Lorenzo De Donato

Artificial Intelligence Techniques for Rail Dependability and Automation

Tutor: Prof. Valeria Vittorini
co-Tutors: Prof. Carlo Sansone,
Prof. Francesco Flammini (Linnaeus University, Sweden)

Cycle: XXXVI

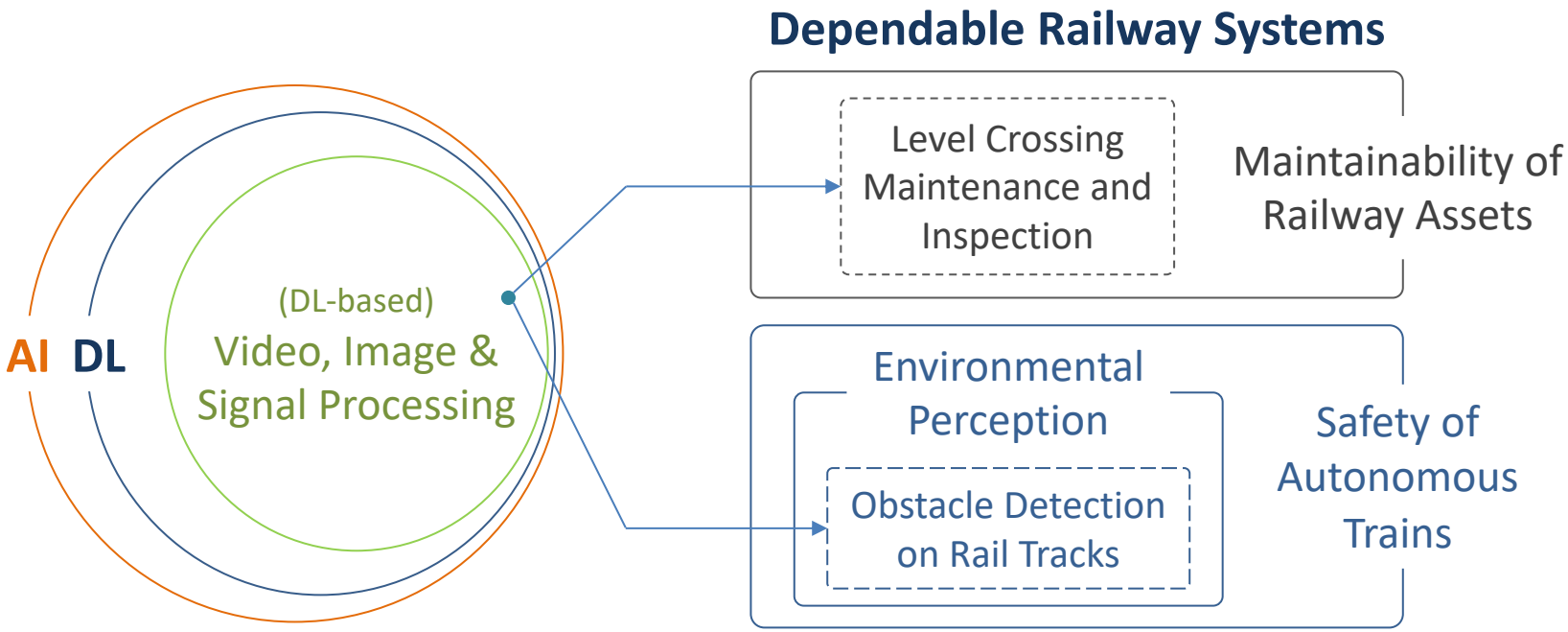
Year: Second

My Background

- **MSc degree**: Computer Engineering
- **Research group/laboratory**:
  - Laboratorio Sicurezza Sistemi Informatici (SECLAB)
  - Pattern analysis and Intelligent Computation for mUltimedia Systems (PICUS)
- **PhD start date**: November 1st, 2020
- **Scholarship type**: funded by CINI, partially on the H2020 Shift2Rail RAILS project
- **Cooperation**:
  - HITACHI Rail STS;
  - Partners of the H2020 Shift2Rail RAILS (Roadmaps for AI integration in the raiL Sector) project:

Research Field

Investigate the potential of Artificial Intelligence (AI) in the rail sector with particular focus on Deep Learning (DL) approaches to improve maintenance, safety, and automation of dependable railway systems.



