



University of
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RAIL
SAFETY AND
STANDARDS
BOARD

Real-Time Railhead Friction Estimation Using Machine Learning: Development of An On-Board-Train Data Capture System.

Presented at the UKRRIN 2025 STUDENT CONFERENCE ON
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A WORLD
TOP 100
UNIVERSITY

PRESENTATION OUTLINE

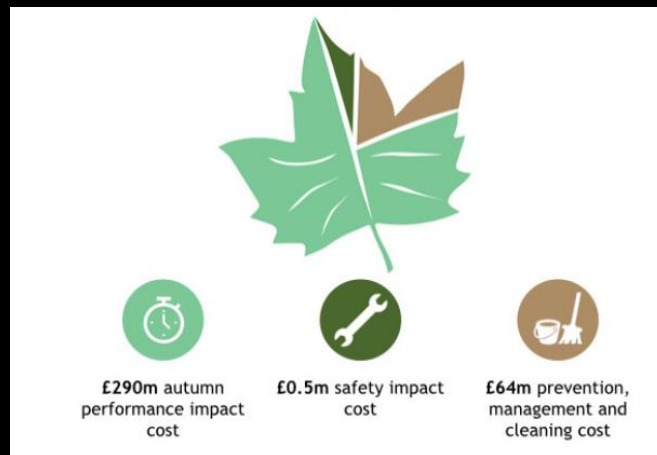
- Introduction
- Aim of Research
- Design process
- On-train data capture
- Camera box field test
- Discussion
- Conclusion and recommendation

INTRODUCTION

- Electrified rail provides greener modes of transportation

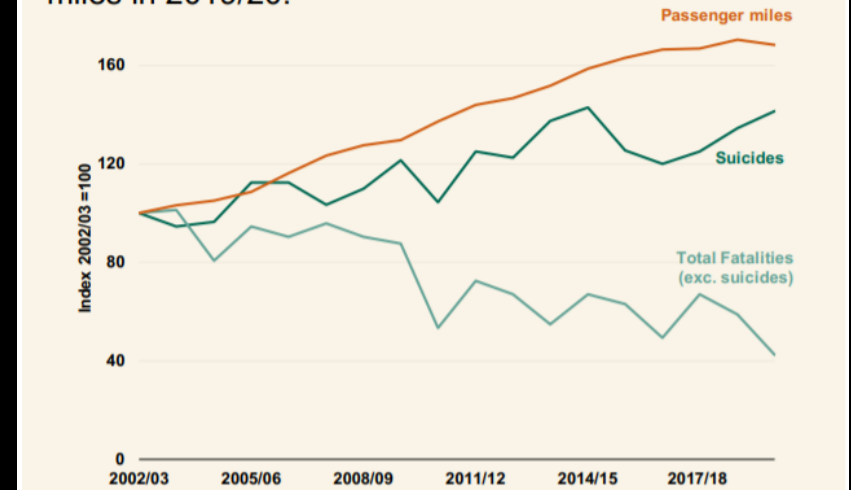


- Low Adhesion costs the UK rail industry approximately £355 million

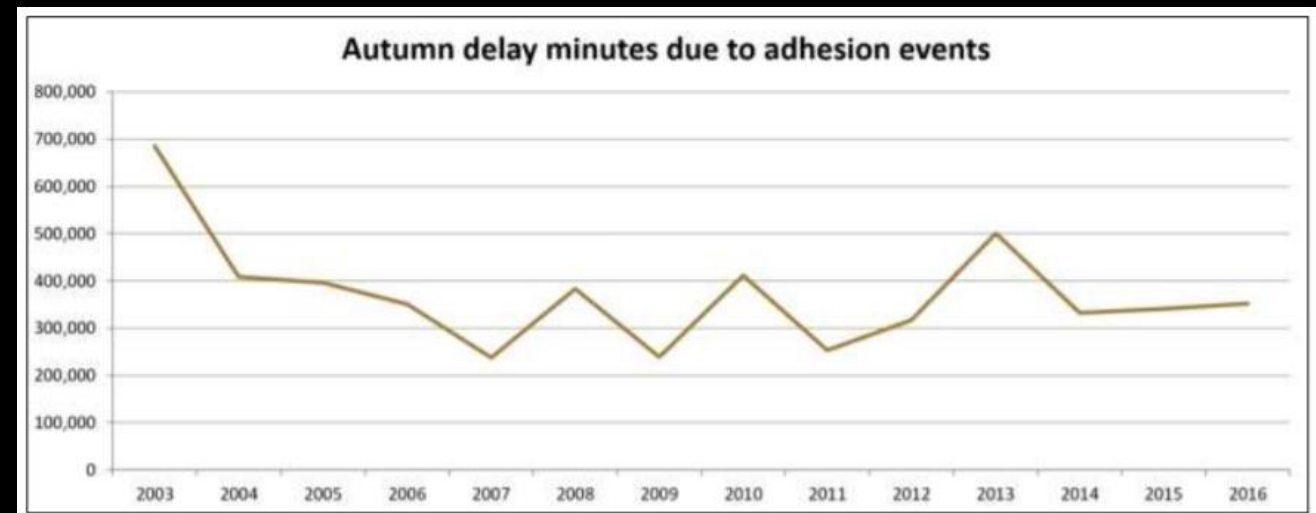


- Rail provides safer travel with only 40 incidents recorded in 2018/19 in the UK

Compared with other modes of transport, rail was the safest with 0.2 fatalities per billion passenger miles in 2019/20.

