C4R

Capacity for Rail

Monitoring Technologies & Sensors identification
Migration of innovative technologies to existing structures

Madrid – 21/09/2017

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UNIVERSITY OF BIRMINGHAM

SEVENTH FRAMEWORK PROGRAMME

Overview

Capacity for Rail

- Sensing technologies and energy harvesting
- Technology identification and evaluation
- Sensors assessment
- System design
- Field tests
- Demonstrator
- Conclusions

Identified Technologies + Technology Evaluation + Context = Technology to be Developed

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Sensing Technologies

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Sensing technologies

Technology	Key Factors
Vision	Frame rate, Resolution, Colour depth / sensitivity, Field of vision (lens angle)
Vibration	Range of operation, Sensitivity, Drift / stability, Sampling rate, Power consumption, Shock tolerance Sensor resonance frequency
Mechanical (Strain)	Bridge configuration, Robustness (operating environment), Target geometry, Installation method
Environmental (Temperature, Humidity, Wind)	Range of operation, Robustness, Accuracy vs. cost, Size, Installation method
Acoustic	Range of operation (sensitivity), Frequency range, Directionality, Physical limitations (size) Robustness / operating principle
Electrical	Range of operation, Sensitivity, AC or DC, Sampling rate, Physical limitations (size) Installation method, Isolation
Specialist / Multifunction (Fibre)	Operational benefits arising from multi-modal operation (sensing and communications)

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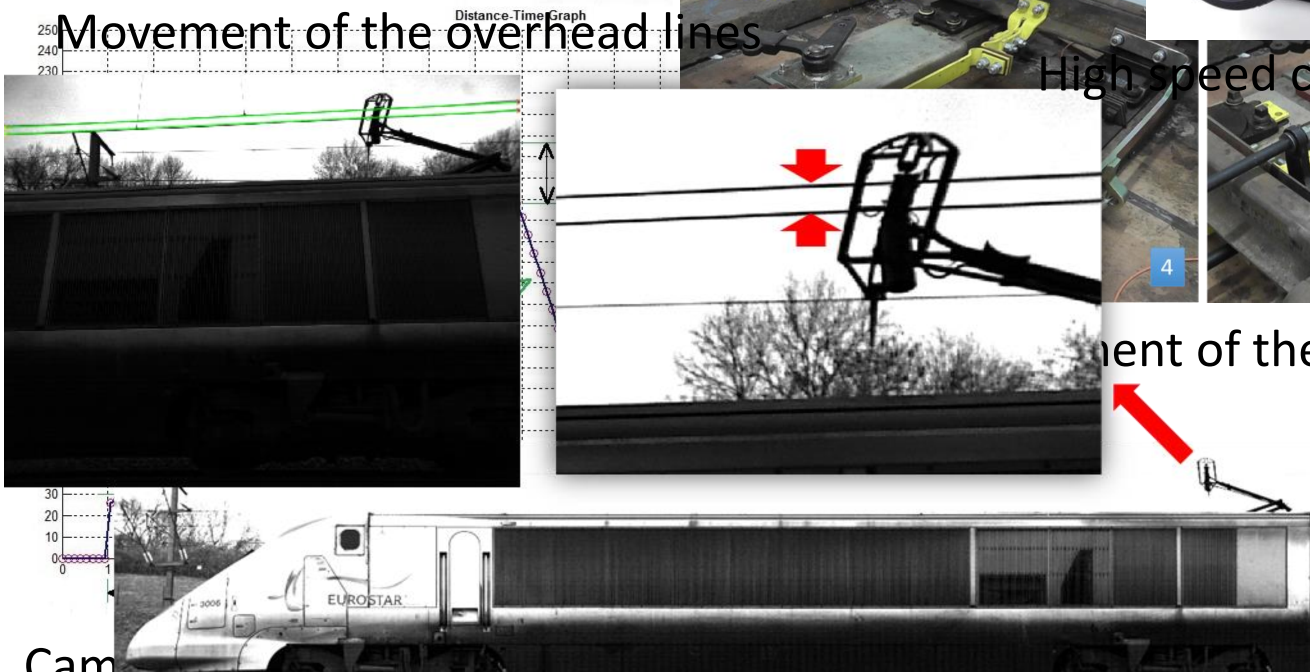
Vision

High speed camera - FASTCAM

ent of the drive rod

Movement of the overhead lines



Cam

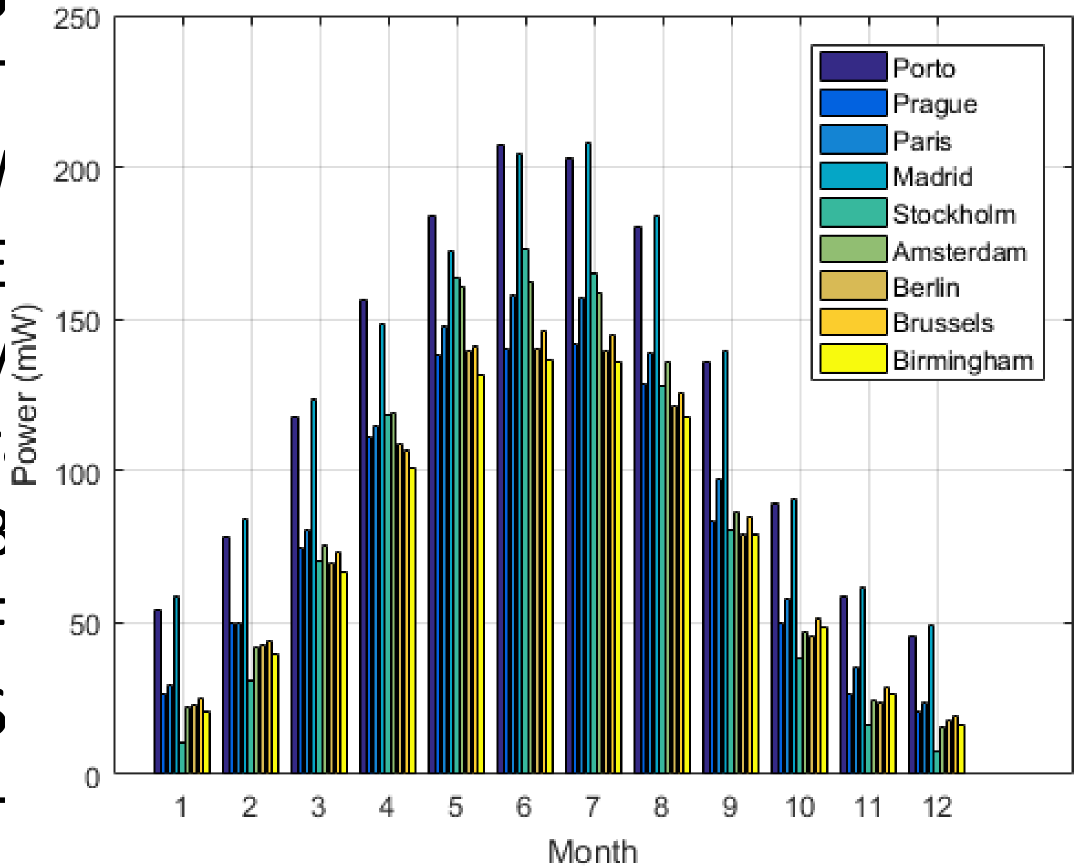
Eurostar @ 300 km/h

Energy harvesting and storage

- Energy Harvesting
  - Solar
  - T
  - V
  - E
  - V
- Stor
  - B
  - F
  - S
  - H
  - Thermal

