Sorter Monorail and Carrier Wheel Condition Monitoring and Reporting System for the APPS

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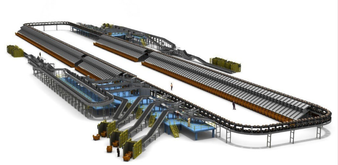
Objectives & Background

Background:

The USPS Automated Package Processing System (APPS) sorts packages using conveyors, scanners, and automated routing. This project monitors key mechanical components to improve reliability and reduce downtime.

Objectives:

- Monitor carrier wheel condition using vibration and rotational data
- Detect abnormal behavior (wear, misalignment, failure)
- Design a compact, non-intrusive device for monorail integration
- Provide actionable data to support maintenance decisions



Standards

- ISO 261
- ISO 965
- ASME B1.13M
- DIN 985
- SAE International J429
- ASTM International
- ASTM International D3165
- EN 50716:2023
- ISO/IEC 27001
- USPS Handbook MS-63
- B221
- SAE International AMS-QQ-A-200
- ISO 898-1
- ASTM International F568M
- ISO 10816
- ASTM International E756
- IEC 61508
- ASTM International D1002
- ISO 4587
- ASME Y14.5
- ISO 2768
- FGSV 304/5
- IEEE 3110
- ISO/AEC AWI 24940
- IEEE P3110/D7

Design Process

Hardware

Requirements

- Acquire/process/store images suitable for computer vision
- Acquire/process/store high-resolution vibration data
- Support real-time data collection and communication

Design Decisions

- Selected camera based on sensor size and shutter type/speed
- Selected triaxial vibration sensor for predictive monitoring
- Selected a distributed processing method for wheel monitor to balance data size and speed

Software

Requirements

- Process vibration and encoder data in real time
- Provide clear reporting and visualization for maintenance

Design Decisions

- Implemented FFT-based preprocessing on STM32 for efficient signal analysis
- Used machine learning models for detection and Grafana for visualization

Constraint

- Limited processing resources required distributed computation across STM32 and Raspberry Pi

Mechanical

Requirements

- Maintain secure mounting and proper sensor alignment
- Minimize vibration interference to ensure accurate measurements

Design Decisions

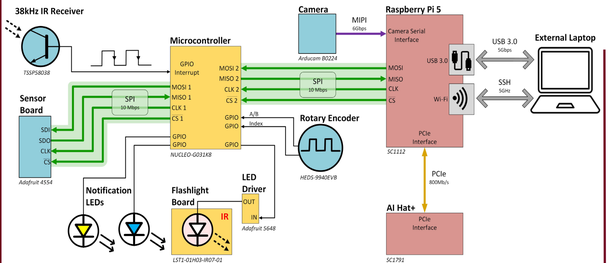
- Selected neoprene-based damping solution for vibration isolation
- Designed compact mounts and housings for integration with monorail system

Constraint

- Must not interfere with carrier motion or alter load-bearing structures

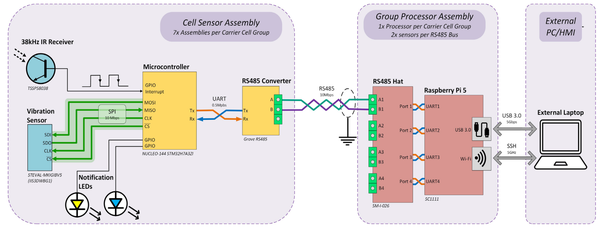
Hardware Layout

Rail Monitor



- Computer vision on Raspberry Pi is processes images from camera
- Location data from various sensors is processed by STM32
- Backup "jostle" vibration sensor detects rail damage that is missed by computer vision (unusual vibrations are flagged)

Wheel Monitor

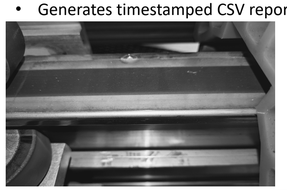


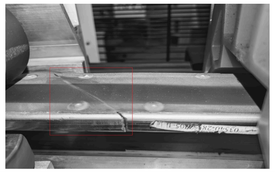
- Each carrier has a triaxial vibration sensor and STM32 for digital signal processing
- Each group of 7 carriers has a Raspberry Pi for final processing/communication with central data storage
- Each carrier "node" communicates with the Pi via RS485 (daisy chain pattern)

Computer Functions

Rail monitoring

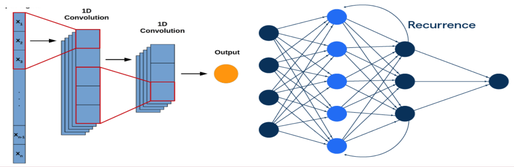
- Receives real-time vibration and encoder data from STM32 via SPI
- Captures rail images via MIPI CSI camera
- Performs OpenCV preprocessing (downscaling, contrast, and Gaussian noise reduction
- Runs YOLOv26 crack/rivet detection on Hailo-8 AI accelerator
- Fuses sensor data and tags detections with encoder location
- Generates timestamped CSV reports for technician HMI