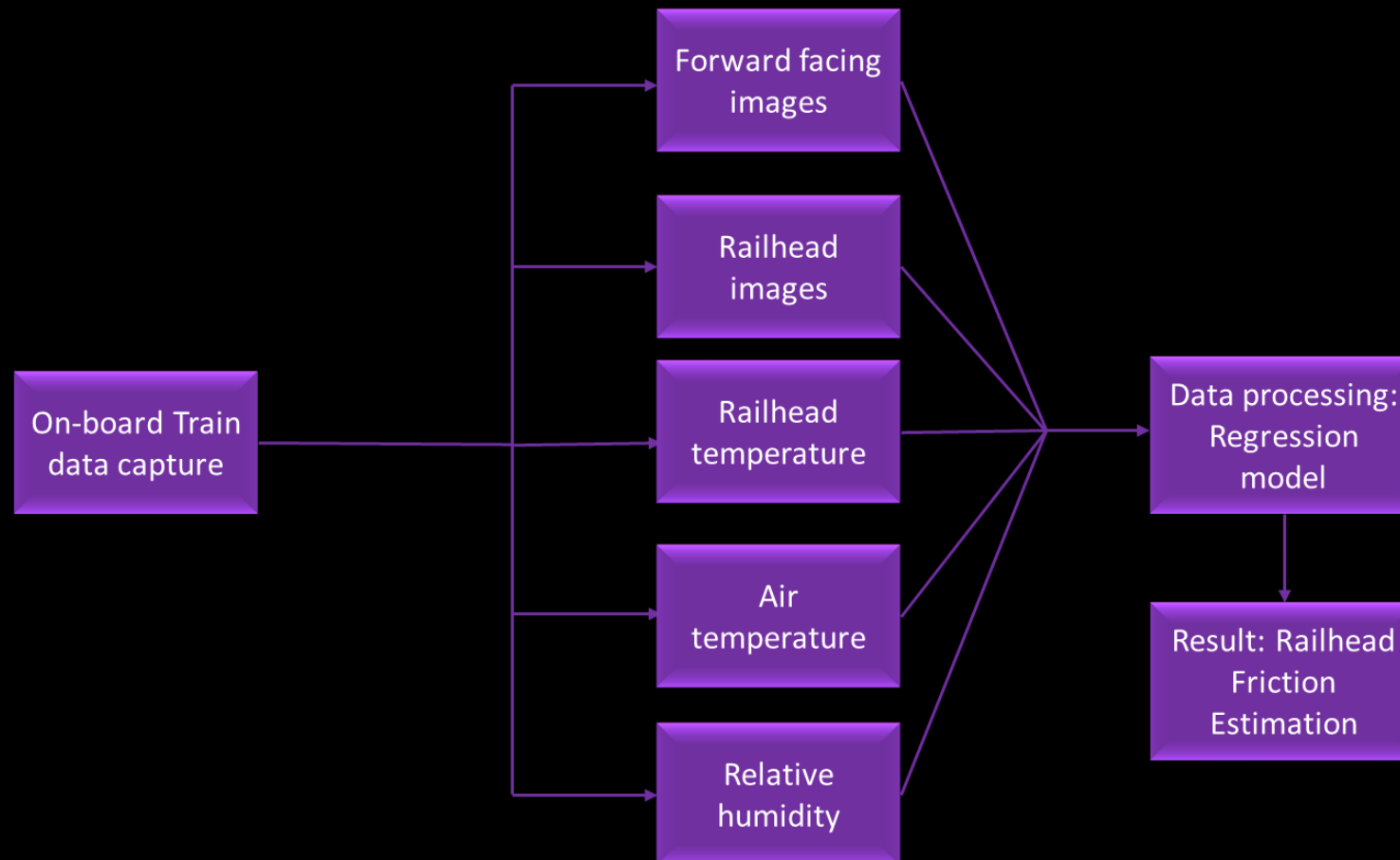


- Low adhesion between wheel/rail contact is one of the major causes of trains delays in the UK

