On-Board Equipment Condition Monitoring

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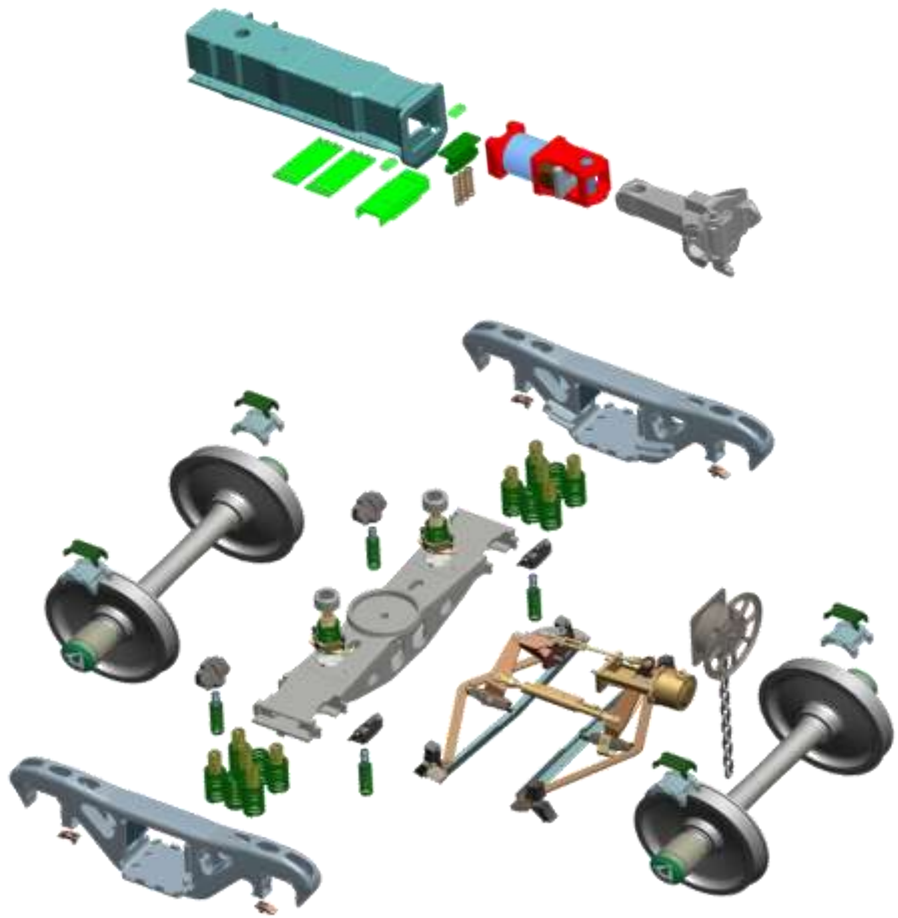
Agenda

1. Remote Asset Monitoring Overview
2. Condition Monitoring Framework
3. Condition Monitoring R&D
4. Status Monitoring R&D
5. Conclusions

Remote Asset Monitoring Platform

Monitor what we make



AmstedRail

IONX Platform

Condition Monitoring vs. Status Monitoring

Program Overview

Remote Asset Monitoring

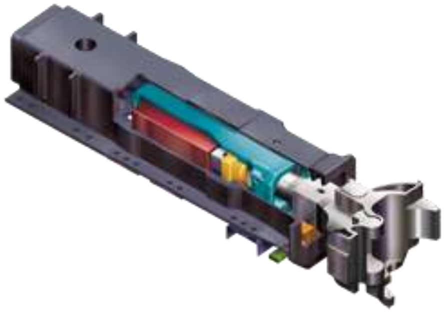
Condition Monitoring & Fault Diagnostics

Detect, ***Diagnose***, and ***Trend***

1. Fault Detection
2. Fault Classification & Diagnostics
3. Trending & Prognostics

Truck Condition

Draft Gear Condition



Bearing Condition

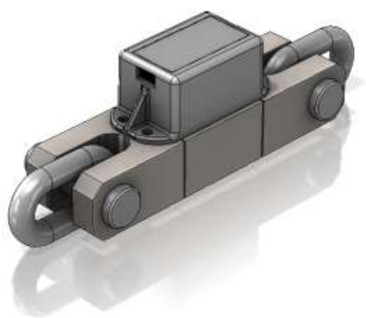
Remote Asset Monitoring

Status Monitoring

1. Vehicle On-Board Weighing
2. Handbrake Chain Force
3. Hatch/Gate Status
4. Airbrake Pressure

On-Board Weighing

Handbrake Status



Airbrake Pressure

[Measurement Specialties, Inc.]