Example: Solar panel power depends on the location

Thermogeneratoer



Monthly average generated power

Solar panel

Wind Turbine

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Technology identification and evaluation

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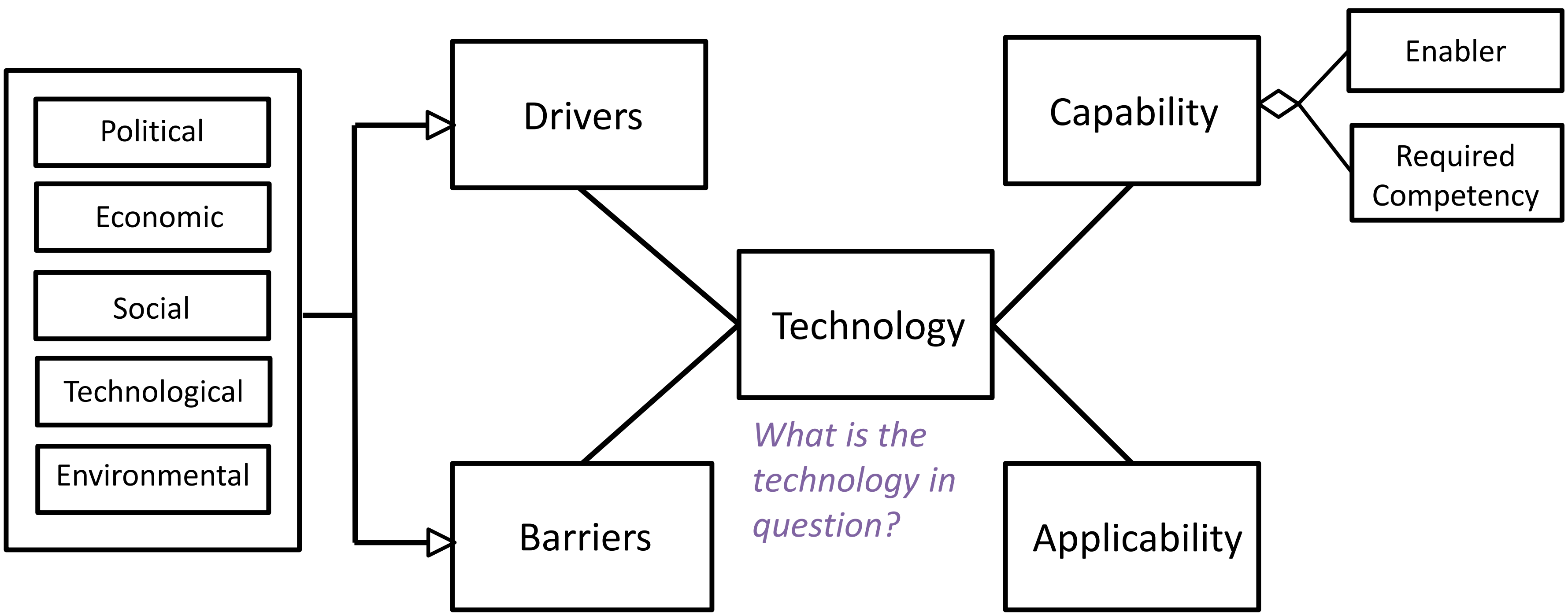
Technology identification framework

Technology Market Place

Which technologies could be developed given the Market Place?
What is missing in the Market Place to progress the technologies?



Technology identification framework

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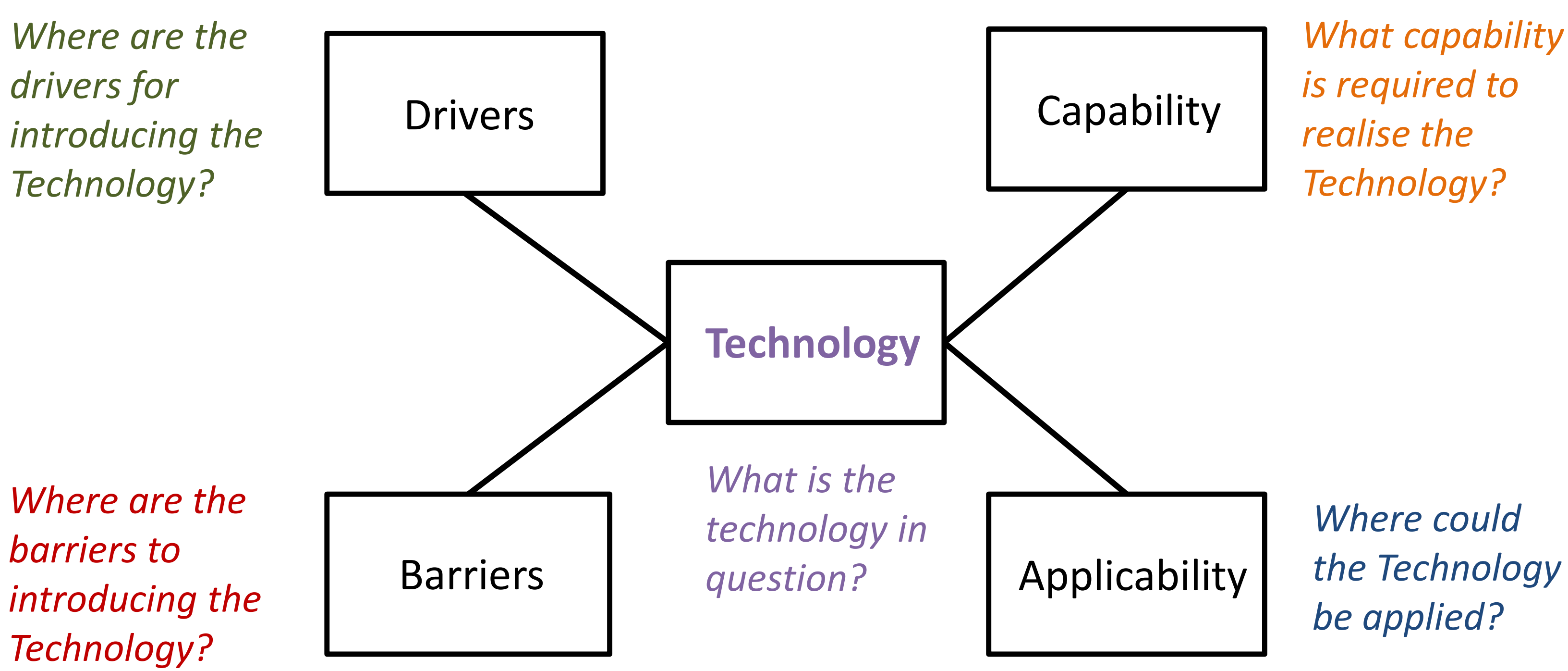