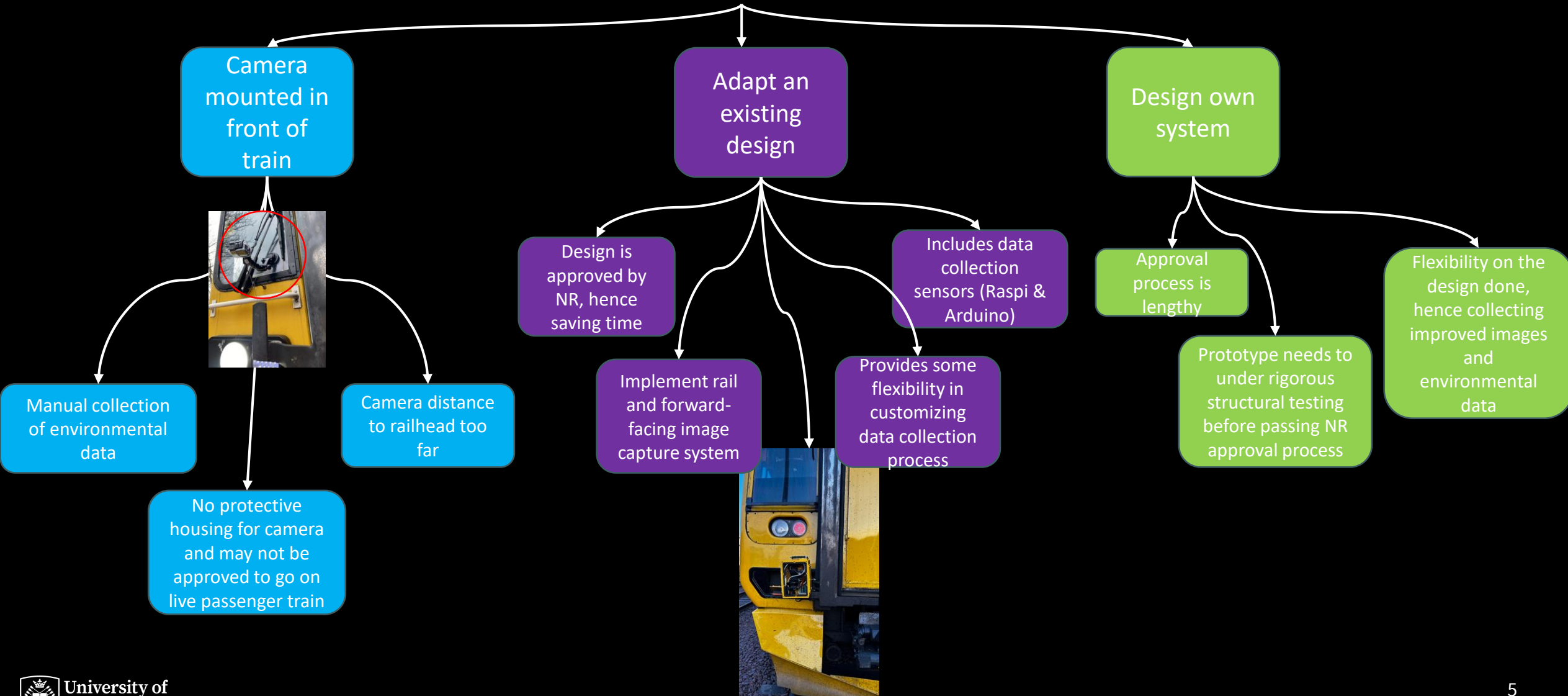


AIM OF RESEARCH

The aim of this work was to implement the friction estimation model (Neural network model) with a real-time data collection system that could be used on a train and use the tool to estimate friction from the collected data.