Condition Monitoring Framework

CM Structure and Phases

Condition Monitoring Framework

Phase 1 – Component Reliability Study

1. Failure Modes
2. MTBF & MTTF
3. Wear-in vs. Wear-out failures

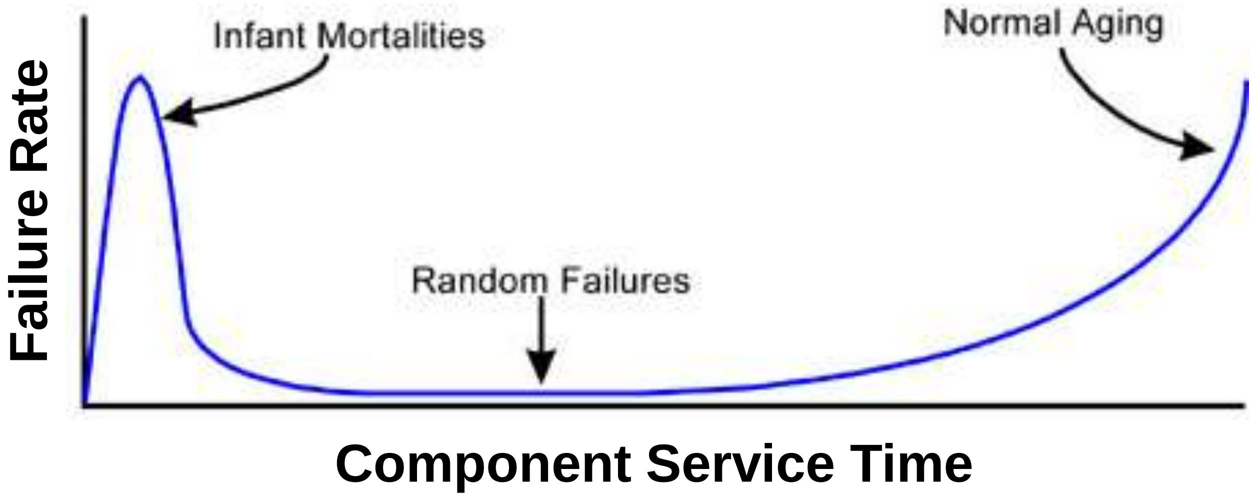
Phase 2 – Maintenance Strategy Survey

1. Component size & cost
2. Redundancy
3. Replacement cost/access
4. Safety critical?
5. **Is a CM-based program needed?**

Condition Monitoring Framework

Why Condition Monitoring?

1. Maintenance when **required**
2. Unnecessary maintenance avoided
3. Extends useful life



Condition Monitoring Framework

Phase 3 – Creating a Condition-Based Strategy

Fault Detection Strategy

- **Measurand** – acceleration, displacement, temperature…
- **Experimentation** – lab & field testing
- **Transducer Selection**
- **Acceptance Limits**

Diagnostics

- **Classification of faults**
- **Modeling** & **Experimentation**
- **Time** & **frequency domain analysis**

Prognostics – can the remaining life be predicted?

Impact Detection & Draft Gear Health

Condition Monitoring Research

Impact Detection & Draft Gear Health

Goals

1. **Detect over-speed/over-force impacts**
2. **Diagnose the health of the draft gear**

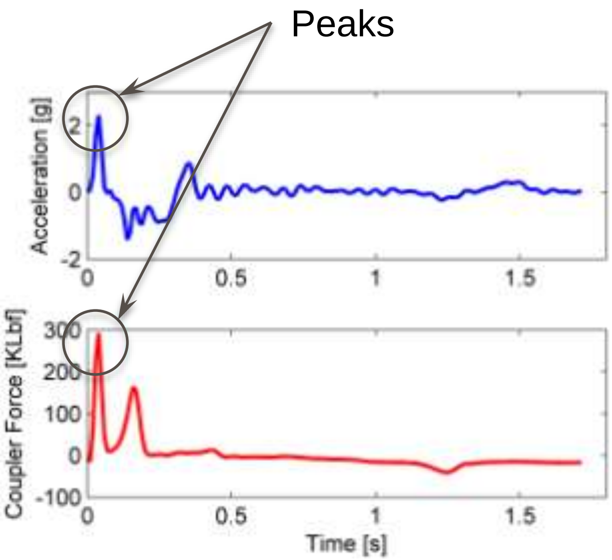
Approach

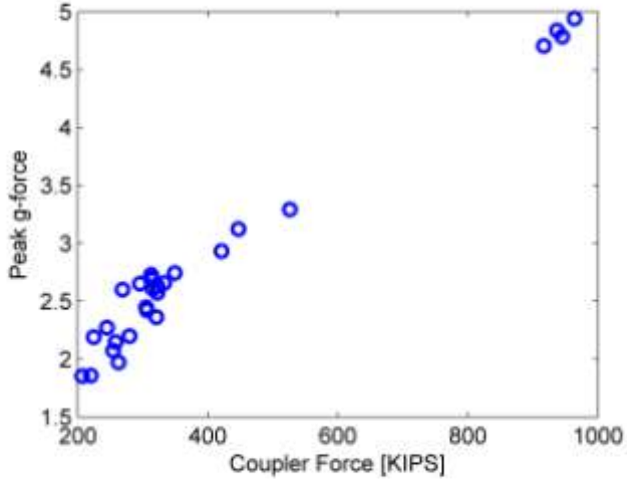
- **Measurand –** acceleration (g's)
- **Transducer –** MEM's inertial sensor
- **Acceptance Limits** – coupler force
- **Experimentation** – coupling events at test facility

Impact Detection & Draft Gear Health

Peak Coupler Force vs. Peak Car-body Acceleration

1. Data **pre-processed** to capture rigid body dynamics
2. Least-squares fit of force vs. acceleration
3. Prediction uncertainty on the order of ± 200 KIPS