Technology identification framework

Drivers
political, economic, social, technological, environmental

No cables
No trip hazard
Easy to install and retrofit
Track movements

Capability
enablers, competencies and relevant stakeholders

Accelerometers and gyroscopes
Signal processing
Communication
Power

Wireless Vibration Monitoring

Barriers
political, economic, social, technological, environmental

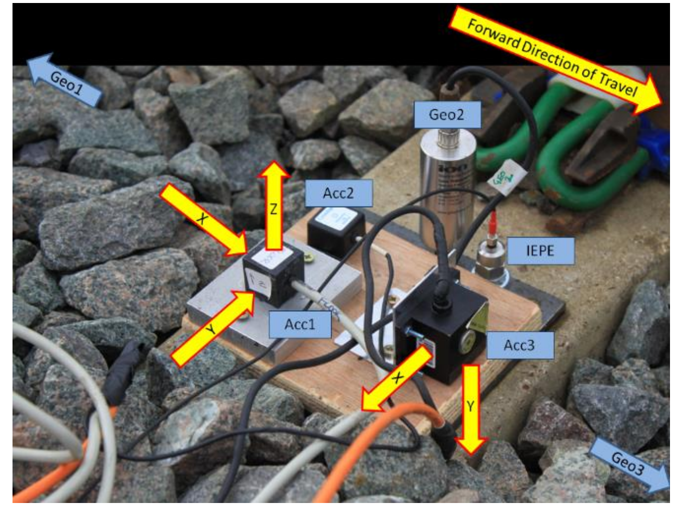
Track access and possession
Power consumption
Energy harvesting environmental limitations

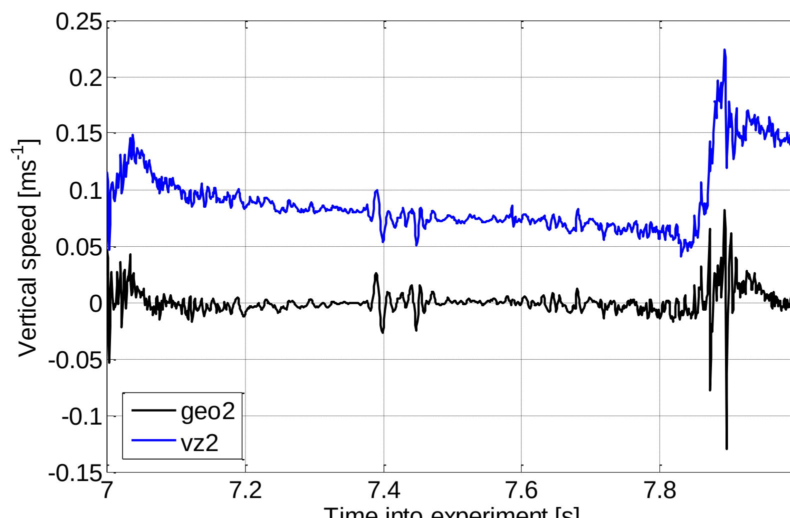
Applicability
application, stakeholders, business case and business model

Switches and crossings
Track geometry monitoring
Wheelflat detection

Sensor evaluation / comparison

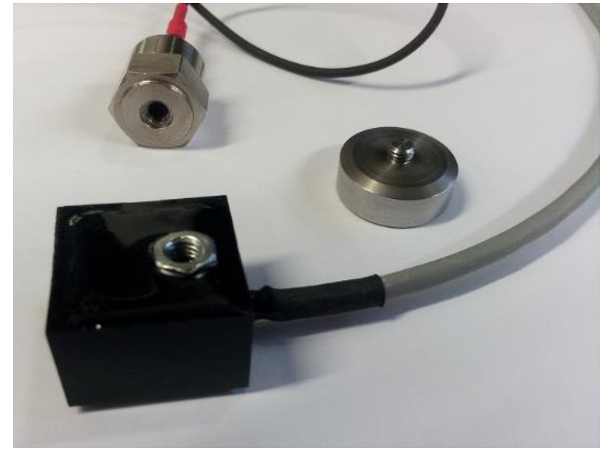
- Testing has been undertaken at the Long Marston facility, Uk
- A variety of different grade (cost) accelerometers have been evaluated
- Cross-comparison of sensors and evaluation against geophones
- High quality (cost) sensor displays reasonable correlation
- Lower quality (cost) sensor displays significant drift – can be reduce by post processing





Accelerometers

- MEMS vs Piezo
  - MEMS average draw of 0.75 mW compared to Piezo of 132 mW
  - MEMS Peak draw of 5 mA (1.5 mW)



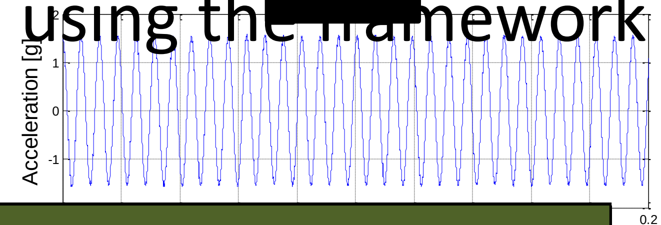
Wide temp range (-40 to 85 ˚C)

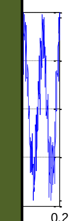
	KS76a (Piezo)	ADXL001 (MEMS)
Interface	IEPE	Voltage
Power	~ 132 mW	< 1 mW
Range	±120 g	± 250 g
Resonant frequency	> 34 kHz	22 kHz
Sensitivity	50 mV/g	4.4 mV/g
Noise	80 µg (20 – 50000 Hz)	95 mg (100 – 400 Hz)

Sensor Evaluation / Comparison

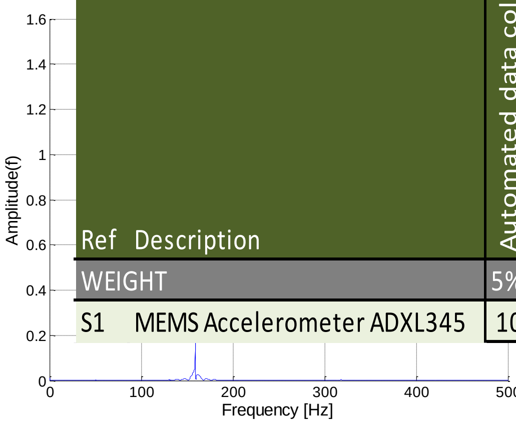
- Example of sensor evaluation using the framework
- Lower SNR in MEMS
- Good match in Freq-domain and in

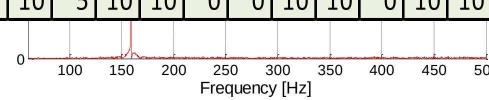
Piezo





SENSORS																								
Ref	Description	Automated data collection	Detection of incipient faults	Event localization	Wake up under event	Different time for sensing/sending	Scalability	Environmental compatibliity	Data collection at line speed	Different measurement modes	Custom reporting of parameters	Custom fault detection rules	Custom submision rate of measurements	Self-diagnostic	Long term stability	Long term robustness and reliability	Calibration	Geometrical compatibility	Compatibility with track maintenance	High availability on component level	High availability on sensor node	Resistance to electromagnetic fields	Mounting simplicity	**SENSOR SCORE**
WEIGHT		5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	
S1	MEMS Accelerometer ADXL345	10	10	10	10	10	5	10	10	0	0	10	10	0	10	10	5	10	10	10	10	10	5	**8.0**





