

Development of measurement and detection system for railway squeal noise

Arthur Vanlimbergen¹

¹Arthur Vanlimbergen, Belgium, arthur.vanlimbergen@student.pxl.be

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PXL Supervisor: Kristel Deckers

Project owner: Johan Odelius

University supervisors: Leevi Toratti, Matti Rantatalo

Abstract

Railway curve squeal is a disturbing tonal noise that can affect residents near curved railway sections. This paper presents the development of a cost-effective outdoor measurement system for event-based detection and documentation of railway curve squeal. The prototype combines acoustic sensing, visual event confirmation, environmental monitoring, local edge processing and wireless data transfer in one integrated measurement unit. Event-based data collection is used to capture and analyse relevant train passages without continuously storing or transmitting data. The system remains within the predefined cost limit of 10,000 SEK per unit, while still meeting the main functional requirements. The squeal detection algorithm reaches an accuracy of 85.25% on a labelled dataset of 2,000 audio files. During a limited field validation, all 10 evaluated measurements are classified correctly. The results show that the concept is technically feasible and provides a practical basis for scalable railway squeal monitoring and further research.

1 Introduction

Railway transportation systems are widely used in urban and interurban environments due to their efficiency and sustainability [1]. However, in curved track sections, a specific acoustic phenomenon known as railway curve squeal can occur under certain operational and environmental conditions [2]. This phenomenon is characterised by high-intensity tonal noise generated by friction-induced vibrations at the wheel–rail interface [2]. The emitted sound typically lies in a frequency range where human hearing is highly sensitive, making it particularly disturbing for residents living near railway curves [2] [3]. Environmental noise exposure has been linked to an increased risk of cardiovascular health effects [4].

In several urban areas, complaints are reported regarding this squealing noise during train passages [2] [3]. Although these disturbances are subjectively perceived, objective confirmation through reliable acoustic measurements remains limited [3]. Existing professional measurement systems are technically advanced but expensive [5]. Moreover, distributed outdoor monitoring systems must account for practical deployment constraints such as weather exposure, vandalism, and theft [5].

Environmental conditions further complicate accurate acoustic measurements. External factors such as rain, wind, traffic, and human activity introduce unwanted noise components that may interfere with the detection of railway squeal [6]. Since standardised acoustic measurements require clearly defined and well-documented measurement conditions, disturbances should be minimised during data acquisition rather than relying solely on post-processing afterwards [7]. In addition, measurement locations are often situated in remote areas without access to wired network infrastructure, which creates challenges for reliable data transmission [8]. Furthermore, privacy considerations impose additional constraints on data handling, as continuous transmission of raw audio recordings may not be acceptable in publicly accessible environments [9].

These technical, environmental, economic, and privacy-related constraints highlight the need for a cost-effective and robust measurement solution [5] [6] [9]. Therefore, the central research question of this study is: how can a cost-effective, outdoor-capable acoustic measurement system be developed and deployed to reliably detect and confirm railway curve squeal noise in urban environments under field conditions by the end of the project period?

To answer this research question, the study is structured around four objectives. First, the functional and environmental requirements for an outdoor acoustic measurement system are defined, including acoustic performance, durability, communication constraints, and privacy-related limitations. Second, a coherent system design is developed by integrating the selected sensors, processing unit, communication hardware, and power supply. Third, a proof-of-concept prototype is realised to detect relevant events, capture acoustic data, and process this data locally. Finally, the prototype is evaluated under representative field conditions to assess its operational performance and technical feasibility.

The methodology of this research consists of both theoretical and practical components. An initial literature study is conducted to establish an understanding of railway squeal noise acoustic measurement techniques and signal processing. In addition, Internet of Things-based monitoring, wireless communication, and privacy-preserving audio processing are considered to support remote and responsible data handling [9]. Based on these insights, system requirements are defined and translated into a prototype design. The prototype is then implemented and tested under realistic outdoor conditions to evaluate whether railway squeal events can be detected, recorded, and processed locally.