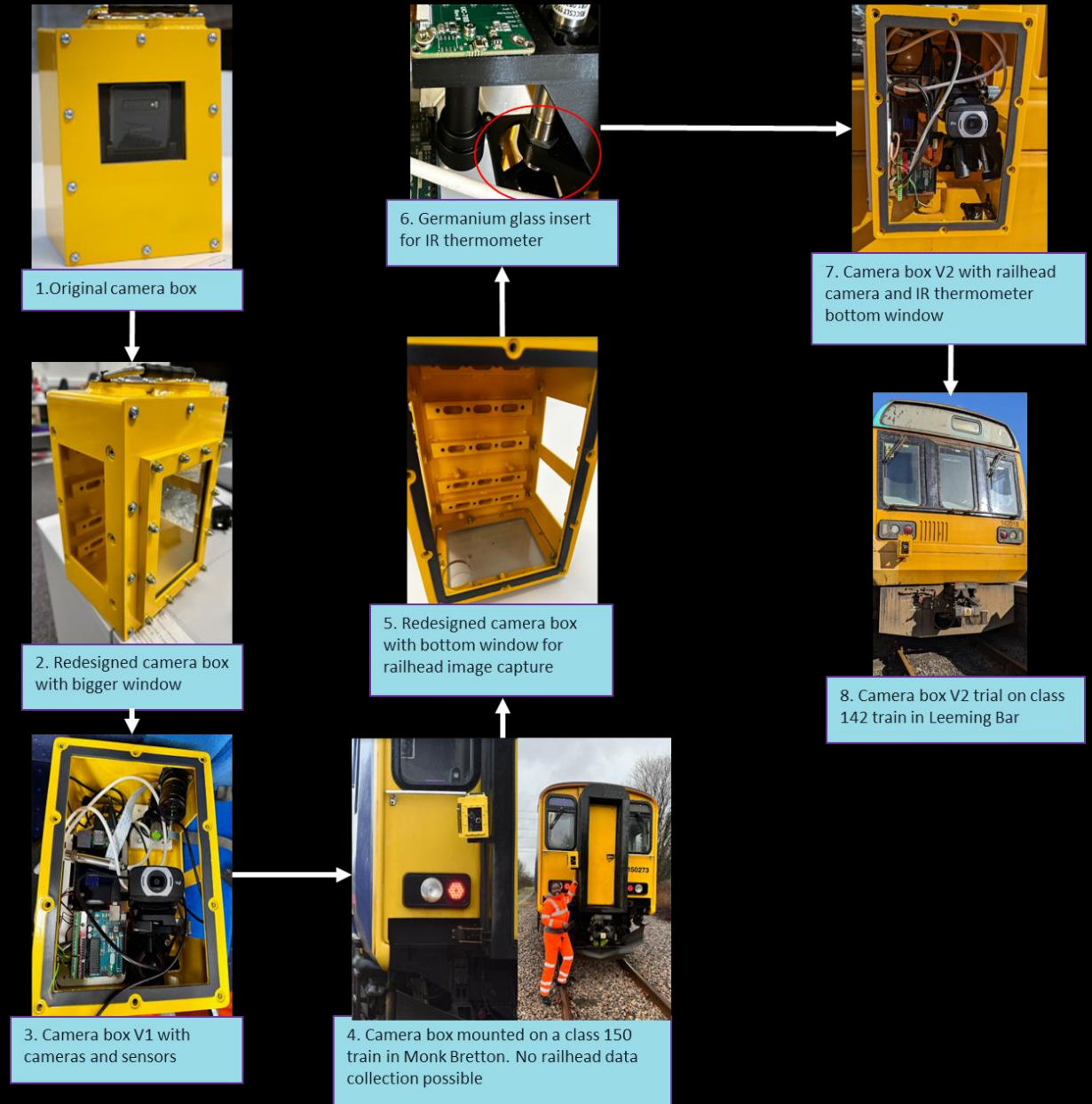


DESIGN PROCESS

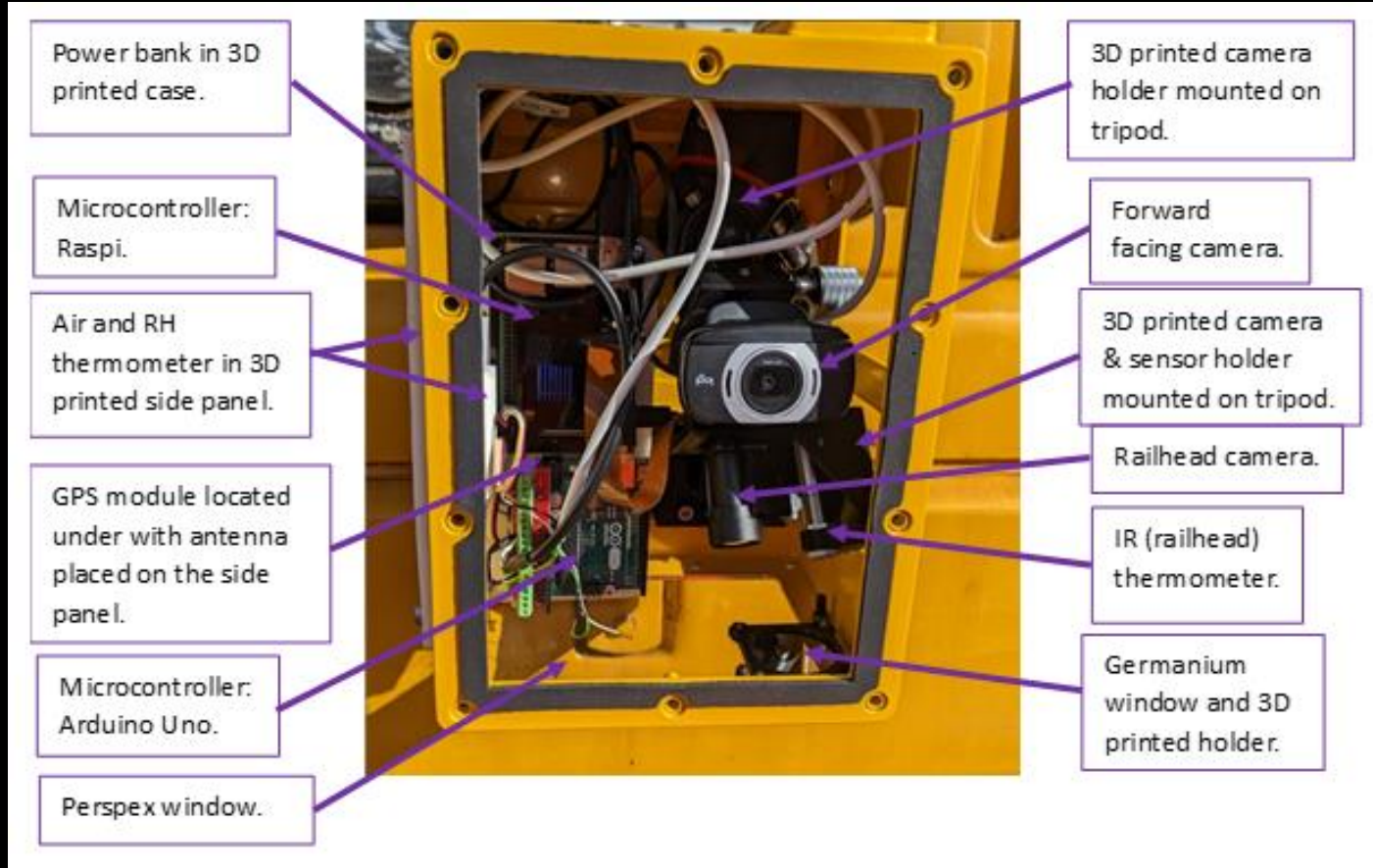


ON-TRAIN DATA CAPTURE

- The process followed to reach the final design chosen for the on-train data capture design, “The yellow camera box”.
- It underwent different modifications before reaching the final stage.



ON-TRAIN DATA CAPTURE (FINAL DESIGN)



- The camera box final design and its components
- Temperatures are validated using a hand-held Infrared thermometer (off-site) and Met Office “Weather Observation Website” (on-site)

CAMERA BOX FIELD TEST: METHODOLOGY

A total of 4 tests were carried out at Wensleydale Heritage Railway (WHR), UK to trial the camera box system. The WHR is located in North Yorkshire. The camera box was attached on a Class 142 lamp bracket.