Piezo

MEMS

Vibration calibrator

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System Design

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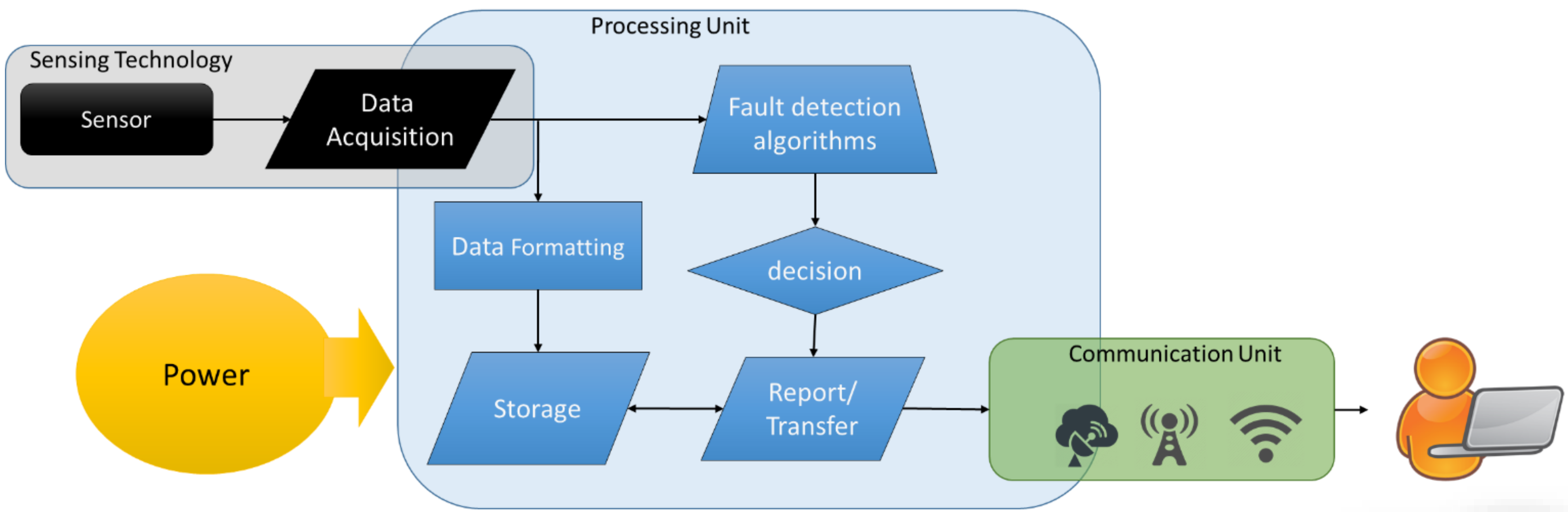
System Design

Vibration based track movement motoring system using accelerometer on sleepers

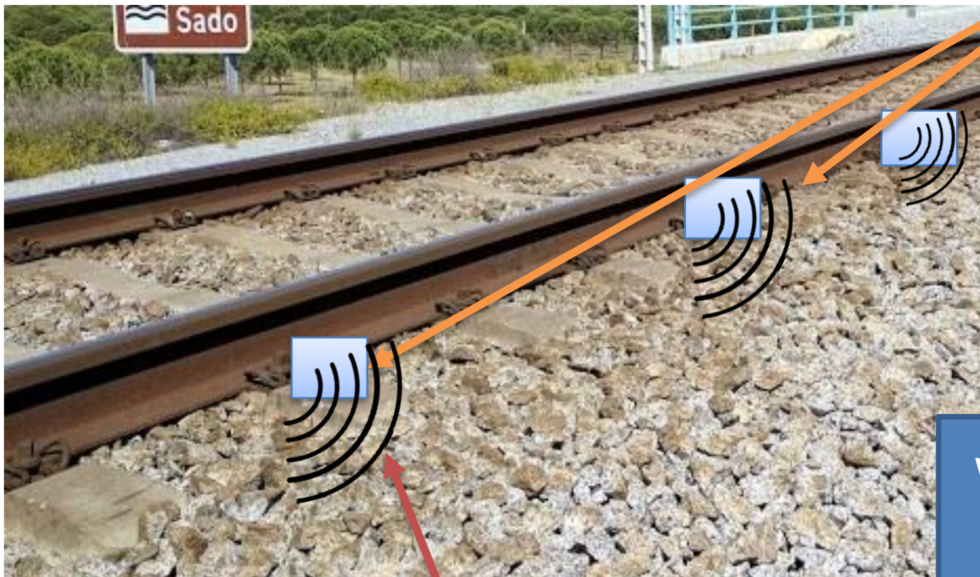
- Low power
- Low cost
- Easy installation
- No wires
- Use of an energy harvesting system
- Remote access