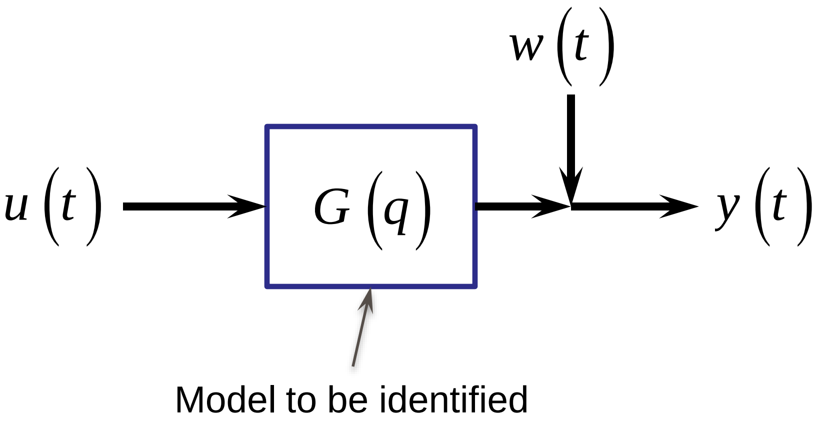


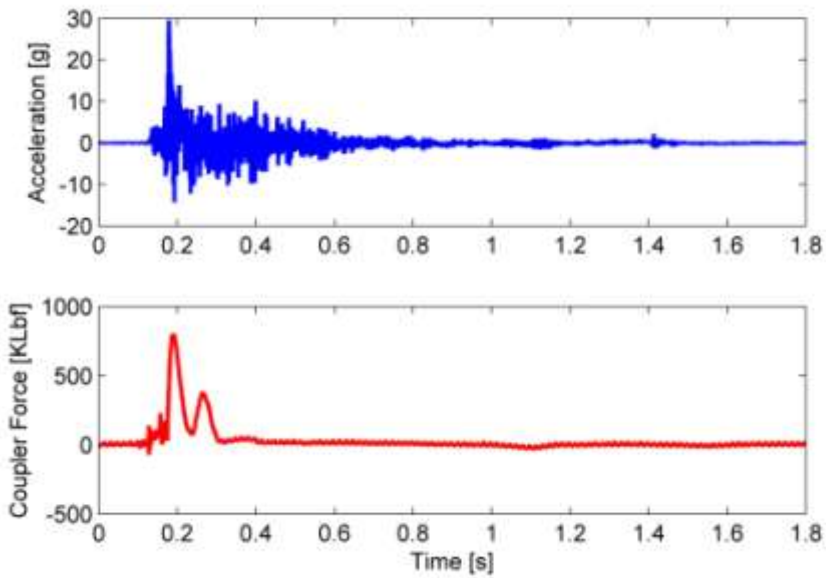
Impact Detection & Draft Gear Health

Black Box System Identification

1. Collect input/output data
2. Pre-process data
3. Choose/create model
    1. ARX Models
    2. State-space Models
    3. Neural Networks
4. Validate Model