Test No.	Date	Location/Route	No. of run	Distance	Railhead Condition	No. of Data points collected
1	14-03-2023	Leeming Bar depot	10	Short	Natural state	141
2	13-07-2023	Leeming Bar depot	7	Short	Natural state	357
3	14-07-2023	Leeming Bar- Leyburn (return)	2	Long	Natural state	2677
4	28-11-2023	Leeming Bar & Leeming Bar – Bedale (return)	10 & 2	Short & Long	Natural state and leaf layer	Camera box 1- 1228 Camera box 2- 971

CAMERA BOX FIELD TEST: METHODOLOGY



Short Run Tests

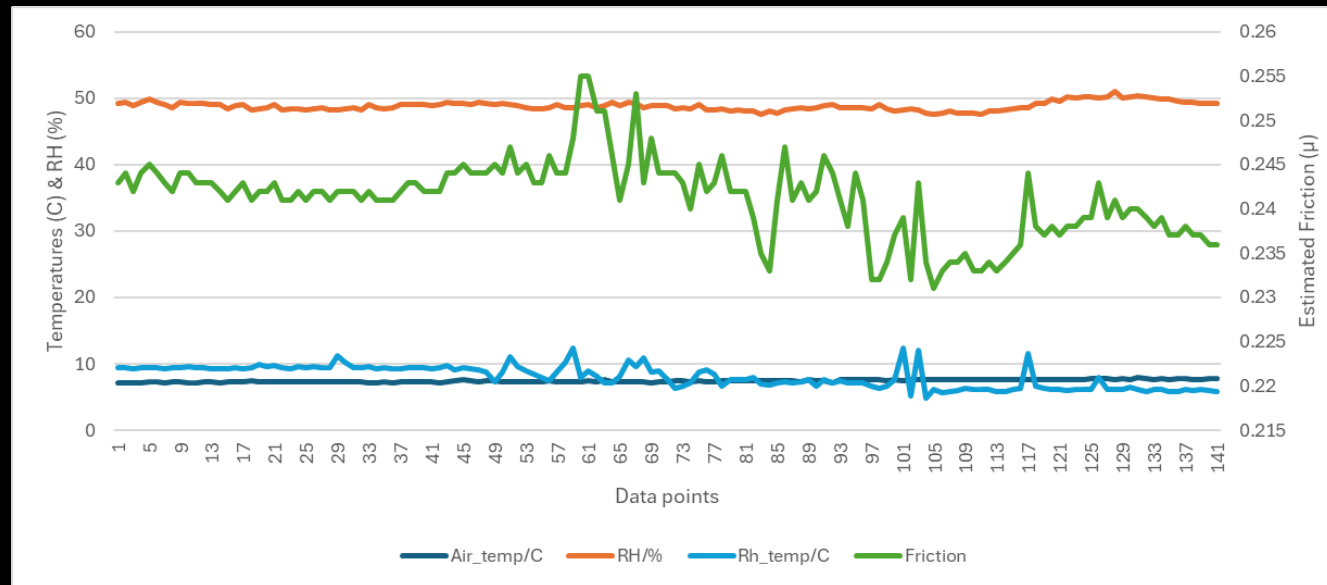
- WHR depot area over a short distance of approximately 260 metres
- Low speed of maximum 10mph
- Data collection rate of 1 per 2 seconds.

CAMERA BOX FIELD TEST: METHODOLOGY

Long Run Tests




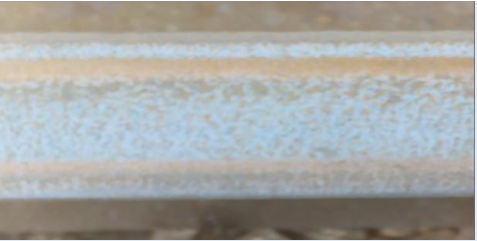




- Train journeys from one station to another.
 - Leeming Bar station, through Bedale (approximately 1.6 miles in distance) to Leyburn station (a total distance of approximately 11.5 Miles), return journey
 - Leeming Bar to Bedale station, return journey
- Train maximum speed of 30mph
- Data collection rate of 1 per 2 seconds.