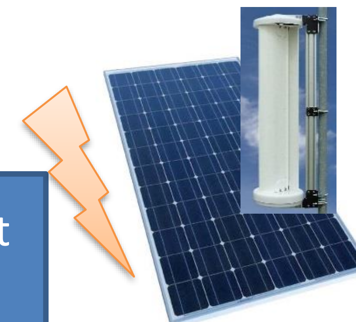
System design

Capacity for Rail

Wireless Vibration Nodes



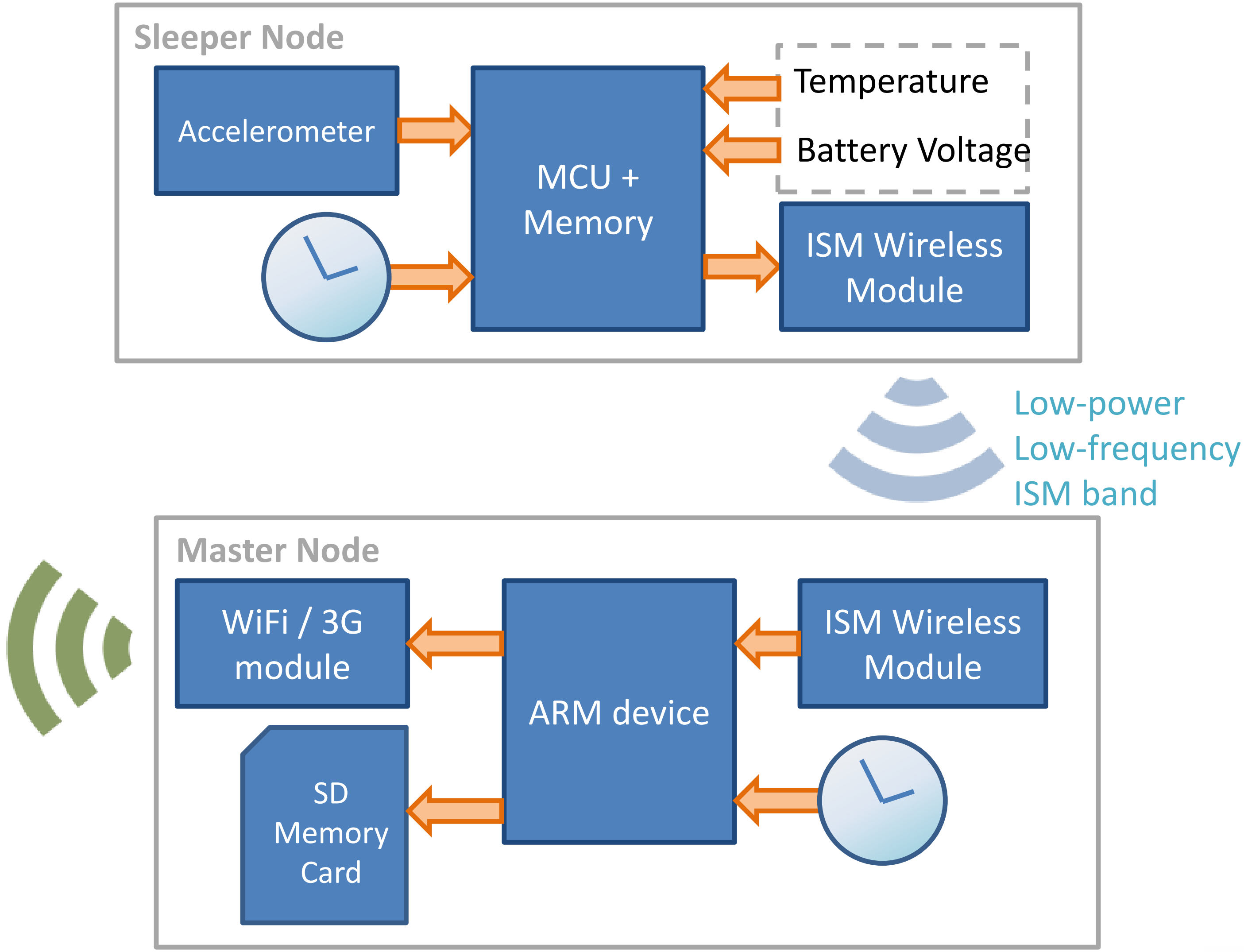
Use of EH for track side system



Wayside central unit
With remote
connection

Short range and low power wireless technology

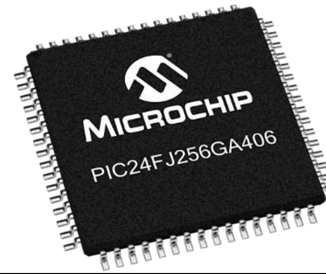
UoB wireless node system overview



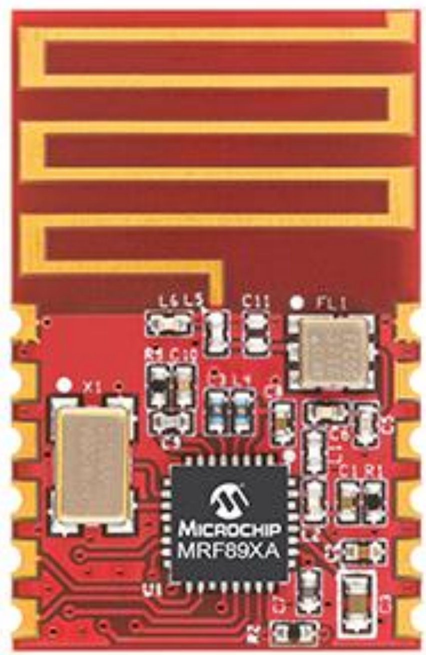
System components

- Data acquisition and processing
  - Microchip PIC24
  - Low cost, low power
  - Easy to integrate with the sensor (SPI bus)
  - Capability for communication modules

Wireless module evaluation



Cost about £3



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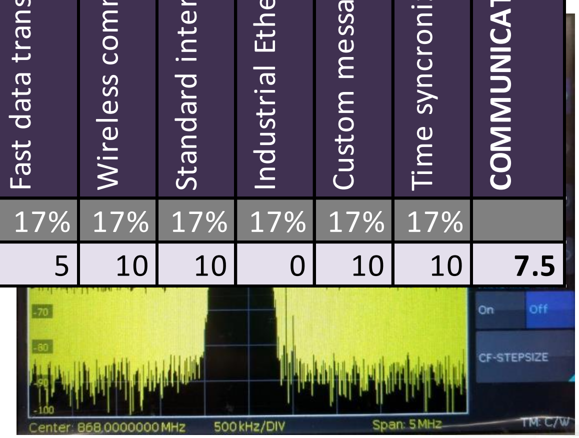
Int

n x 2

- Wide temperature range (-45 to 85 ˚C)

COMMUNICATIONS								
Ref	Description	Fast data transmission	Wireless communication	Standard interface for wireless	Industrial Ethernet communication	Custom message format	Time syncronization	**COMMUNICATION SCORE**
		17%	17%	17%	17%	17%	17%	
C1	MRF89XAM8A	5	10	10	0	10	10	**7.5**

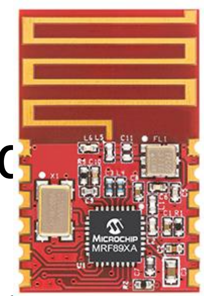


Central unit and remote connection

- Low power and low cost
- Use of energy harvesting
- Remote connection
- Storage system
- Weatherproof
- Easy integration into final proc... minimise pr... development, quicker time to ...:
- Capable of using the selected wireless technolo...

- Raspberry PI 3A
  - Quad core ARM8 processor
  - Serial communication bus
  - Storage – SD card
  - Network connections
  - Linux OS - Open source
  - Small and easy to mount
  - Low power (<3W)
- GPS module – Time sync
- Short range wireless
- IP67 Enclosure
- Operation range
  - (-40 to 85 ˚C) without LAN
  - (0 to 60 ˚C) with LAN, used only for remote access

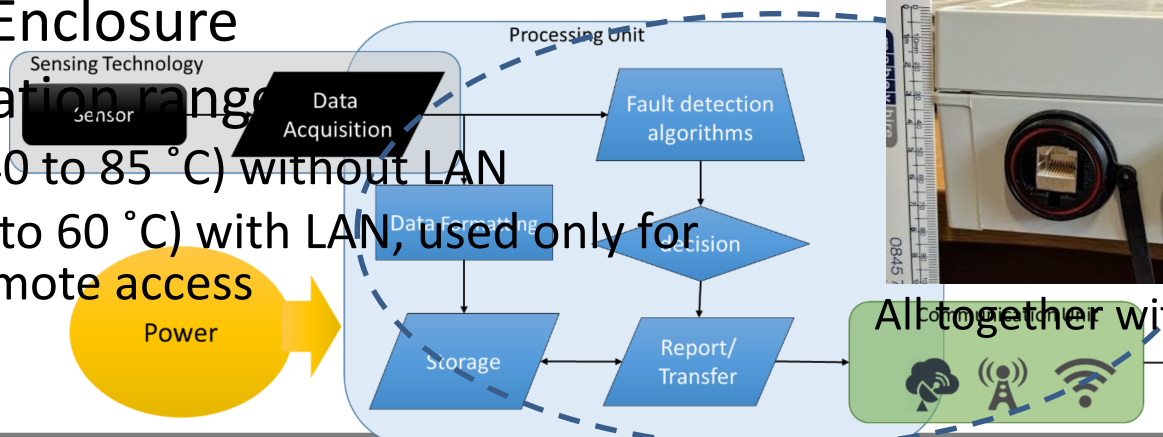
£26



£5

£10

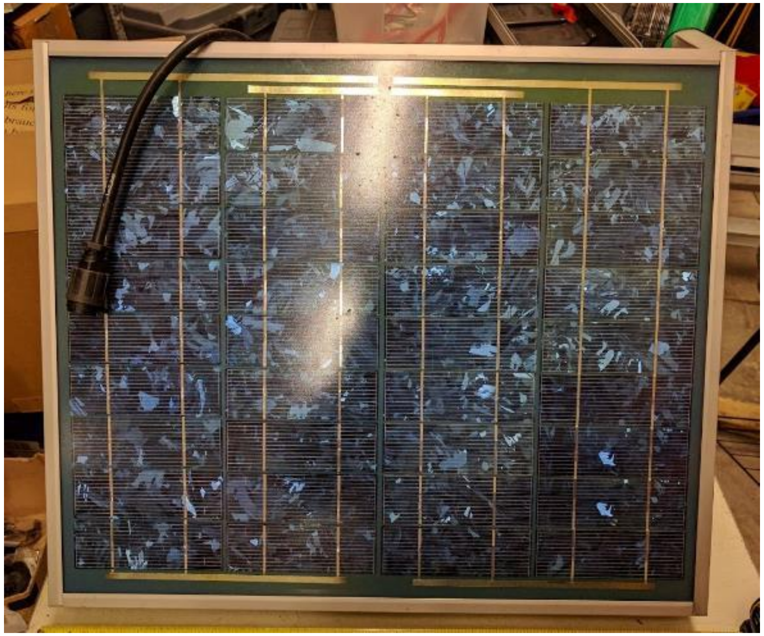
All together with enclosure ~ £50



Energy systems

- 50 cm automotive solar panel (used in traffic lights)
- Up to 20 W power
- Easy to install on the track-side