Summary of study activities

Study activities have been mainly oriented at investigating Computer Vision approaches based on Deep Learning (specifically for Obstacle Detection and Smart Maintenance) and gathering notions in the context of Trustworthy Autonomous Systems/Vehicles.

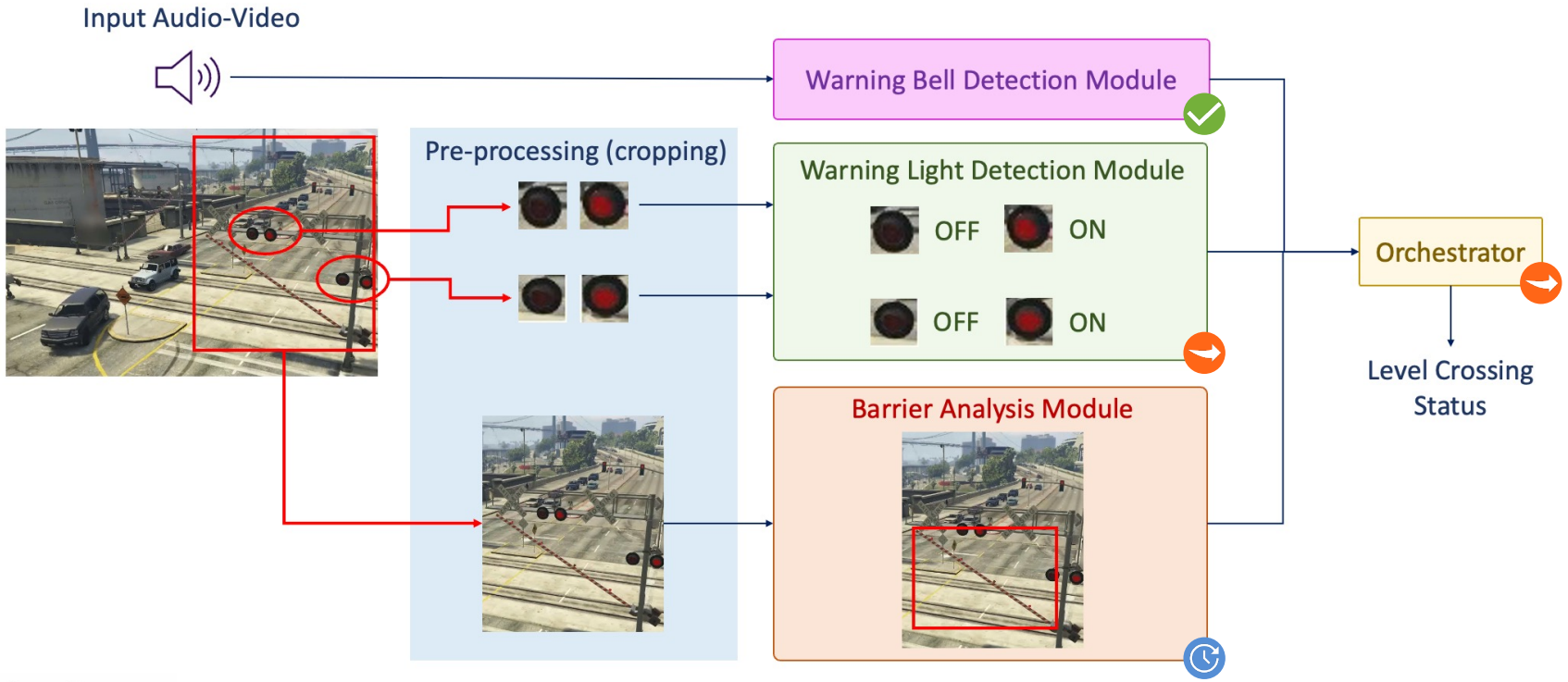
Courses	"Imprenditorialità Accademica"; "Neural Networks and Deep Learning"
Seminars	*Trustworthy Autonomous Systems/Vehicles:* "Self-awareness for autonomous systems"; "Towards Trustworthy AI - Integrating Reasoning and Learning"; "Safety First for Autonomous Vehicles: Where Do We Stand? What is Missing?"; "Mind the Gaps: Trustworthy AI for Autonomous Vehicles"; "Mind The Gaps: Do You Trust AI-Enabled Autonomous Vehicles?" *Advancements within the Rail Sector*: "Potential and challenges of next generation railway signaling systems: Moving Block and Virtual Coupling"; "La sostenibilità del trasporto pubblico locale su ferro: elementi di efficientamento" *Others …*
Conferences and Workshops	*Oral Presentation:* "INNORAIL2021: Future of the railway – Railway of the future" (Budapest, 16-18 November 2021) "RAILS Mid-term Project Workshop" (Online Event, 25 February 022) "WCRR 2022: World Congress on Railway Research" (Birmingham, 6-10 June 2022) *Paper Presentation:* "RSSRail 2022: Reliability, Safety and Security of Railway Systems" (Paris, 1-2 June 2022) *Others:* "MATLAB Expo 2022" (Online Event, 17-18 May 2022)