CAMERA BOX FIELD TEST: RESULTS

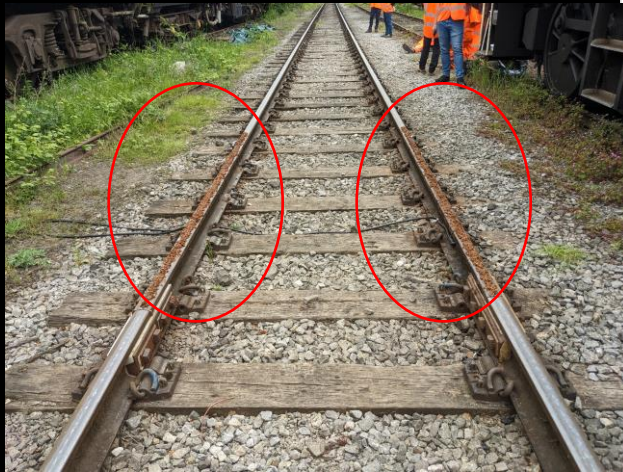


First test
(Short run)
carried out
with camera
box in WHR
on 14-03-23

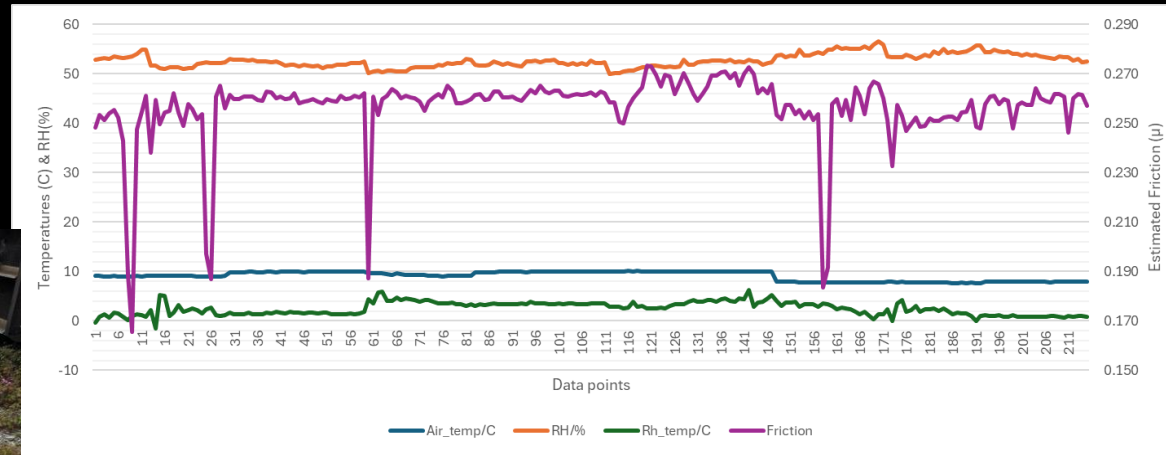
CAMERA BOX FIELD TEST: RESULTS

S/N	Forward facing Image	Railhead Image	Air Temp/°C	Rh Temp/°C	Rh/%	Estimated Friction (μ)
1			7.2	9.3	49.0	0.242
2			7.7	6.1	50.0	0.238
3			7.6	7.7	48.4	0.241
4			7.3	10.5	49.4	0.245

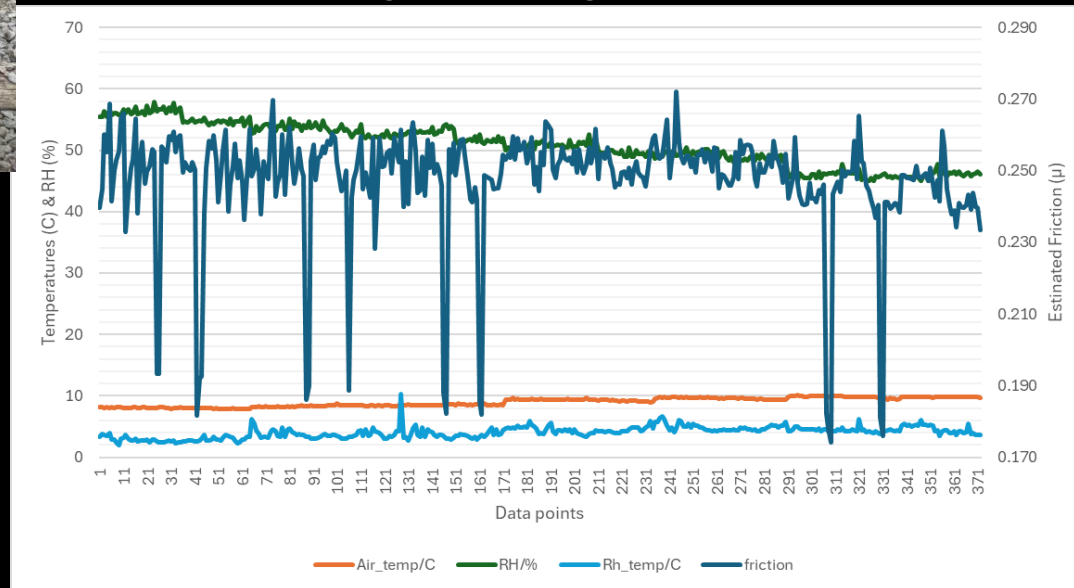
CAMERA BOX FIELD TEST: RESULTS



- Black leaf layer tests on 28-11-23 using dried Sycamore leaves



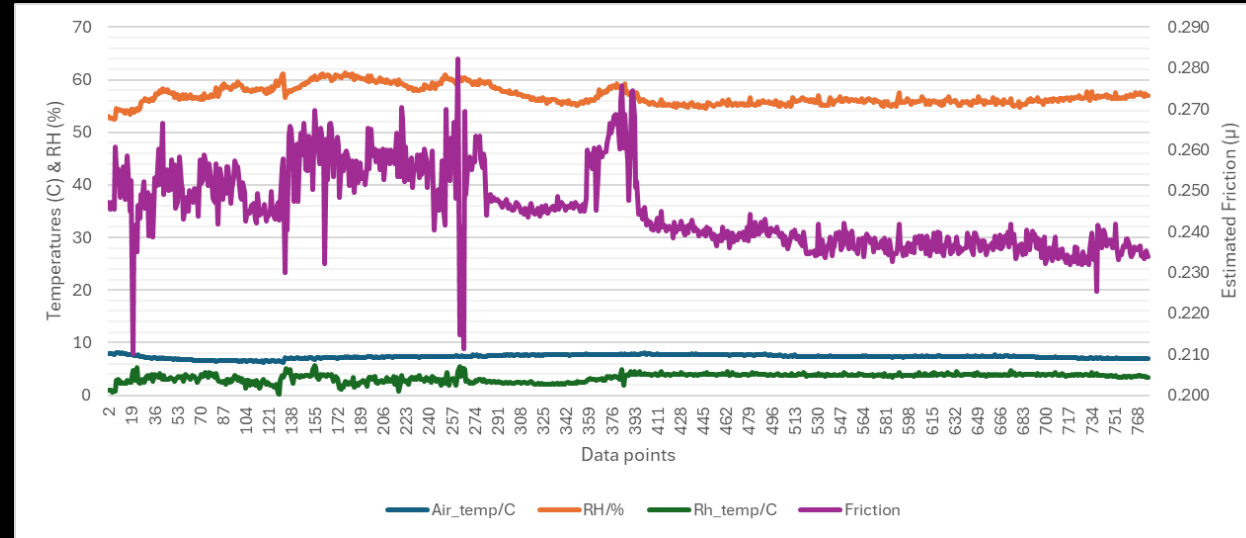
CAMERA BOX 1: Troughs showing effects of leaf layers created