Minimal insight into physics required

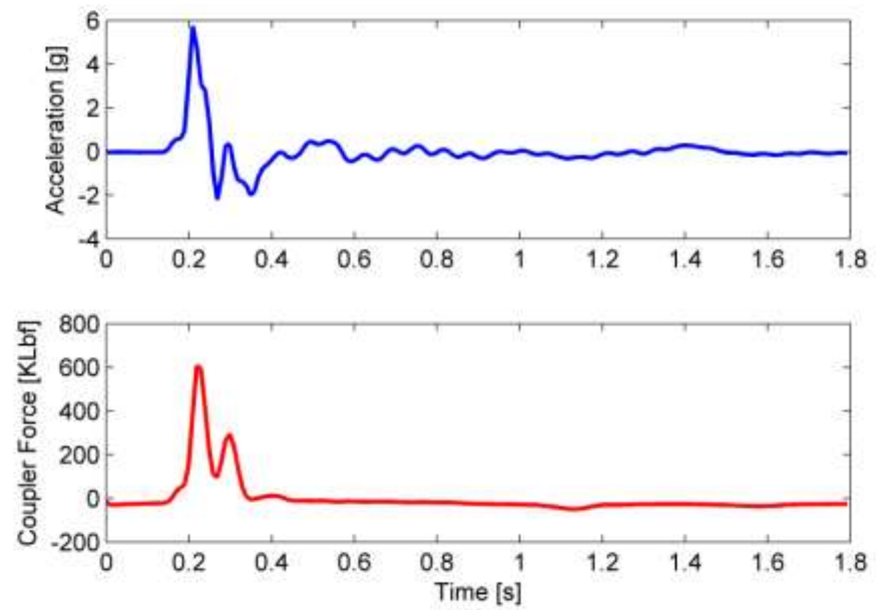


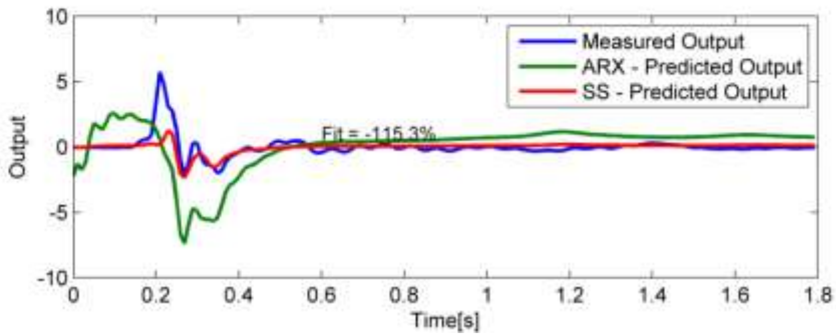


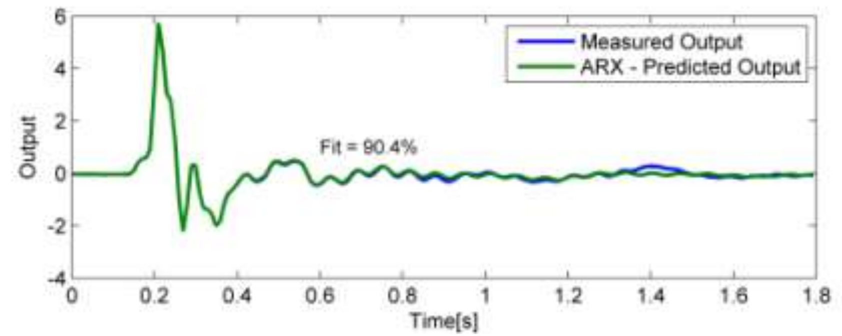
Impact Detection & Draft Gear Health

Parametric Model Creation

1. Test model structures
2. Start with low order
3. Choose <u>simplest</u> model with best performance

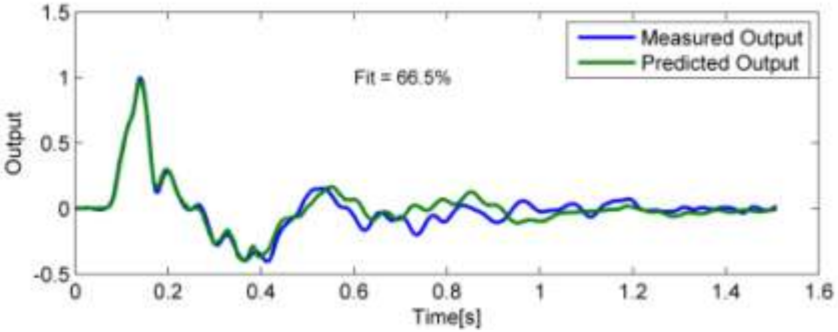




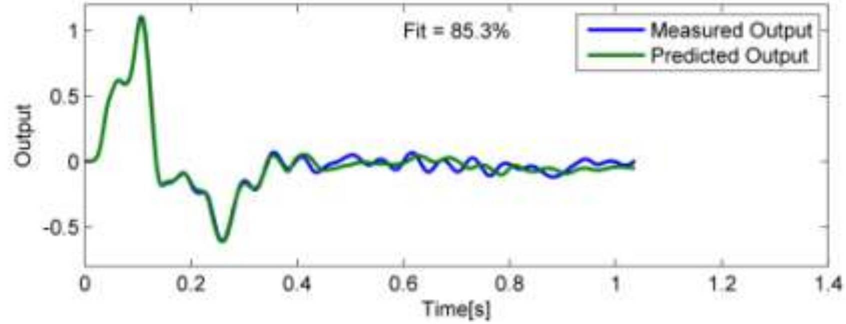


Impact Detection & Draft Gear Health

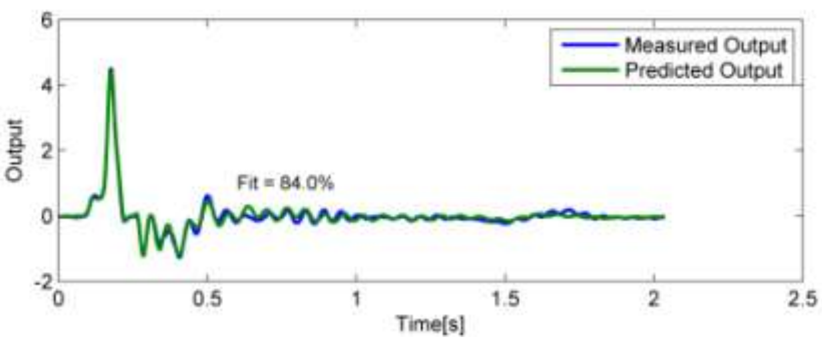
Model Validation with Fresh Data



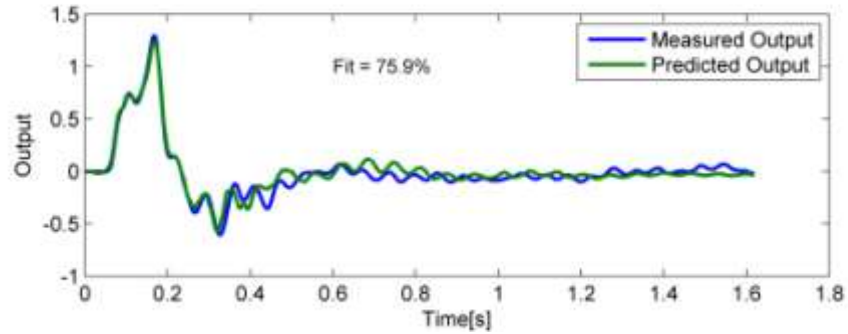
1 mph Coupling



2 mph Coupling



8 mph Coupling

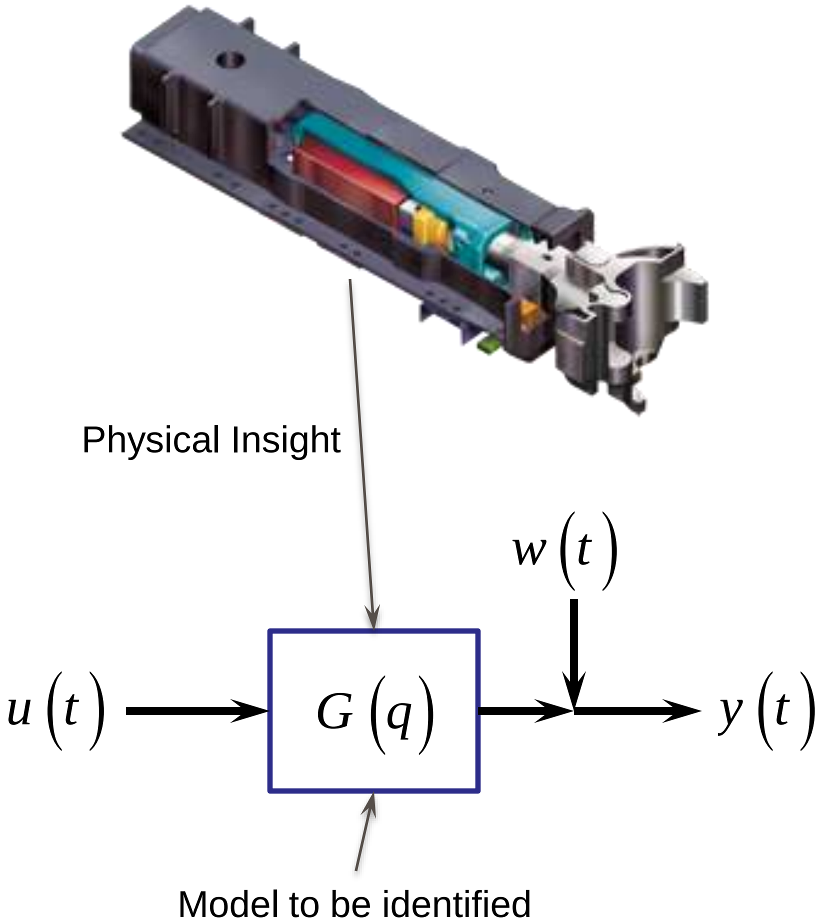


4 mph Coupling

Impact Detection & Draft Gear Health

Future Work and Potential

1. Apply physical meaning to model parameters
2. Connect identified model and mathematical models
3. Monitor degrading conditions
4. Real-time intra-train force prediction