Smart Maintenance at Level Crossings

Problem Move from scheduled-based inspections to continuous monitoring of Level Crossings (and migrate from corrective to predictive maintenance) leveraging non-intrusive sensors.

Objective Design and implement an AI system capable of assessing the health status of Level Crossings relying on data from cameras and microphones.

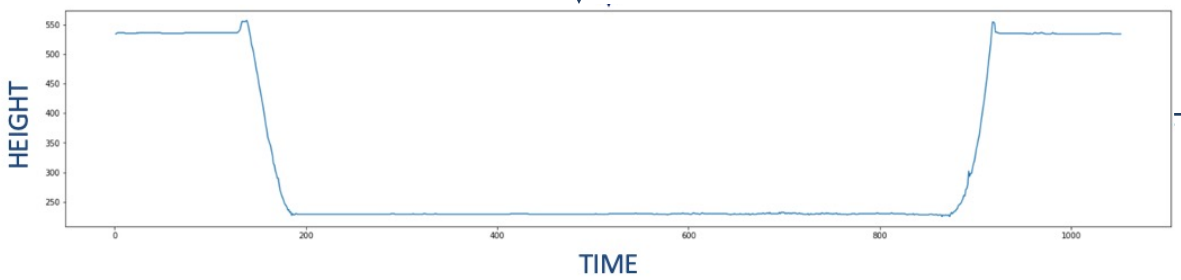
Methodology Non-intrusive modular approach where each AI module analyses a specific component of the Level Crossing while exploiting the characteristics of *fixed* cameras (and microphones).



Barrier Analysis Module

YOLOv5s
(pre-trained)