It is hypothesised that a cost-effective prototype measurement system can be developed using commercially available components, capable of operating autonomously in outdoor environments while maintaining sufficient acoustic accuracy. The prototype is expected to detect train passages, record audio signals, and process these locally to extract relevant information. Only relevant data are transmitted via wireless networks, thereby reducing bandwidth usage and addressing privacy concerns [8] [9]. As a result, the developed prototype is anticipated to demonstrate the feasibility of a scalable approach for monitoring railway squeal noise in urban environments.

2 Theoretical background

This section explains the acoustic and practical background needed to understand the development of the measurement and detection system.

2.1 Mechanisms of railway curve squeal

Railway curve squeal is a tonal noise phenomenon that can occur when a rail vehicle negotiates a curved track section [2] [3]. It is associated with friction-induced vibrations at the wheel–rail contact, where lateral creepage, angle of attack and contact conditions can lead to dynamic instabilities in the wheel–rail system [2]. Unlike general rolling noise, which is often broadband, curve squeal is characterised by clearly distinguishable tonal components [2] [3]. This tonal character makes curve squeal acoustically recognisable, but its occurrence is difficult to predict because it depends on a combination of vehicle, track, operational and environmental conditions [2].

2.2 Acoustic indicators for squeal detection

Because curve squeal is mainly characterised by tonal components, detection cannot rely only on overall sound pressure levels (SPL). A loud train passage does not necessarily contain squeal, while squeal is more specifically indicated by narrowband peaks in the frequency spectrum sustained at 1–10 kHz [3] [10]. For this reason, spectral and time-frequency analysis are useful for detecting curve squeal. One-third-octave band analysis can be used to describe the general distribution of acoustic energy over frequency bands, but it provides limited detail for identifying narrow tonal components. Short-time Fourier transform (STFT)-based features are therefore more suitable when the frequency and duration of tonal character need to be evaluated over time [3] [10]. Previous work on automatic wheel squeal detection shows that spectral analysis can be used to estimate parameters such as squeal level, duration and frequency content [10].

2.3 Field conditions affecting acoustic measurements

Field measurements of railway curve squeal are influenced by several factors that are less controllable than in laboratory conditions [3] [6] [7]. Background noise, weather, microphone placement, train speed, track condition and surrounding sound sources can affect the recorded signal [3] [6] [7]. Environmental factors such as temperature, humidity and surface conditions are also relevant because they can influence the friction conditions at the wheel–rail contact [2] [3]. Standardised railway noise measurement methods, such as ISO 3095 [7], provide procedures for obtaining reproducible and comparable exterior noise levels and spectra of

noise emitted by railbound vehicles. In this project, however, curve squeal monitoring also requires project-specific choices for sensor placement, event triggering, time synchronisation, environmental protection and data handling [3] [7]. These considerations define the technical context in which the prototype measurement system is developed.

The reviewed literature shows that railway curve squeal is characterised by narrowband tonal components, making overall sound pressure levels alone insufficient for reliable detection. Spectral or time-frequency analysis is therefore required, while outdoor measurements must account for background noise, weather, sensor placement and other field conditions.

3 Methods

At the beginning of the project, railway curve squeal is reported in urban railway environments, but objective confirmation through distributed acoustic measurements remains limited. The project is carried out at Luleå University of Technology, within the Department of Civil, Environmental and Natural Resources Engineering and more specifically within the Division of Operation and Maintenance Engineering. This division conducts railway curve squeal research in collaboration with Trafikverket, the Swedish Transport Administration responsible for Sweden's transport infrastructure. Within this research context, the bachelor project was positioned as a practical contribution to ongoing doctoral research on railway curve squeal by developing and evaluating a cost-effective field measurement system.