Hunting Detection & Vehicle Dynamics

Condition Monitoring Research

Hunting Detection & Vehicle Dynamics

Goals

1. **Detect hunting and vehicle instabilities**
2. **Diagnose the health of the truck system**

Approach

- **Measurand –** acceleration (g's) or angular rotation rate
- **Transducer –** MEMS inertial sensor
- **Acceptance Limits** – dependent upon application
- **Experimentation** – track testing

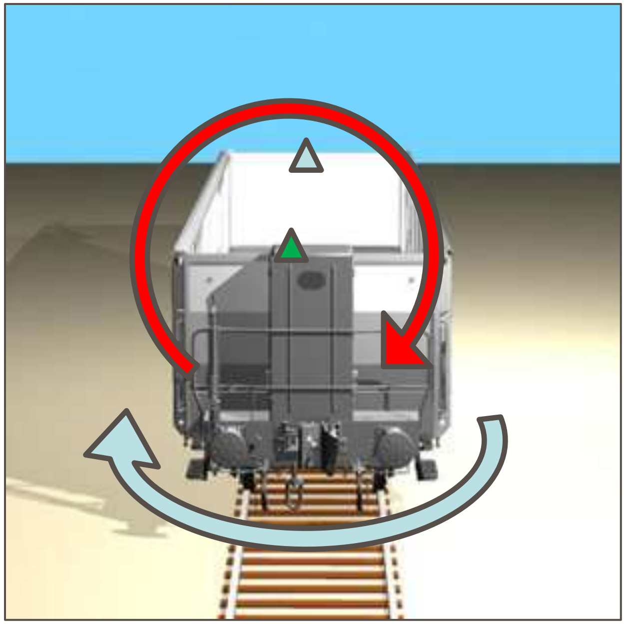
[ST Microelectronics]

Hunting Detection & Vehicle Dynamics

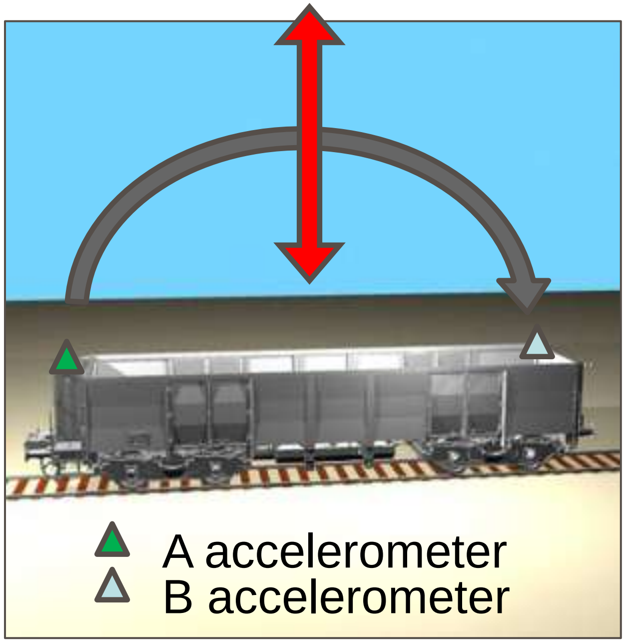
Rigid Body Modes

1. Quantifiable with inertial sensors
2. A and B-end sensors capture all modes
3. Other locations possible with 6 DOF sensor