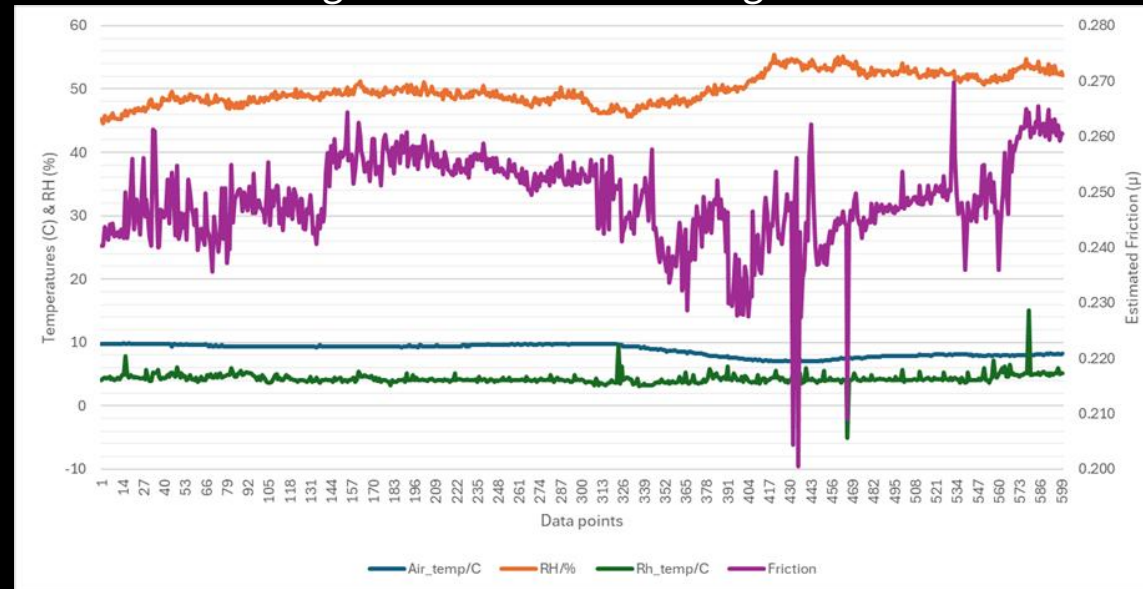
CAMERA BOX 2: Troughs showing effects of leaf layers created

- Two camera boxes were used; camera box1 in front of the train and camera box2 at the rear end.
- They captured railhead images from 2 different rail tracks (ie both opposite tracks).
- Camera box 1 estimated a maximum friction of 0.282 and minimum friction of 0.166
- Camera box 2 estimated a maximum friction of 0.272 and minimum friction of 0.174.

CAMERA BOX FIELD TEST: RESULTS








CAMERA BOX 1: Long run tests from Leeming Bar to Bedale



CAMERA BOX 2: Long run tests from Leeming Bar to Bedale






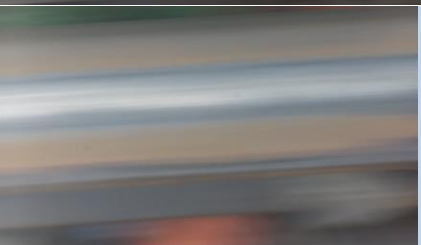
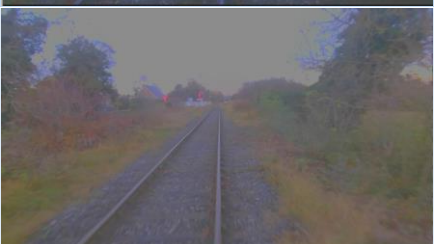
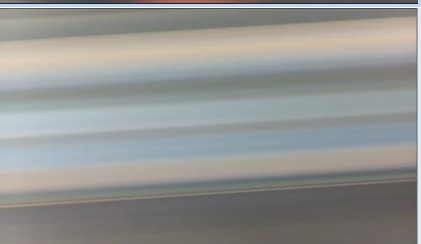


CAMERA BOX FIELD TEST: RESULTS

S/N	Forward facing Image	Railhead Image	Air Temp/°C	Rh Temp/°C	Rh/%	Estimated Friction (μ)
1			9.3	4.1	50.6	0.172
2			7.6	2.8	59.7	0.189
3			7.1	3.1	60.4	0.191
4			9.1	0.8	54.9	0.261