The problem definition is linked to two Sustainable Development Goals (SDGs). It relates to SDG 9.1, which focuses on developing quality, reliable, sustainable and resilient infrastructure, because objective monitoring of railway curve squeal can provide insight into an operational disturbance affecting railway infrastructure and its surrounding environment [11]. The project also indirectly relates to SDG 11.6, which focuses on reducing the adverse environmental impact of cities, because railway curve squeal can contribute to environmental disturbance in urban areas [12]. Therefore, the development of an outdoor acoustic monitoring system supports the collection of objective information needed to understand and evaluate this disturbance.

The first goal is to define the functional and environmental requirements for an outdoor acoustic measurement system. This is approached by studying railway curve squeal, acoustic measurement principles, outdoor measurement constraints and practical deployment limitations. Based on this information, requirements are determined for acoustic performance, environmental protection, communication, power supply, data handling and privacy. These requirements provide the basis for selecting suitable components and defining the measurement concept.

Based on these requirements, the next step is to develop a coherent system design for a cost-effective prototype. To reach this goal, the selected sensors, processing unit, communication hardware and power supply are combined into one measurement setup. The system design takes into account outdoor deployment, protection against environmental influences, autonomous operation, cellular data transfer and practical installation near railway infrastructure. This step defines how the different technical subsystems are integrated into one functional measurement system.

After the system design has been defined, a proof-of-concept prototype is realised for event-based acoustic monitoring. To reach this goal, the hardware setup and software framework are developed so that relevant events can be detected, acoustic data can be captured around these events, and measurement information can be organised for further analysis. The software workflow is designed to combine event triggering, temporary buffering, contextual data collection, local acoustic processing and selected data upload. This event-based approach limits unnecessary data collection while retaining the information needed to evaluate possible squeal events.

Finally, the prototype and the detection method are evaluated under representative conditions. To reach this goal, the evaluation is divided into an offline algorithm evaluation and a limited field validation. The offline evaluation is used to assess whether the selected acoustic features and classification method can distinguish between squeal and non-squeal audio examples. The field validation is used to evaluate whether the integrated prototype can detect events, capture relevant train passages, process audio locally and collect contextual information during outdoor operation. The project therefore evaluates both the technical implementation of the prototype and the

practical feasibility of using it for event-based railway noise monitoring.

4 Results

4.1 Development of the outdoor measurement system

A complete outdoor measurement system was developed to detect and document railway curve squeal events under field conditions. The system was designed as a compact edge-based setup that could be installed near a railway curve without requiring fixed network infrastructure. It combined acoustic sensing, visual event confirmation, environmental monitoring, local processing and wireless data transfer in one integrated system. An overview of the developed measurement system is shown in Figure 1.

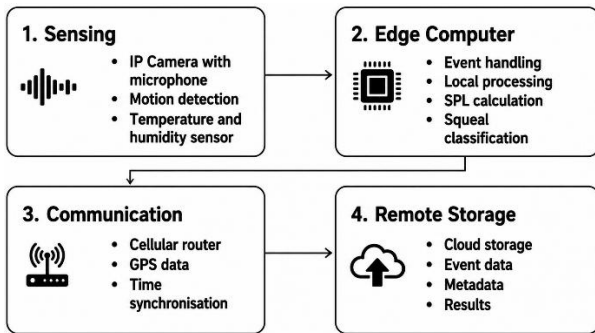


Figure 1: Functional overview of the measurement system

The final setup consisted of a Raspberry Pi edge computer, a weatherproof IP camera with an integrated microphone, a cellular router, a temperature and humidity sensor, and the required power and network connections. The IP camera was used for motion detection and for collecting audio and visual information during train passages. Its integrated microphone recorded audio at 48 kHz sampling rate, which was above the minimum sampling rate of 16 kHz required to analyse the high-frequency tonal components associated with railway squeal. The Raspberry Pi acted as the central processing unit by receiving motion events, capturing event data, processing audio and preparing the results for upload. The cellular router provided the local network, mobile internet connection, GPS information and the communication interface for the temperature and humidity sensor.