Wheel Monitoring

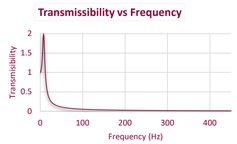
- Processes vibration data in real time using STM32H7A3ZI-Q
- Applies a Fast Fourier Transform (FFT) to the accelerometer data
- Converts the FFTs into spectrogram and stores them into Influx database
- The 1D CNN (Convolutional Neural Network) learns the vibrations patterns
- The RNN (Recurrent Neural Network) learn how those vibrations evolve over time
- Displays real time information about the conditions of the system using Grafana



Mechanical

Material Selection

Property	Aluminum	Sorbothane	Design Relevance
Elastic Modulus	86.9 GPa	N/A	Indicates material stiffness
Density	168 lb/ft^3	84 lb/ft^3	Weight for mount design
Hardness/ Brinell	95	N/A	Resistance to surface deformation
Tensile Strength	310 MPa	0.737 MPa	Reflects resistance to fracture



•Aluminum: lightweight, rigid, and easy to manufacture
•Sorbothane (40 durometer): high damping for vibration isolation
•Performance: ~70%+ vibration reduction at 27 Hz (protects sensor)

Calculations

Vibration Analysis

$$k_{stiffness} = \frac{F}{\delta} = \frac{2.5kg(9.81\frac{m}{s^2})}{0.00343m} = 24.5\ N$$

Natural Frequency

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{24.5\ N}{2.5\ kg}} = 8.5\ Hz$$

Frequency Ratio For Bearing Failure

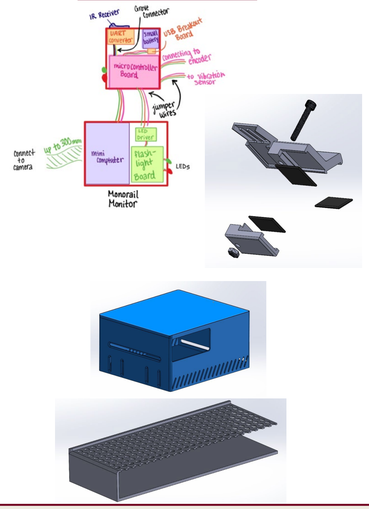
$$f > \sqrt{2}f_n \quad f > 1.414(8.5Hz) \approx 12\ Hz$$

$$r = \frac{f}{f_n} = \frac{27}{12} = 2.25$$

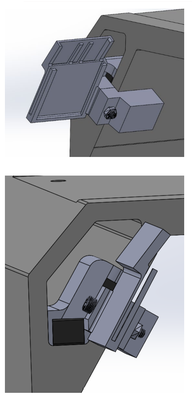
Transmissibility

$$T = \frac{\sqrt{1+(2\times 0.3\times 2.25)^2}}{\sqrt{(1-2.25)^2+(2\times 0.3\times 2.25)^2}} = 0.23$$

Prototyping



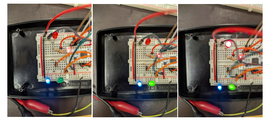
Mounting



Testing

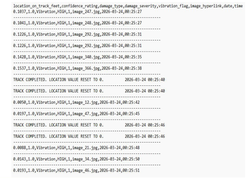
Hardware

- Sensor data acquisition and sampling
- STM32-Raspberry Pi communication



Software

- Signal preprocessing and data handling
- Visualization and reporting pipeline
- Testing of the ANNs (Artificial Neural Networks) is done using damaged and undamaged wheels

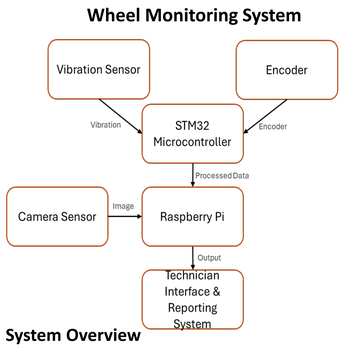




Mechanical

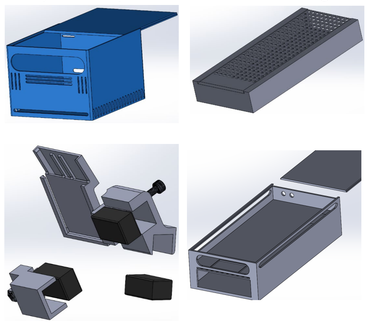
- Check for tolerances and fittings
- Mounting stability and alignment
- Vibration isolation effectiveness

Final Design



System Overview

- Systems collect vibration, rotation, and IR sensor data
- STM32 and Raspberry Pi perform real-time processing and analysis
- System outputs actionable data through a technician interface



Mechanical Overview:

- Mount made to be light and securely hold camera
- Hardware housing includes forced air cooling
- Neoprene rubber added to mount for vibration dampening
- Ease of access lids for all housing