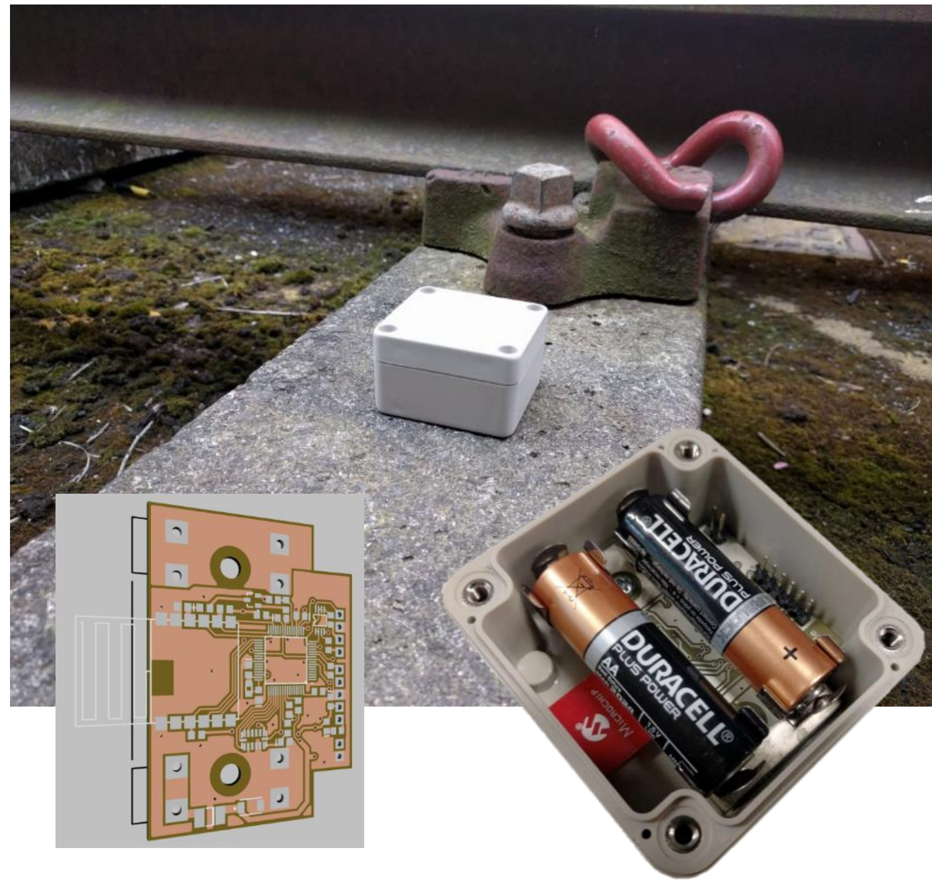
ENERGY HARVESTING								
Ref	Description	Suitability for installation at different sites	Monitoring and reporting of battery status	Self-diagnostic	Environmental compatiblity	Resistance to electromagnetic fields	Mounting simplicity	**ENERGY HARVESTING SCORE**
	Weight	17%	17%	17%	17%	17%	17%	
E1	Solare panel BP SX20U	5	5	0	5	10	10	**5.8**



- Wide operating temperature range
- Resilient unit, does not require further housing / protection

UoB sleeper node

- Easily deployable networks of sensors
- Internal accelerometer
- ‘Sleeps’ until a train is detected
- Samples at 1600 Ss^{-1}
- Downsamples to 800 Ss^{-1}
- Stored in local memory
- Transmitted to master node after train has passed
- Battery powered
    - ~5 years (3A Lithium Iron)
    - EH for local master node
- Includes a temperature sensor
- Wide temperature range to operate (-20 to 60 ˚C)



Around £20 for a prototype

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Field Testing / Demonstration Activities

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UoB - Live trial initial tests

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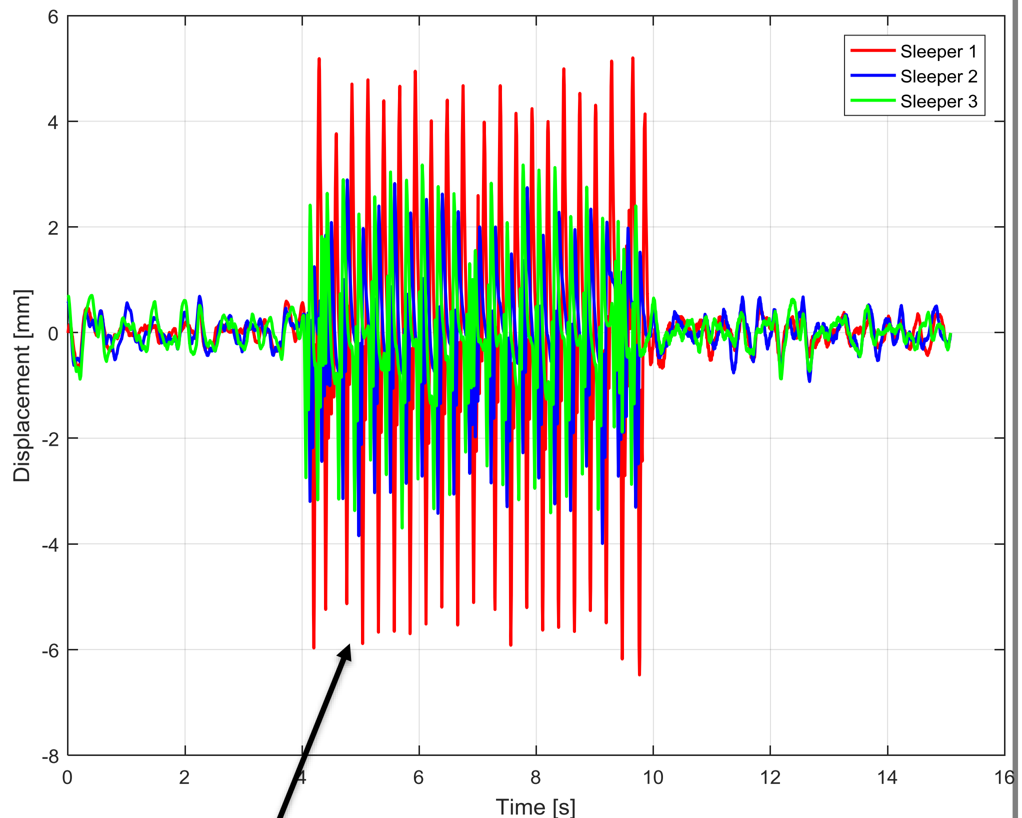
- Monitoring sleepers on the UK High Speed 1 line using low power accelerometers and embedded microcontrollers
  - Eurostars, 300 km/h
  - Javelins, 220 km/h
  - Freight, 100 km/h
- Around 1400 train passages were recorded over a 2 week period