The hardware cost of the final measurement unit was evaluated because cost-effectiveness was

one of the design requirements. The agreed cost limit was 10,000 SEK per unit. The total cost of one complete unit was 7,580 SEK, corresponding to 75.8% of the allowed budget. This left a margin of 2,420 SEK, or 24.2%, below the agreed limit. The cost overview therefore showed that the proof of concept could be realised within the predefined financial boundary.

Because the system had to operate in outdoor conditions, the physical integration of the components was an important part of the result. The main components were selected and combined in a way that allowed local data processing while keeping the system transportable, protected against rain and dust exposure, and suitable for field deployment. The use of edge-based architecture reduced the need for continuous data transfer, because only relevant event data had to be stored and uploaded. This was especially important for a system using a cellular connection with limited mobile data availability.

In addition to the main measurement components, a radiation shield was designed and 3D-printed for the temperature and humidity sensor, as shown in Figure 2. This shield was added to reduce the influence of direct solar radiation and precipitation on the environmental measurements. At the same time, the design allowed airflow around the sensor, which is necessary for representative temperature and humidity measurements. The radiation shield therefore formed part of the environmental protection of the prototype and improved the practical usability of the temperature and humidity measurements during outdoor deployment.



Figure 2: Temperature and humidity sensor inside the radiation shield

The resulting hardware setup as shown in Figure 3 provided a functional basis for event-based railway noise monitoring. The complete unit had

dimensions of 470 × 405 × 130 mm and a total weight of 4.5 kg, making it transportable and suitable for field installation. It was able to capture audio, visual and environmental data around train passages. The final outdoor measurement system therefore provided a practical test platform for developing and evaluating the software framework and detection algorithm under field conditions.

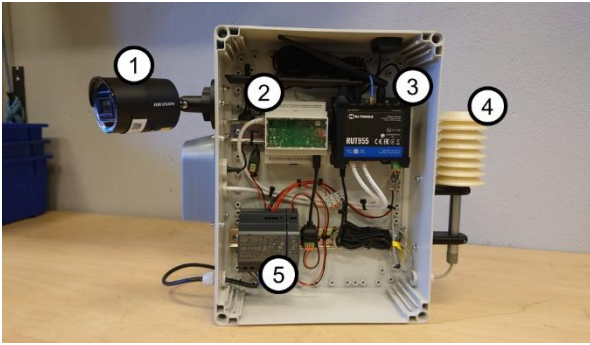


Figure 3: Final hardware measurement system
Main components: 1) Hikvision IP Camera, 2) Raspberry Pi, 3) Teltonika 4G router, 4) temperature and humidity sensor, 5) power supply

4.2 Implementation of event-based data collection

Event-based data collection was implemented to capture relevant train passages without continuously storing or transmitting data. Instead of continuously monitoring and storing data, the system was designed to react only when a relevant event was detected. This approach reduced unnecessary data handling and made the setup more suitable for outdoor measurements, where bandwidth, storage capacity and privacy requirements have to be considered.

Event creation was triggered by the motion detection function of the IP camera. When motion was detected near the railway track, the camera sent an event notification to the Raspberry Pi. This notification was used as the starting point for the data collection process. The Raspberry Pi then created a structured event in which all information related to the detected passage could be grouped together.

As shown in Figure 4, a temporary stream buffer was used to include acoustic information from shortly before and after the motion trigger. This was necessary because railway noise is not limited to the moment at which the train physically passes the sensor. Sound is already present before the train

reaches the measurement point and remains present after it has passed. The buffer therefore allowed the acoustic analysis to represent a complete train passage.