Post-processing



Compare with nominal behaviour to get barrier's status

Videos from GTA
(Grand Theft Auto 5)
With different light and weather conditions

Dataset: 1738 Frames
Training: 1212
Validation: 263
Test: 263

Best performances

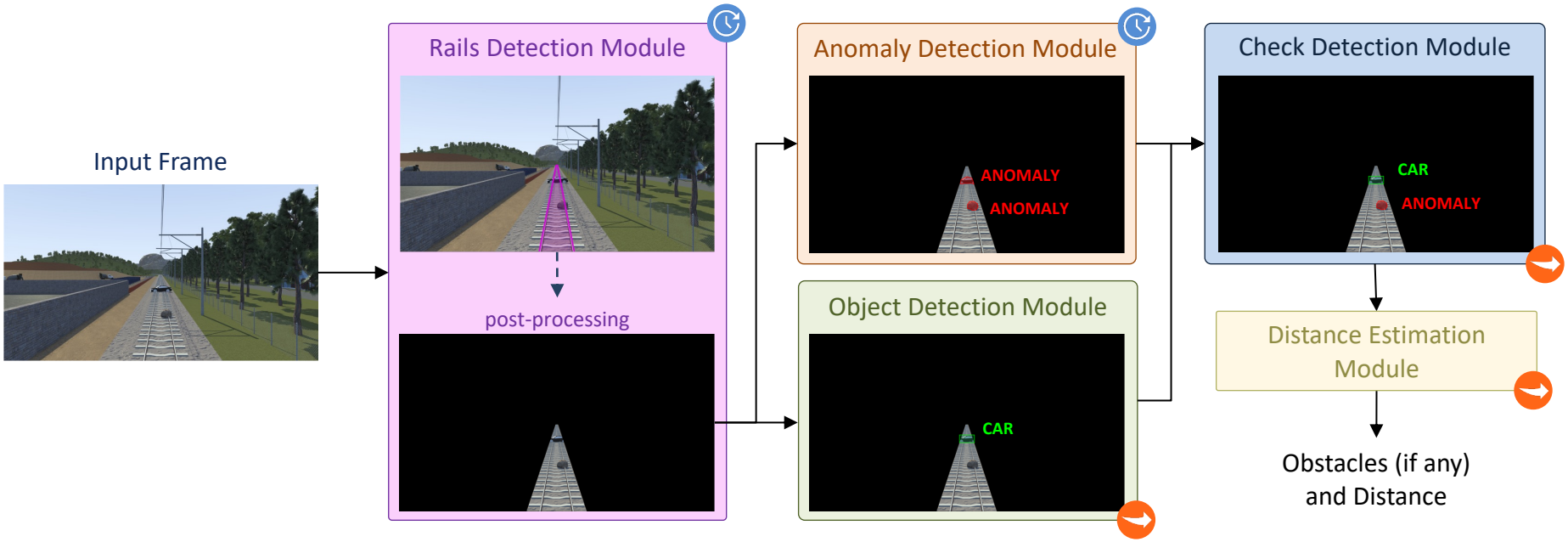
Set	Precision	Recall	mAP@0.5	mAP@0.5:0.95
Validation	0.998	1	0.995	0.929
Test	1	0.996	0.995	0.927

Vision-based Obstacle Detection on Rail Tracks

Problem Improve the coverage of Vision-based AI systems oriented at detecting obstacles on rail tracks which typically leverage supervised DL approaches.

Objective Design and implement an AI system capable of detecting both obstacles known a-priori (namely objects) and obstacles unknown a-priori (namely anomalies).

Methodology Considering the characteristics of the rail domain, the approach is based on the integration of DL techniques for object detection (supervised) and anomaly detection (unsupervised).