Data sample from
Camera Box 1,
Short run test. 28-
11-23

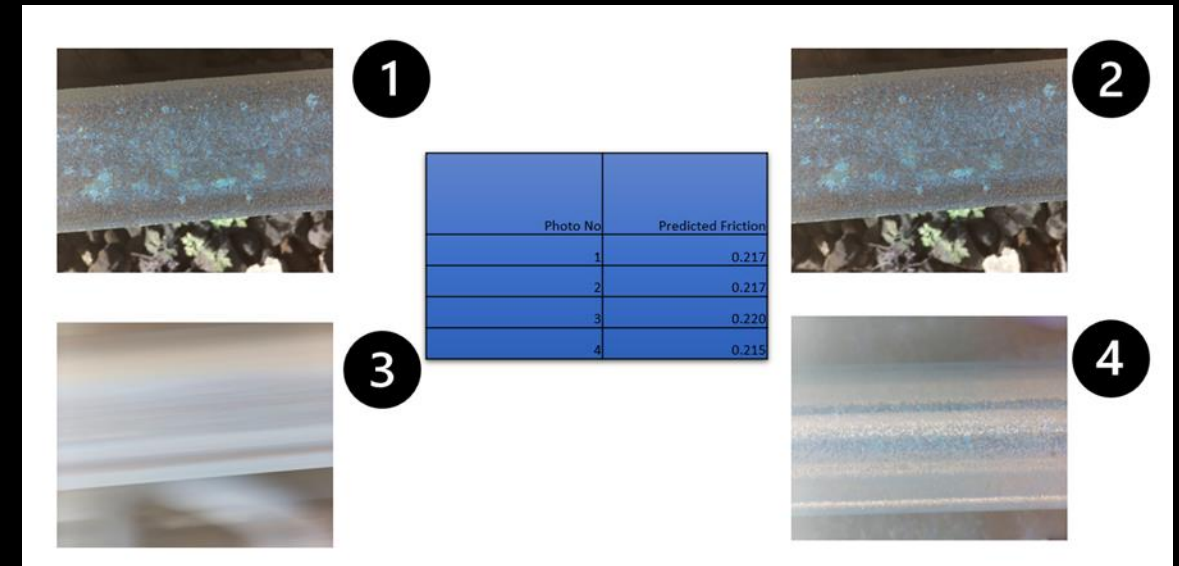
CAMERA BOX FIELD TEST: RESULTS

S/N	Forward facing Image	Railhead Image	Air Temp/°C	Rh Temp/°C	Rh/%	Estimated Friction (μ)
1			8.0	2.9	57.3	0.159
2			7.9	2.5	54.7	0.178
3			8.3	3.4	53.3	0.173
4			7.3	3.6	52.6	0.241

Data sample from Camera Box 2, Short run test. 28-11-23

DISCUSSION: TEST 14-03-23

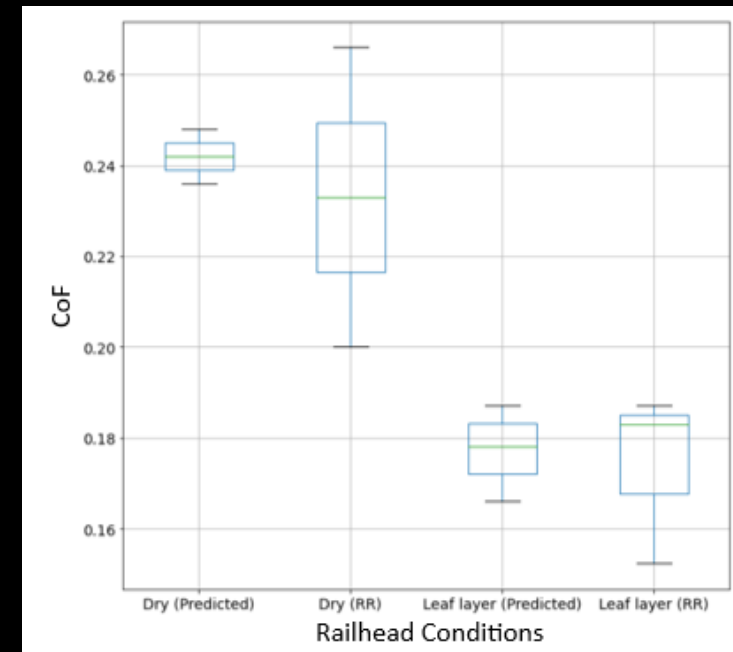
- The movement of the train during testing, caused some image blurriness. However, this did not affect the friction estimation tool's ability to process the images or determine friction coefficients, as it could still identify key colors.



- Forward-facing images remained clear enough to recognize vegetation and surroundings, and future work may include using strobe lights and specialized cameras to enhance railhead image quality.
- Friction estimates ranged from 0.231 to 0.255, consistent with the conditions at WHR. Railhead temperature sensors effectively captured real-time variations (4.8°C – 12.4°C), with sunlight exposure on certain rail sections causing temperature peaks, while shaded areas remained cooler, as confirmed on corresponding forward-facing images showing the surroundings.

DISCUSSION: TEST 28-11-23

- In the final trial, the two camera boxes recorded similar air temperatures ($8\pm 2^{\circ}\text{C}$), indicating consistent sensor performance. Railhead temperatures for Camera Box 1 ranged from -1.6°C to 6.2°C , with lower readings at the train's front. Camera Box 2 recorded 1.9°C – 7.9°C , slightly with higher readings at the trailing side where the railhead had been warmed by train wheels.
- The friction estimations from the camera box final short run test were compared to friction measurements by the Rivelin Rail tribometer. After six passes, the final estimated friction for the black leaf layer was 0.187 (box 1) and 0.182 (box 2), compared to the measured friction of 0.152. A second test showed similar trends, with estimated friction values closely matching tribometer readings, demonstrating the tool's potential for accurate friction estimation with additional training on black leaf layer data
- The estimated friction for the long run ranged between 0.227 to 0.282 and 0.227 to 0.270 with exclusion of the tunnel effects and railhead temperature anomaly for camera box 1 and 2 respectively.



CONCLUSIONS AND RECOMMENDATION

□ CONCLUSIONS

- The camera box demonstrated the feasibility of on-train data collection and friction estimation.
- Estimation outputs were consistent and sensitive to railhead conditions (e.g., wet/dry states).
- Friction estimations compared well with Rivelin Rail tribometer measurements.
- Current camera box setup is temporary due to varying rolling stock configurations.
- An integrated system near the wheel bogie is recommended for clearer railhead images.

□ RECOMMENDATIONS

- Use the camera box for other purposes: railhead monitoring, temperature/humidity tracking, vegetation management, and GPS-based event localization.
- Integrate tools into industry practices, focusing on specialized data collection and automated processing with collaboration from rail operators.
- Explore global adaptation to assess applicability across different railway environments and climates.

Thank you for listening