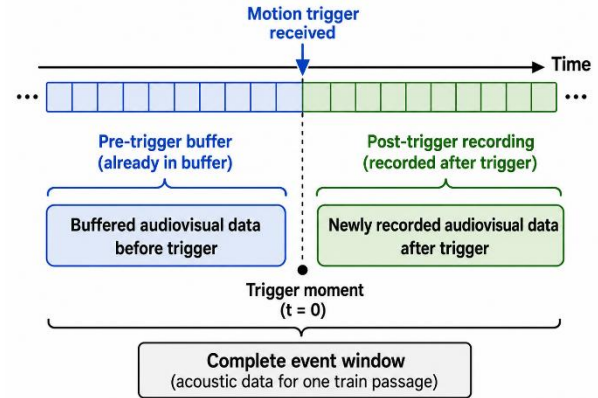


Figure 4: Stream buffer principle for capturing a complete train passage

For each event, the system combined the acoustic analysis results with contextual information. This included visual snapshot information for later interpretation, the most recent valid GPS information from the cellular router and environmental data from the temperature and humidity sensor. The visual snapshots were mainly included to support future train type identification. In this way, each event contained the necessary data for later analysis without relying on continuous raw recordings.

The implemented event-based data collection method formed the practical link between the outdoor measurement system and the later processing steps. It made it possible to handle train passages as structured events while avoiding unnecessary continuous data storage.

4.3 Development of the Python edge framework

A modular Python edge framework was developed to coordinate the local measurement workflow on the Raspberry Pi. The framework connected the physical measurement system with the event-based data collection process and the later analysis steps. It received event triggers, controlled the collection of contextual data, started the processing steps and prepared the resulting output. This software layer was necessary to make the different hardware and software components work together as one measurement system. The internal workflow of the Python edge framework is shown in Figure 5.

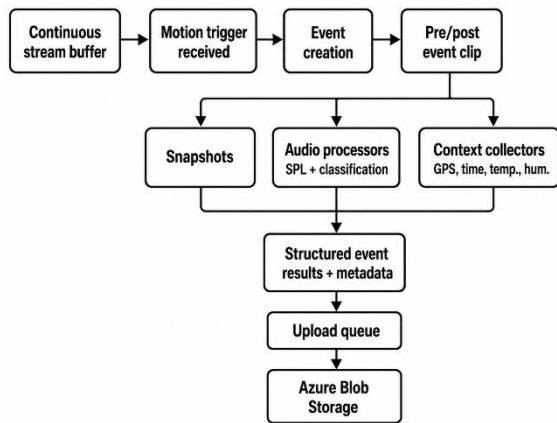


Figure 5: Workflow of the Python edge framework

The framework was developed as a modular software structure. A central controller coordinated the event workflow, while separate modules were responsible for specific tasks. The stream ingest module handled the camera stream and buffering process. Collector modules added contextual data, such as GPS information and environmental measurements. Processor modules analysed the event data and generated the acoustic results. Finally, uploader modules handled the transfer of selected results and metadata. An overview of the main module groups and their role in the event workflow is shown in Table 1. This modular structure made the framework easier to test, maintain and extend.

Table 1: Main module groups of the Python edge framework

Module group	Role in the workflow
Controller and trigger handling	Coordinates event creation after accepted motion triggers.
Stream and media handling	Maintains the stream buffer and creates event audio/video.
Snapshot handling	Captures visual snapshots during the event.
Collectors	Record GPS, time and environmental metadata.
Processors	Calculate acoustic metrics and classify squeal.
Queue and upload handling	Upload selected event data and metadata.
Configuration and cleanup	Load runtime settings and manage local storage.

The framework was made configurable by using a central configuration file. Important settings, such as the device identification, camera stream, trigger settings, collectors, processors and upload options, could be changed without modifying the source code. Existing Python libraries were used for specialised tasks such as signal processing, HTTP communication, sensor communication and cloud interaction. This reduced the need to implement low-level functionality from scratch and allowed the development to focus on the integration of the complete measurement workflow.

During the development of the Python edge framework, an AI-assisted agent workflow was used as a supporting development tool. The agent was guided through project-specific prompts and used to analyse the repository, implement code changes and perform initial tests before deployment. The generated code and test results were reviewed, adapted where necessary and verified before the changes were included in the deployed framework.