Roll & Yaw



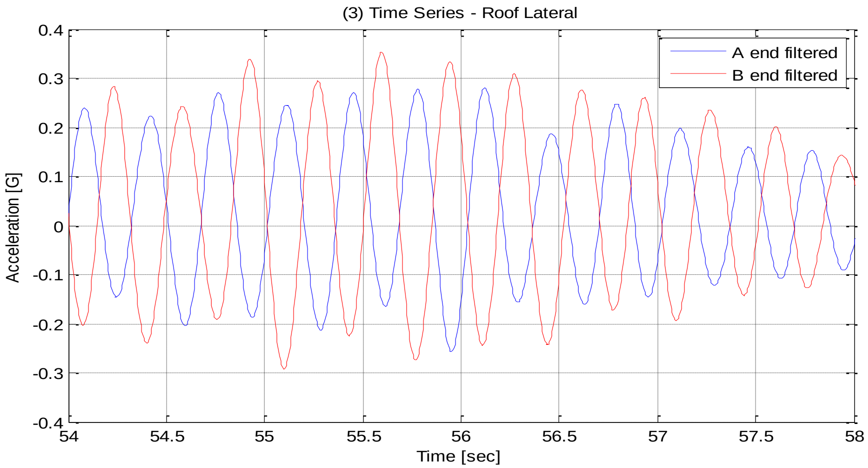
Pitch & Bounce



Hunting Detection & Vehicle Dynamics

Time Domain Approach

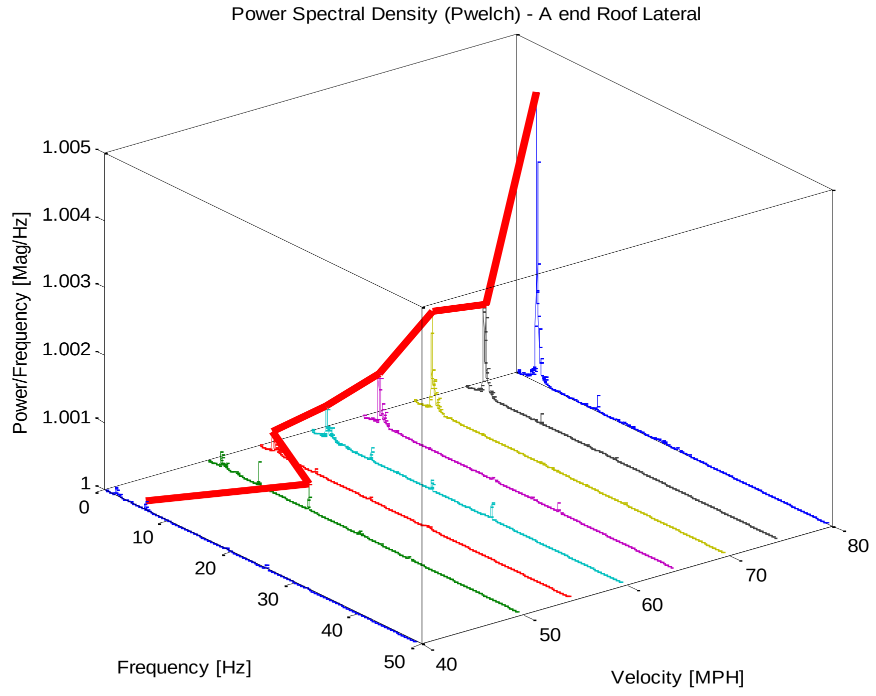
1. Phase used to determine type of motion
2. Magnitude used for severity of body motion
3. A and B-end mounted inertial sensors



Hunting Detection & Vehicle Dynamics

Frequency Domain Approach

1. Cascade plot illustrates development of instability
2. Similar approach to rotating equipment diagnostics



Future Work

1. **Diagnostics** – connect measured modes with component health
2. Connect modes with **hollow worn wheels**, **truck warp** & **mis-alignment**

Bearing Fault Detection & Diagnostics

Condition Monitoring Research

Bearing Fault Detection & Diagnostics

Goals

1. **Impending failure detection**
2. **Classification of detected faults – e.g. cup, cone, roller defect…**
3. **Prognostics – remaining life**

Approach

- **Measurand –** temperature and/or acceleration (g's)
- **Transducer –** wireless temperature/vibration sensor
- **Acceptance Limits** – multiple methods used
- **Experimentation** – bearing test rig and field trials

Bearing Fault Detection & Diagnostics

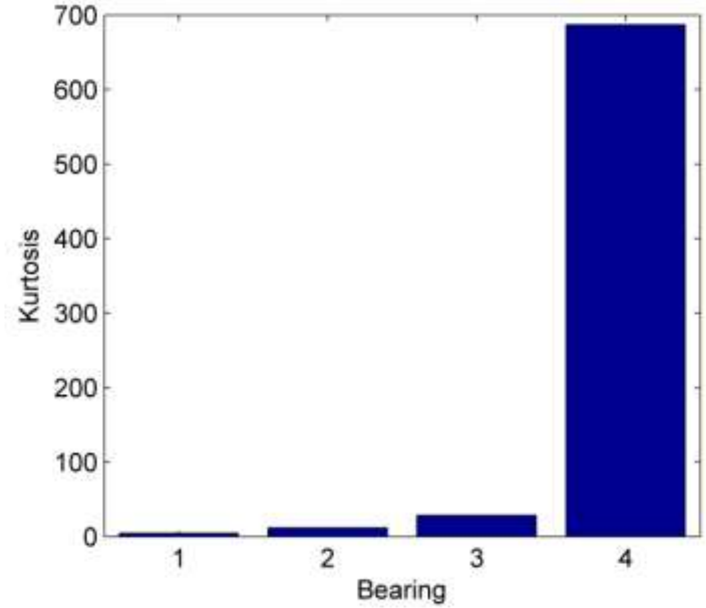
Temperature Based Fault Detection

1. Algorithms compare multiple bearing temperatures, temperature above ambient…

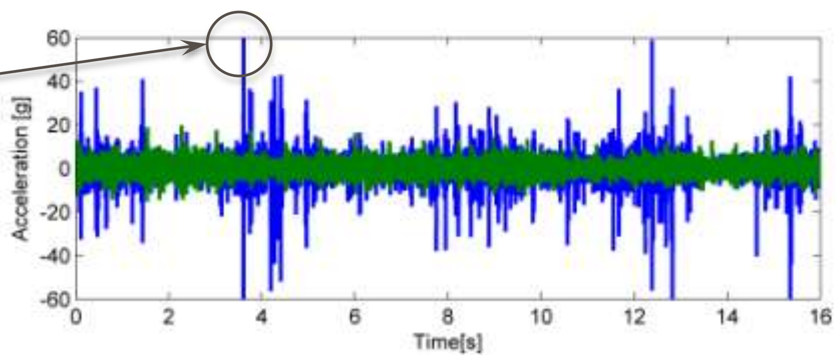
Bearing Fault Detection & Diagnostics

Vibration Based Fault Detection

1. **Time Domain** – statistical moment (R.M.S, mean, kurtosis…)
2. **Frequency Domain** – detection of defect frequencies, harmonic resonance…



Impulsive Signal



Vehicle On-Board Weighing System

Status Monitoring

Vehicle On-Board Weighing System

Goals

1. **Build a 1% accurate vehicle on-board weighing system**

Approach

- **Measurand –** displacement or strain
- **Transducer –** custom instrumented truck component
- **Calibration** - in the field or laboratory