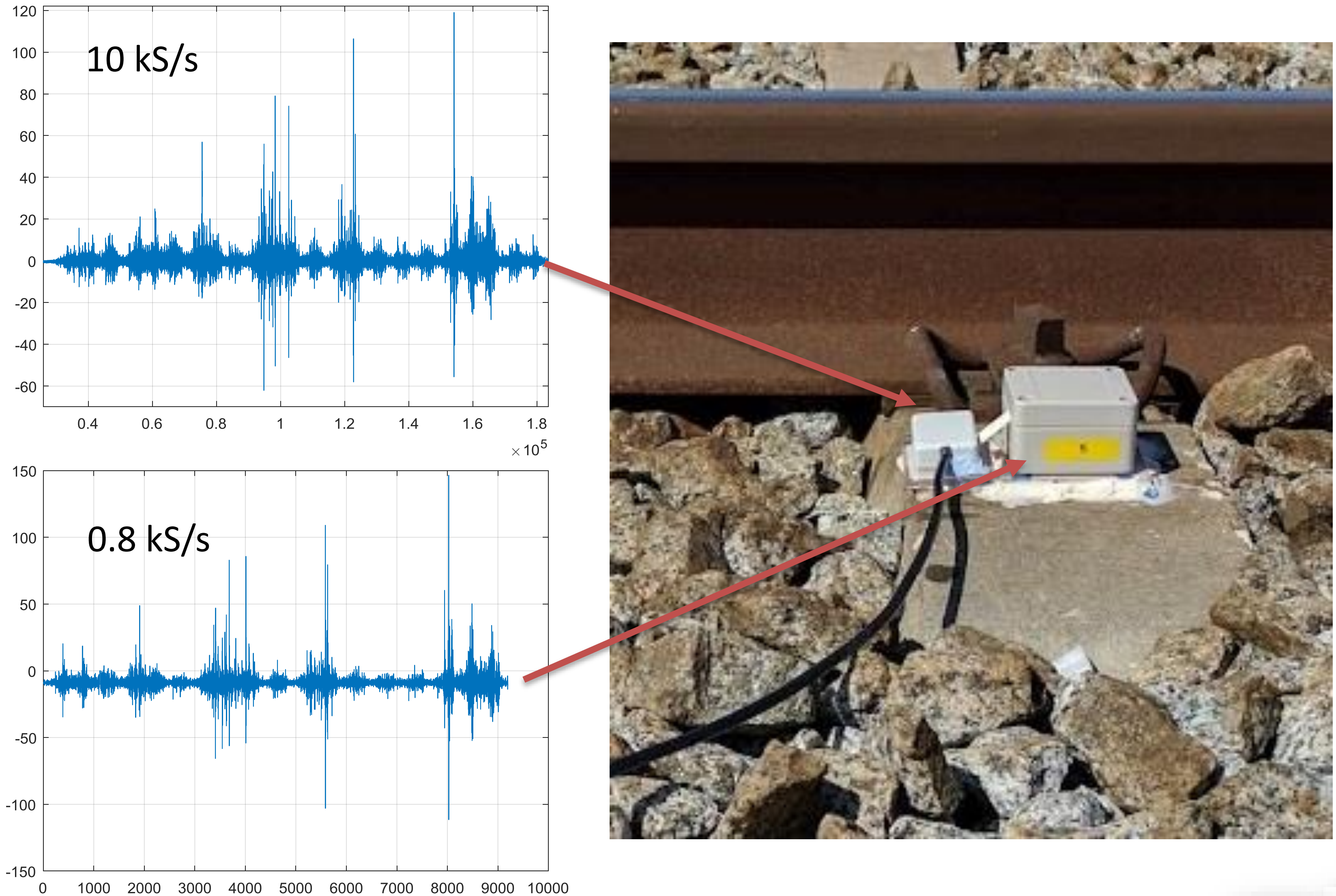
Data analysis - Accelerometers

- Displacement curves for the three accelerometers
- One is significantly larger than the other two



Less-well supported sleeper

Sensor evaluation



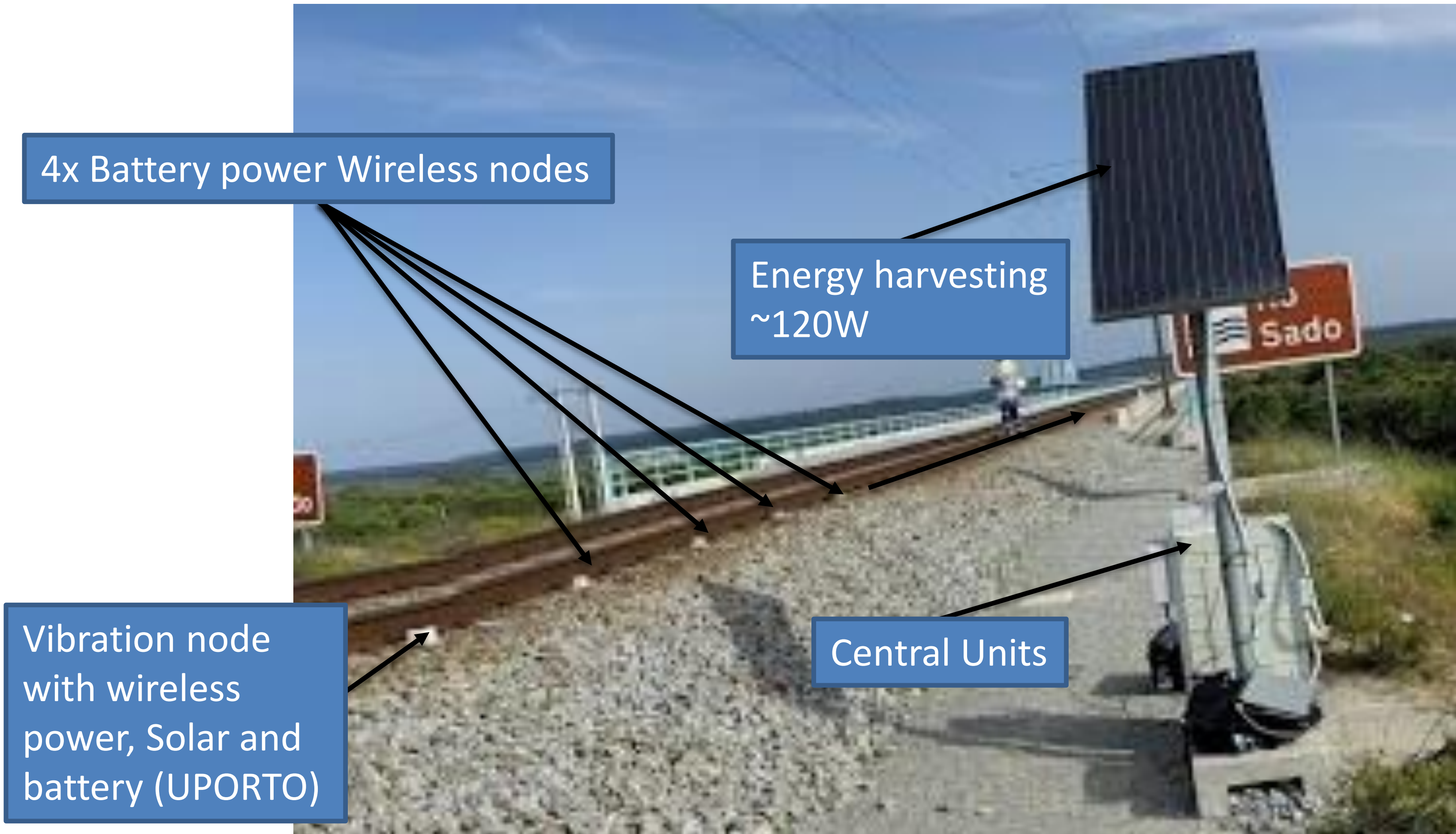
UoB & UPorto - Live trial demonstration testing