The framework was configured to run automatically on the Raspberry Pi. A Linux system service was used to start the software during boot and to keep the measurement workflow active during field operation. Logging was included to make it possible to inspect the behaviour of the system after a test. This automatic operation was important because the measurement setup had to function during unattended outdoor measurements.

The developed Python edge framework formed the software basis of the measurement system. It coordinated event-based monitoring and provided the structure for acoustic processing, sound pressure level calculation and field validation. The modular design also allows additional collectors, processors or upload methods to be added during later development.

4.4 Design of the railway curve squeal detection algorithm

A railway curve squeal detection algorithm was designed for local acoustic analysis of the recorded event audio. The algorithm was developed to analyse the temporary event audio on the Raspberry Pi and to determine whether a detected train passage contained curve squeal. Because the system was intended for edge deployment, the algorithm had to remain computationally lightweight while still focusing on the acoustic characteristics that distinguish curve squeal from general railway noise.

The detection approach was based on the tonal character of railway curve squeal. Instead of evaluating only the overall sound level of a train passage, the algorithm focused on detecting narrowband tonal components in the frequency content of the event. This design choice was important because curve squeal is mainly characterised by dominant tonal behaviour, while normal train noise contains more broadband components. The algorithm therefore searched for acoustic features that were more specific to squeal than the general sound level of a passing train.

The first processing step prepared the temporary event audio for acoustic analysis. The audio signal was filtered and divided into smaller analysis windows so that changes in the frequency content could be evaluated over time. This window-based approach made it possible to analyse the development of tonal components during the full passage instead of reducing the event to one overall value. As a result, the algorithm could take both the strength and the duration of tonal behaviour into account.

After preprocessing, a low resolution STFT was used to identify tonal activity in the event. This low-resolution approach was selected to reduce computational overhead on the edge device while still retaining sufficient frequency-domain information for tonal detection. The algorithm searched for dominant narrowband peaks within the relevant frequency range and extracted features related to their frequency, duration and prominence compared to the surrounding spectral content. This step was necessary to avoid classifying short random peaks or general broadband railway noise as curve squeal. The result of this step was a set of acoustic indicators describing the tonal behaviour of the event.

The extracted tonal features were used as input for a binary classification model based on logistic regression. This model was trained to distinguish between squeal and non-squeal events based on labelled audio examples. As a result, the final detector did not rely only on fixed threshold values, but combined several acoustic indicators into one classification result. The output of the algorithm consisted of a squeal or non-squeal classification together with supporting acoustic information that could be used for later interpretation. This processing flow is shown in Figure 6.

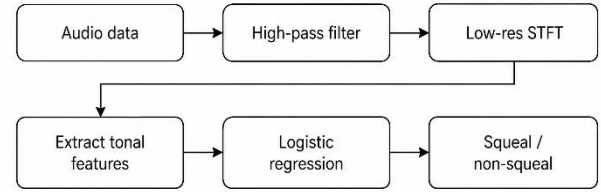


Figure 6: Acoustic processing flow for squeal detection

The designed algorithm formed the acoustic processing layer of the monitoring system. It converted temporary event audio into structured acoustic results without requiring raw audio to be retained after processing. This allowed the algorithm to be integrated into the privacy-aware and event-based monitoring workflow of the measurement system.

4.5 Detection performance and algorithm validation

The detection algorithm was evaluated in three separate steps. First, the model was trained and tested offline using a labelled dataset. Second, the exported model was integrated into the Python edge framework. Finally, a limited field validation was performed with the complete prototype during outdoor measurements. This separation was necessary because the dataset-based benchmark evaluated the detection algorithm itself, while the field validation evaluated the operation of the integrated measurement system.

The offline benchmark was performed using a labelled dataset containing squeal and non-squeal audio examples. This dataset was not recorded with the final prototype, but was used to evaluate whether the selected features and the logistic regression model could distinguish between the classes. The benchmark setup and classification results are summarised in Table 2.