Raw Readings

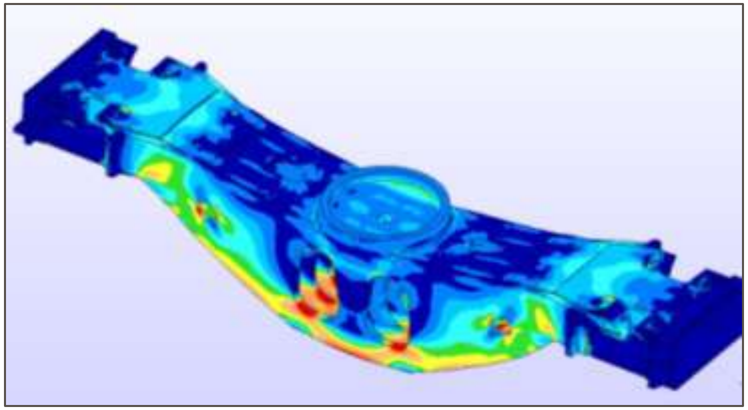
Sealed Parameters in CMU

GPRS, Bluetooth, WiFi…

Vehicle On-Board Weighing System

Key Challenges

1. Strains very low on truck system components (less than 10% of typical load cells)
2. Calibration and instrumentation
3. Temperature compensation



Design & Development

- Transducers with 5X strain amplification developed
- Over 300 Generation I systems deployed (3% accuracy)

Vehicle On-Board Weighing System

Lab & Field Testing

1. Complete truck testing and calibration in load frame
2. Field trials deployed with continuous data acquisition

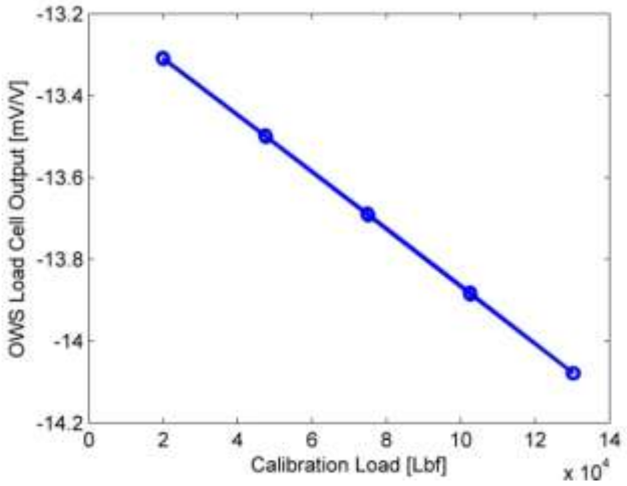
Industry Standards

- Calibration according to ASTM E74
- Performance metrics according to ISA/NIST/NCWM standards

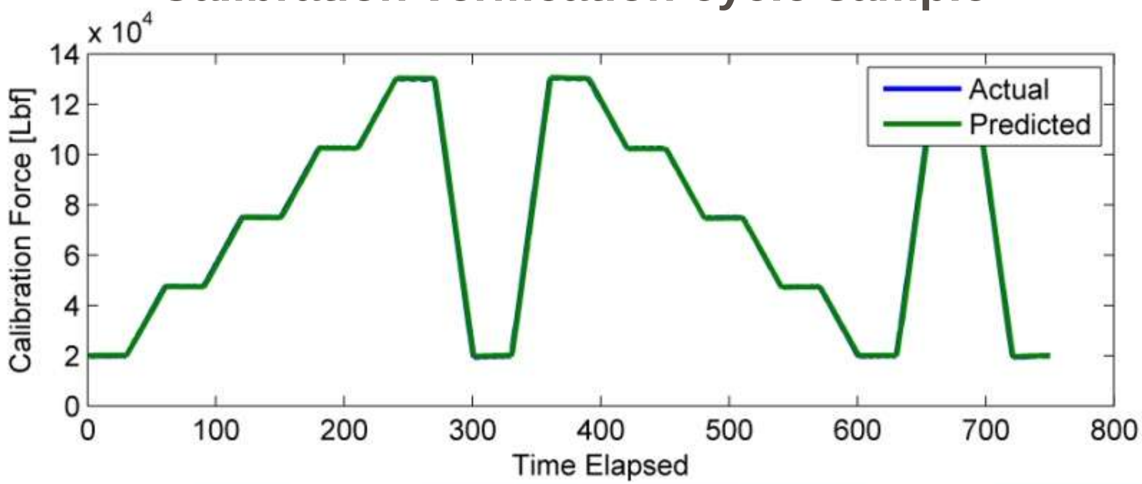
Vehicle On-Board Weighing System

Lab Performance

1. ±500 Lbf uncertainty possible
2. Hysteresis, linearity, and repeatability better than 0.5% full-scale