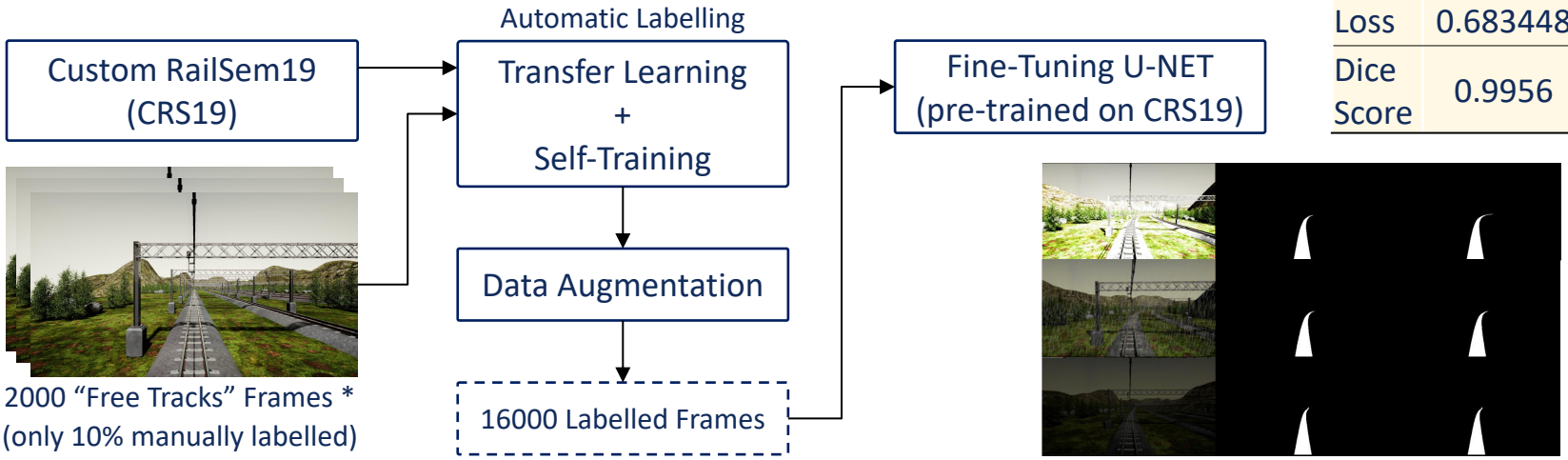


Rails Detection Module

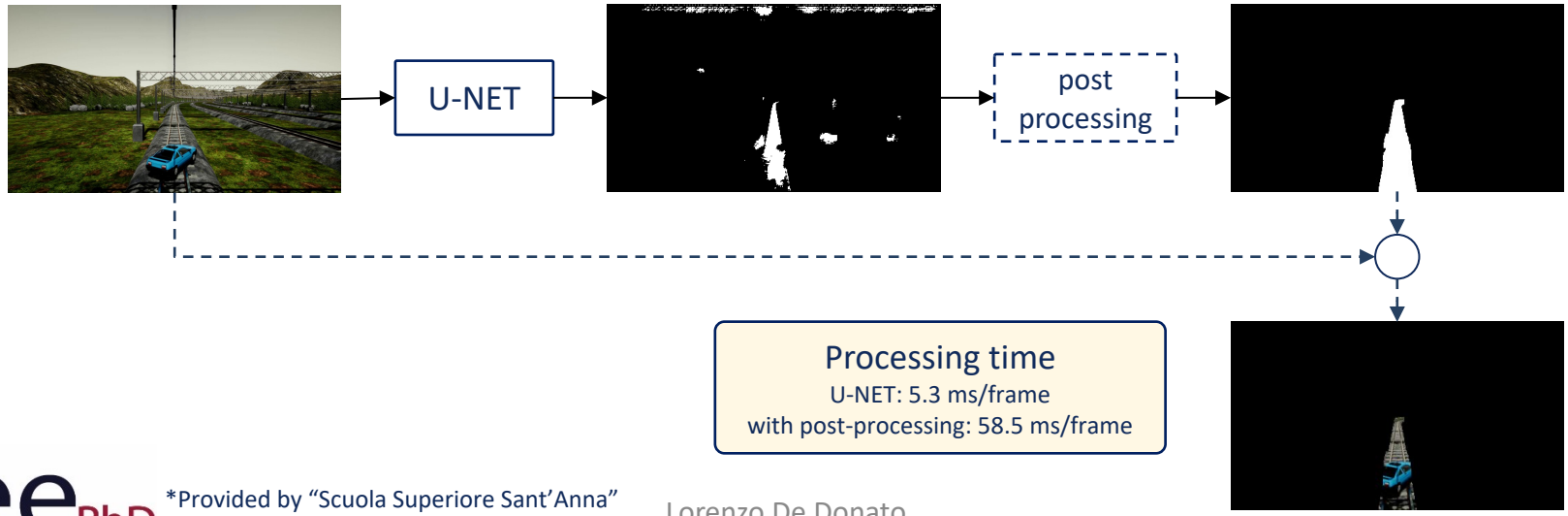
Phase 1: Training U-NET while coping with the data labelling problem

Best Performances

	Validation	Test
Loss	0.683448	0.683460
Dice Score	0.9956	0.9948



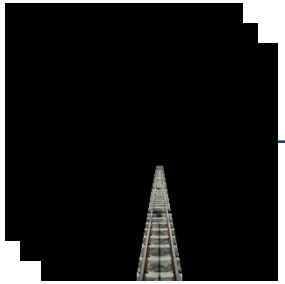
Phase 2: Test on fames with obstacles



*Provided by “Scuola Superiore Sant’Anna”