Table 2: Performance of the squeal detection algorithm

Metric	Value
Dataset size	2000 audio files
Squeal examples	1000 audio files
Non-squeal examples	1000 audio files
Training set	1600 audio files
Test set	400 audio files
Accuracy	85.25%
Precision	79.75%
Recall	94.50%
Specificity	76.00%
F1 score	86.50%
True positives	189
True negatives	152
False positives	48
False negatives	11

The detector achieved an accuracy of 85.25% and an F1 score of 86.50% on the test set calculated in Formula (1). The high recall shows that most squeal examples were correctly detected. However, the lower specificity indicates that some non-squeal examples were incorrectly classified as squeal. This behaviour is acceptable for a proof-of-concept screening method, because missing actual squeal events would be more problematic than flagging additional events for later review. Nevertheless, the false positives show that further refinement is still required before the detector can be considered a fully reliable automatic classification system.

$$F1 = 2 \times \frac{(Precision \times Recall)}{(Precision + Recall)} \quad (1)$$

After the offline benchmark, the trained logistic regression model was exported and added to the Python edge framework. This allowed the Raspberry Pi to perform classification locally without retraining the model during field operation. During deployment, the framework used the temporary event audio data as input, extracted the time-frequency features and applied the exported model to classify the event as squeal or non-squeal. In this workflow, machine learning training was separated from edge deployment. The Raspberry Pi only performed feature extraction and inference during field operation.

4.6 Field deployment and system validation

The completed measurement system was deployed near Sunderby Sjukhus station in Södra Sunderbyn to evaluate its operation in an outdoor railway environment. The field deployment was

used to test the integrated measurement unit rather than one individual component, so the event-based workflow, Python edge framework, GPS information, environmental measurements and acoustic processing were evaluated together during the same measurement day. The measurement unit was installed next to the railway track at a distance of 4 m from the centre of the track. The location was suitable for testing the system, but natural railway curve squeal was not expected there. Therefore, squeal was simulated with a loudspeaker during part of the validation. In total, 10 validation measurements were evaluated: eight real non-squeal train passages, one loudspeaker-only simulated squeal measurement, and one real train passage combined with simulated squeal as shown in Figure 7.



Figure 7: Measurement system near Sunderby Sjukhus station with loudspeaker as squeal simulation

During the field validation, all 10 evaluated this result should be interpreted with caution because the validation was limited in size and partly based on simulated squeal. The offline benchmark evaluated the detector on a larger labelled dataset, while the field validation mainly assessed whether the integrated prototype could operate correctly during outdoor measurements. The measured train passages included different train types, such as commuter and cargo trains as shown in Figure 8. One iron ore train passage was too long for the configured capture window, so the complete passage was not captured. This limitation can be addressed by increasing the capture duration in the system configuration. More measurements at different locations and under different environmental and operational conditions, preferably including naturally occurring railway curve squeal, would be required for complete validation.



Figure 8: Measurement system during a commuter train passage

The field deployment also revealed practical limitations of the measurement setup. The original microphone gain setting caused saturation during train passages at the selected measurement distance, which showed that gain adjustment and SPL calibration were necessary before the measurements could be interpreted reliably. Overall, the test confirmed that the event trigger, local processing workflow and contextual data collection could operate together during outdoor use, but the limited test duration means that the results should be interpreted as a preliminary field validation rather than a complete system validation.

4.7 Calibration of the SPL calculation

The sound pressure level calculation was calibrated because the microphone did not provide calibrated sound pressure levels by default. The microphone was evaluated at the same measurement distance as used during the field deployment, namely 4 m from the centre of the track. At this relatively short distance from passing trains, the original microphone gain setting caused saturation during all recorded train passages. The microphone gain was therefore reduced from 60% to 5%. This adjustment was made to avoid saturation during high sound pressure levels while maintaining sufficient sensitivity for the acoustic analysis.