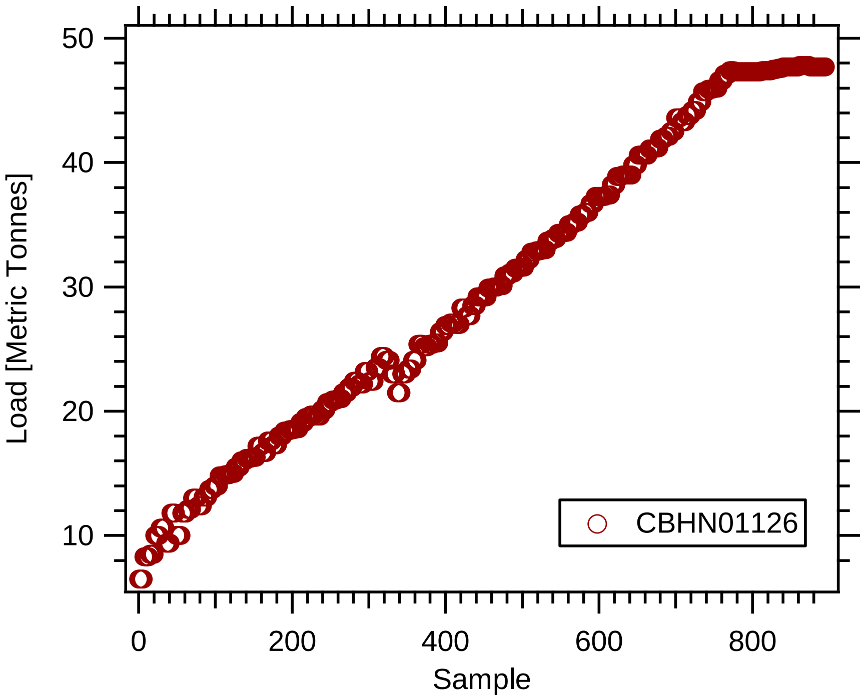
Calibration verification cycle sample



Vehicle On-Board Weighing System

Field Performance

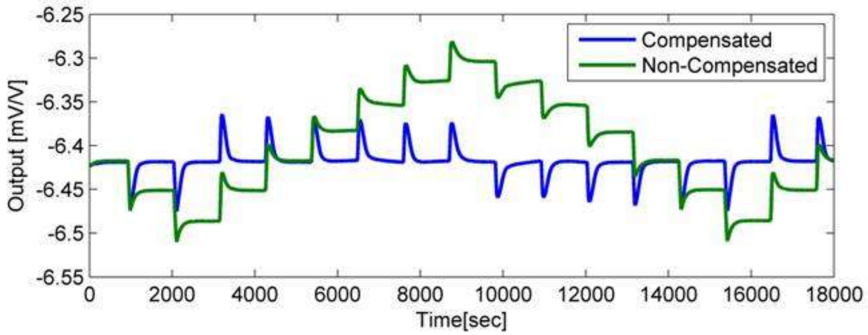
1. 287 Systems Deployed on Grain Cars (Summer 2012)
2. 3% Accuracy typical



Vehicle On-Board Weighing System

Future Work

1. Statistical certainty
2. Temperature Compensation
3. Class IIIL accuracy classification
4. NTEP Compliance – NIST Handbook 44
5. Dynamic truck behavior monitoring



Handbrake Monitoring System

Status Monitoring

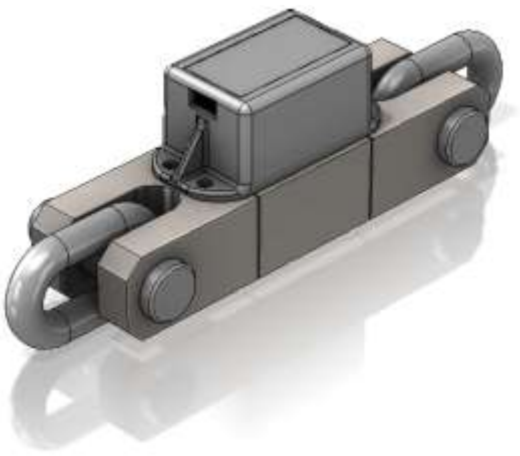
Handbrake Monitoring System

Goals

1. **Build a wireless force-based handbrake monitoring solution**

Approach

- **Measurand –** handbrake chain tension
- **Transducer –** custom handbrake chain link with wireless electronics
- **Status –** on/off based on force levels



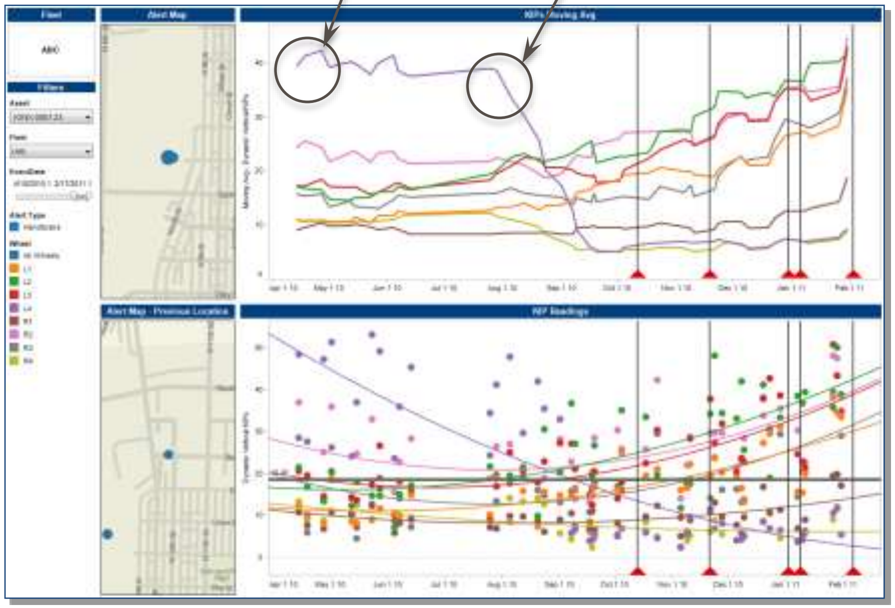
Handbrake Monitoring System

Handbrake Events vs. Wheel Impacts

1. **Handbrake event –** handbrake engaged with car moving
2. Leads to flat spots in wheels
3. Eventually detected at WILD site

Handbrake events detected

Wheelset change



Future Work

1. Correlation between chain force and probability of sliding wheels

Conclusions

The Future of Embedded Systems

1. Increased **memory** & **processing power**
2. Decreased **power consumption**
3. Reduced **Cost**

[Energy Micro]

The Future of Condition Monitoring

1. Wireless sensing systems **easier** & **cheaper** to deploy
2. Large amount of data needs to be processed, analyzed…

Thank You!

Questions?