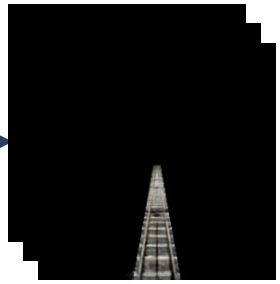
Anomaly Detection Module

Phase 1: Training



Non-Anomaly Frames
(Train: 1440 | Validation: 1600)

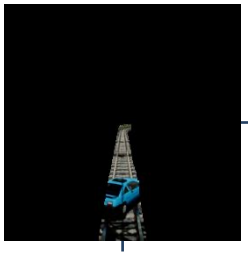
VQ-VAE
(SSIM Loss)



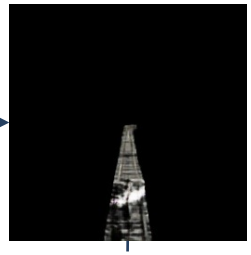
Reconstructed Image

Lowest Loss (1-SSIM) on the Validation Set: 0.01085

Phase 2: Test on fames with obstacles



VQ-VAE
(SSIM Loss)

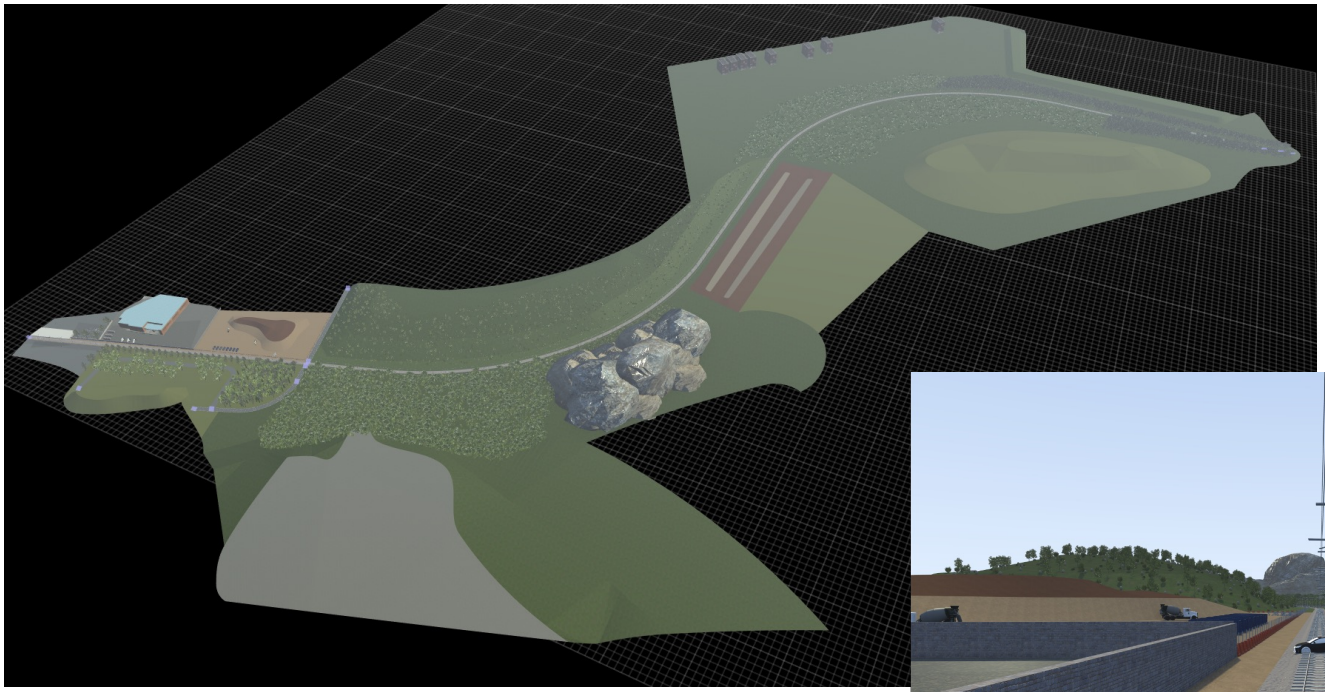


Processing time
VQ-VAE: 3.5 ms/frame
with comparison: 68.4 ms/frame

Comparison
(SSIM)