After the gain adjustment, the microphone output was compared with a laboratory reference level for stationary pink noise. The reference value was an A-weighted maximum sound pressure level (L_{Amax}) of 101.6 dB. With the reduced gain, the uncalibrated system measured an L_{Amax} of 86.5 dB. This resulted in a difference of 15.1 dB. Because the SPL calculation is based on pressure signal amplitude, this difference was converted to a linear calibration factor using $10^{(\Delta dB/20)}$. This resulted in a calibration factor of 5.6885, which was applied to

the audio samples before the SPL calculation. The calibration values and resulting correction are summarised in Table 3.

Table 3: SPL calibration values

Parameter	Value
Microphone gain after adjustment	5%
Reference L_{Amax}	101.6 dB
Uncalibrated L_{Amax}	86.5 dB
Difference ΔdB	15.1 dB
Calibration factor	5.6885
Calibrated L_{Amax}	101.54 dB

After applying the calibration factor, the measured L_{Amax} closely matched the laboratory reference value, as shown in Table 3. The remaining difference was 0.06 dB, which was within the predefined acceptable calibration margin of ± 1 dB. Therefore, the calibrated SPL calculation was considered sufficiently accurate for interpreting high-level train passage measurements in this prototype.

5 Conclusions

The aim of this project was to investigate how a cost-effective, outdoor-capable acoustic measurement system could be developed and deployed to detect and confirm railway curve squeal noise in urban environments under real field conditions. This research question was answered at proof-of-concept level. A complete measurement system was developed and tested in an outdoor railway environment, combining acoustic sensing, visual event confirmation, environmental monitoring, local edge processing and wireless data transfer. This demonstrated that an event-based and cost-effective approach for railway squeal monitoring was technically feasible within the scope of this project.

The developed prototype translated the functional and environmental requirements into an integrated measurement unit. The final setup consisted of a Raspberry Pi, a weatherproof IP camera with an integrated microphone, a cellular router, a temperature and humidity sensor, and the required power and network connections. The system was designed to operate without fixed network infrastructure and to process data locally before selected information was uploaded. The cost requirement was also met, as one complete measurement unit had a total hardware cost of 7,580 SEK, which was 2,420 SEK below the predefined limit of 10,000 SEK.

The event-based Python edge framework provided the software structure needed to interconnect the different parts of the system. Motion detection from the camera was used to create structured measurement events, while a temporary stream buffer allowed acoustic information from before and after the trigger to be included. Each event combined audio data, visual snapshots, GPS information, environmental measurements and acoustic processing results. This workflow reduced unnecessary continuous data storage and transmission, making the system more suitable for bandwidth-limited and privacy-aware field deployment.

The detection method provided usable proof-of-concept results. In the offline benchmark, the detector achieved an accuracy of 85.25% and an F1 score of 86.50% on the test set. The recall of 94.50% showed that most squeal examples were detected, while the specificity of 76.00% showed that some non-squeal examples were still incorrectly classified as squeal. During the limited field validation, all 10 evaluated measurements were classified correctly. However, these results were based on a small number of measurements and partly on simulated squeal, because naturally occurring railway curve squeal was not present at the test location. The sound pressure level calculation was also calibrated, resulting in an A-weighted maximum sound pressure level of 101.54 dB compared with a reference value of 101.6 dB.

The hypothesis was largely confirmed within the limits of the proof-of-concept validation. A cost-effective prototype was developed using commercially available components, relevant train passages were captured, and local acoustic processing was performed on the edge device. At the same time, additional measurements under more varied operational and environmental conditions are required before the system can be considered fully validated for long-term railway squeal monitoring.

Future work should focus on longer field deployments at locations where natural railway curve squeal is known to occur. The developed proof of concept can also provide a practical basis for ongoing doctoral research on railway curve squeal. In that context, the system could be used to collect additional measurements, test improved detection algorithms and develop a more permanent deployable version. If the concept is further validated and developed, it could support scalable measurement campaigns for railway squeal noise.

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