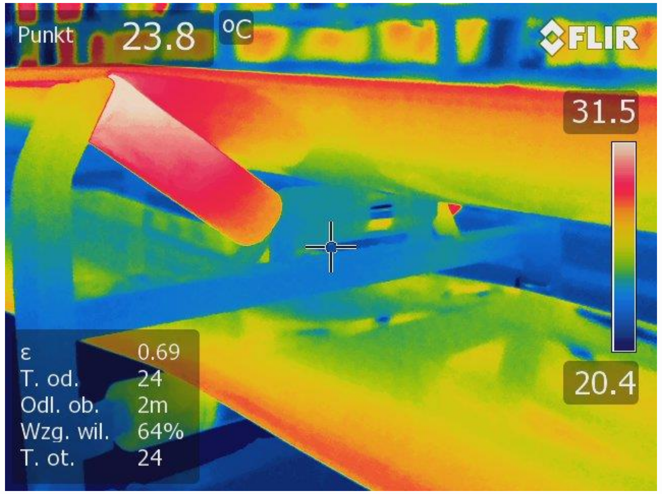
(b) Overheated idler: faulty

General comparison of the acoustic and IR images based CM methods

Spectral Coherence maps

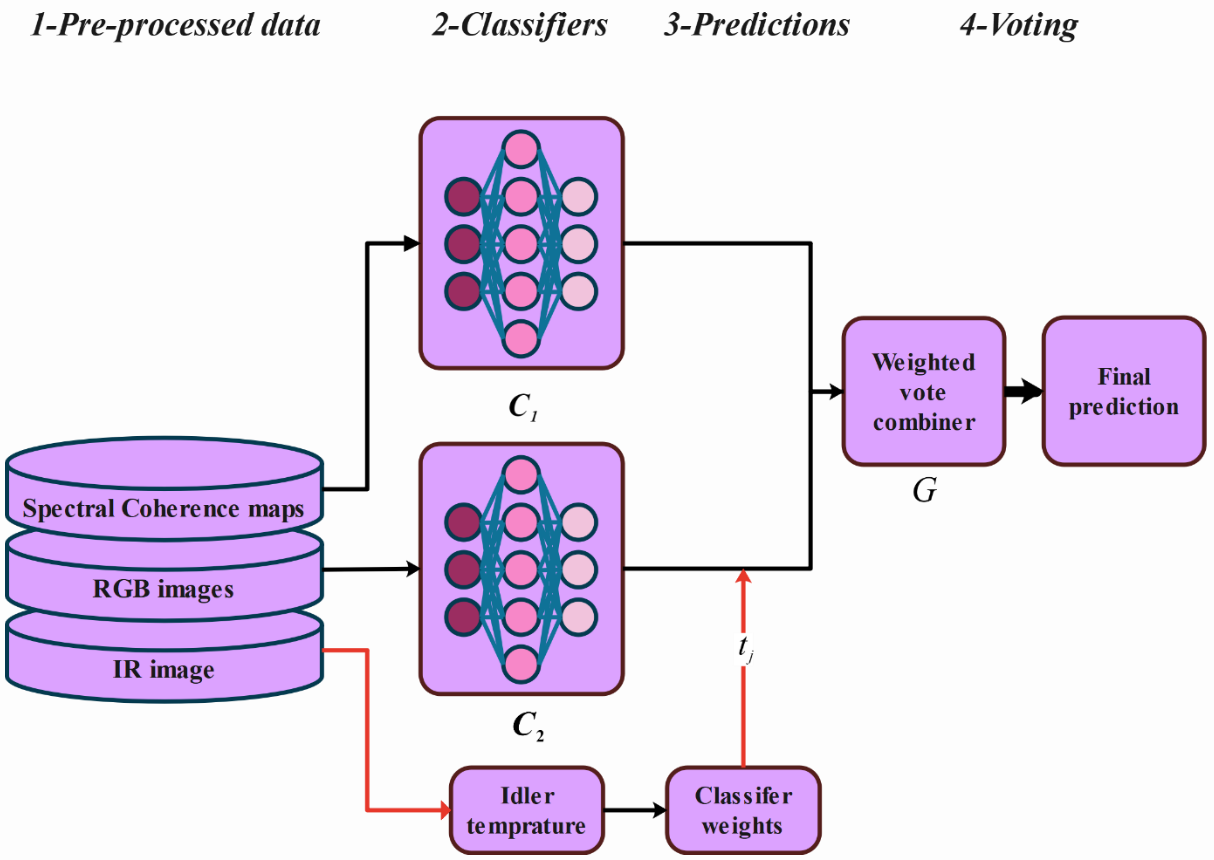


Thermal image



RGB Videos

Classifier fusion approach



Results

Table 2. Results of the studied deep learning model in classification of extracted RGB images and Spectral Coherences

Model	Depth	Number of parameters	Accuracy		Recall		F1 score	
			RGB Image	Acoustic signal	RGB Image	Acoustic signal	RGB Image	Acoustic signal
VGG16-RF	16	138.4 M	0.8958	0.75	0.7916	0.7777	0.8837	0.7555
VGG16-XGboost			**0.9375**	0.75	**0.8750**	0.7222	**0.9333**	0.7301
Inceptionv3-RF	189	23.9 M	0.7083	**1**	0.4166	**1**	0.5882	**1**
Inceptionv3-XGboost			0.7916	0.75	0.5833	0.7222	0.7368	0.7388
ResNet-50-RF	107	25.6 M	0.9166	0.625	0.8333	0.6666	0.9090	0.6238
ResNet-50-XGboost			0.8541	0.50	0.7083	0.5555	0.8292	0.4330
Xception-RF	81	22.9 M	0.7708	**1**	0.5416	**1**	0.7027	**1**
Xception-XGboost			0.7291	0.875	0.50	0.8888	0.6486	0.8666

Results

Table 3. Performance comparison of proposed sensors fusion in true detection method in true detection of damaged idlers

Source of information	Accuracy	Recall	F1 score
Acoustic signal (Inceptionv3-RF)	0.75	0.6	0.75
RGB image (VGG16-XGboost)	0.5	0.2	0.33
Fusion (Acoustic, IR image, RGB image)	0.85	0.80	0.88

Conclusion

- In conclusion, this research presents a novel sensor fusion approach focused on addressing challenges associated with condition monitoring by using inspection mobile robots during real-world scenarios.

- The introduced methodology focusses on information gaps to mitigate false information captured by the sensors used.

- The study specifically focusses on the monitoring of conveyor belt idlers in a mining site as a real and challenging case study, using a combination of acoustic signals, RGB images, and IR images.

- Additionally, a comprehensive comparison study of eight computational neural network-transfer learning (CNN-TL) models is conducted, evaluating their effectiveness in identifying different fault signatures in RGB images and Spectral Coherence.

Conclusion

- The research further proposes a dynamic weighted majority voting ensemble approach to fuse the gathered information. This approach continuously updates the weight of each model on the basis of the surface temperature of the idler obtained from the IR images.

- In summary, the proposed sensor fusion strategy, coupled with the utilization of CNN-TL models and dynamic weighted ensemble techniques, provides an effective framework for improving the accuracy and reliability of condition monitoring systems.

- The findings contribute to the advancement of robotics and automation in industrial applications, showcasing the potential of multisensory fusion for improved fault detection and classification.

Acknowledgments

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Thank you

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