Rail “Simulator”

Scene built in RoadRunner



Sample Frame

Papers and Technical Reports

[J1]	Nikola Bešinović, Lorenzo De Donato, Francesco Flammini, Rob M.P. Goverde, Zhiyuan Lin, Ronghui Liu, Stefano Marrone, Roberto Nardone, Tianli Tang, and Valeria Vittorini, "Artificial Intelligence in Railway Transport: Taxonomy, Regulations and Applications", IEEE Transactions on Intelligent Transportation Systems, 2021 (Published).
[J2]	Ruifan Tang, Lorenzo De Donato, Nikola Bešinović, Francesco Flammini, Rob M.P. Goverde, Zhiyuan Lin, Ronghui Liu, Tianli Tang, Valeria Vittorini, and Ziyulong Wang, "A literature review of Artificial Intelligence applications in railway systems", Transportation Research Part C: Emerging Technologies, 2022 (Published).
[J3]	Lorenzo De Donato, Francesco Flammini, Stefano Marrone, Claudio Mazzariello, Roberto Nardone, Carlo Sansone, and Valeria Vittorini, "A Survey on Audio-Video Based Defect Detection Through Deep Learning in Railway Maintenance", IEEE Access, 2022 (Published).
[J4]	Lorenzo De Donato, Stefano Marrone, Francesco Flammini, Carlo Sansone, Valeria Vittorini, Roberto Nardone, Claudio Mazzariello, and Frédéric Bernaudin, "Intelligent Detection of Warning Bells at Level Crossings through Deep Transfer Learning for Smarter Railway Maintenance", Engineering Applications of Artificial Intelligence, 2022 (Submitted).
[C1]	Francesco Flammini, Lorenzo De Donato, Alessandro Fantechi, and Valeria Vittorini, "A Vision of Intelligent Train Control", Reliability, Safety, and Scurity of Railway Systems. Modelling, Analysis, Verification, and Certification (RSSRail 2022). Lecture Notes in Computer Science, 2022 (Published).
[C2]	Ruth Dirnfeld, Lorenzo De Donato, Francesco Flammini, Mehdi Saman Azari, and Valeria Vittorini, "Railway Digital Twins and Artificial Intelligence: Challenges and Design Guidelines". European Dependable Computing Conference (EDCC). Dependable Computing - EDCC 2022 Workshops. Communications in Computer and Information Science, 2022 (Published).
[D1]	Francesco Flammini, Stefania Santini, Lorenzo De Donato, and Valeria Vittorini, "Deliverable D2.1: WP2 Report on case studies and analysis of transferability from other sectors", published, 2022 (Published).
[D2]	Nikola Bešinović, Francesco Flammini, Lorenzo De Donato, Ruifan Tang, Zhiyuan Lin, and Valeria Vittorini, "Deliverable D3.1: WP3 Report on case studies and analysis of transferability from other sectors", 2022 (Published).
[D3]	Stefania Santini, Lorenzo De Donato, Valeria Vittorini, Francesco Flammini, and Rob M.P. Goverde, "Deliverable D2.2: WP2 Report on AI approaches and models", 2022 (Published).
[D4]	Francesco Flammini, Lorenzo De Donato, Zhiyuan Lin, Ruifan Tang, "Deliverable 3.2: WP3 Report on AI approaches and models", 2022 (Published).

J : Journal Papers | C : Conference/Workshop Papers | D : RAILS Deliverables

Next Year

Research activities during the next year will be oriented at:

Finalising proof-of-concept of Deep Learning techniques for:

- ❖ Smart Maintenance at Level Crossings
- ❖ Vision-based Obstacle Detection on Rail Tracks

While coping with:

- ❖ Limited data availability
- ❖ Trustworthiness concerns