- Transition zone onto a bridge
- Use of EH at trackside
- Battery powered nodes
- Short range wireless system
- LTE for remote access

New Sado river crossing

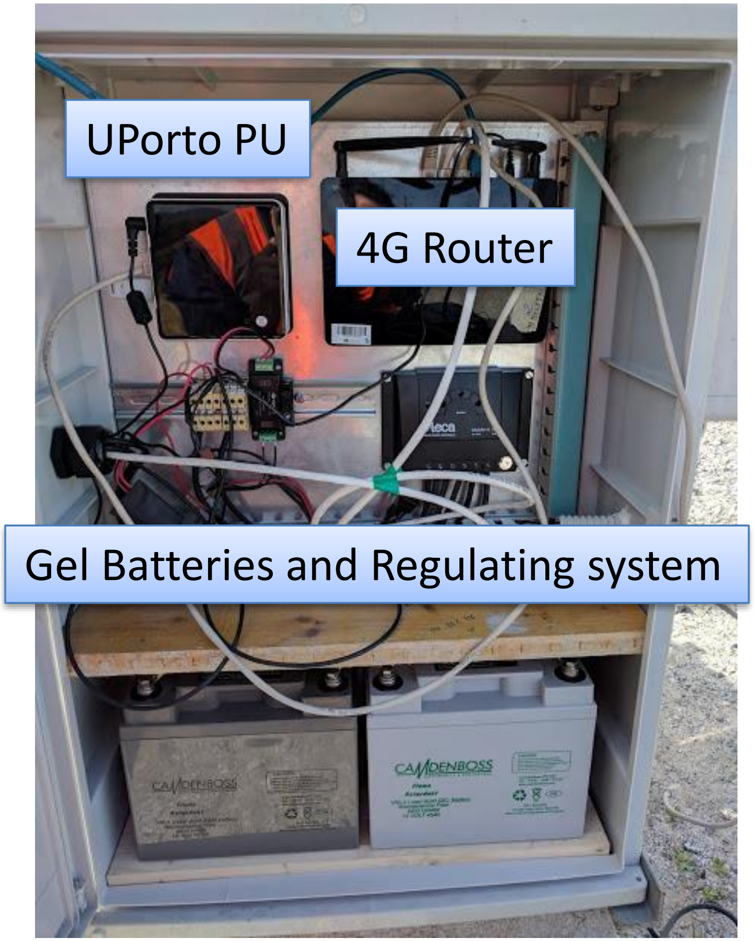
Alcácer do Sal

C4R Capacity for Rail



Alcácer do Sal

Main control panel



UPorto Vibration Node

UoB Central PU

UoB Vibration Node

Alcácer do Sal

Capacity for Rail

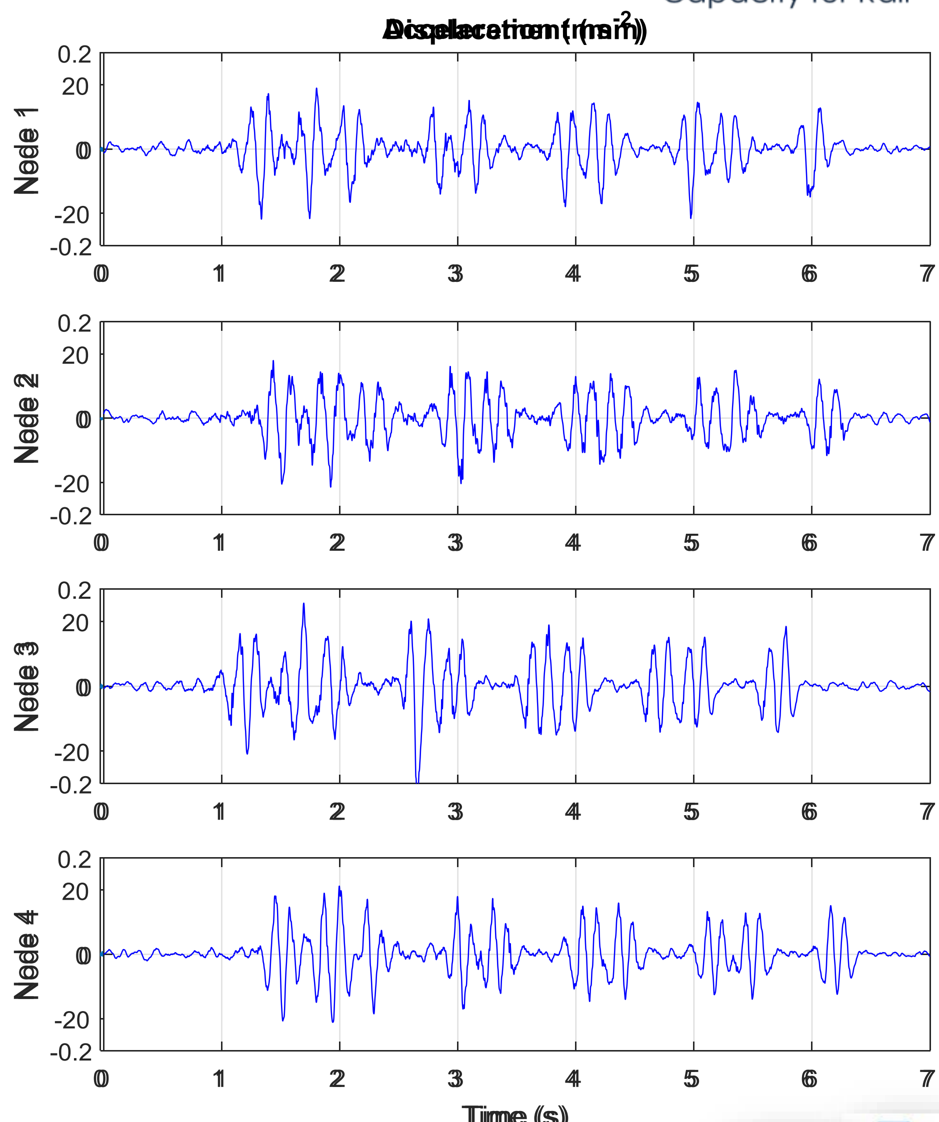
UoB - Recording on April 20 at 10:54am

Results

- Vibration data in m/s^2
- Different vibration behaviour
- Different vibration level
- Interesting peaks on Node 2

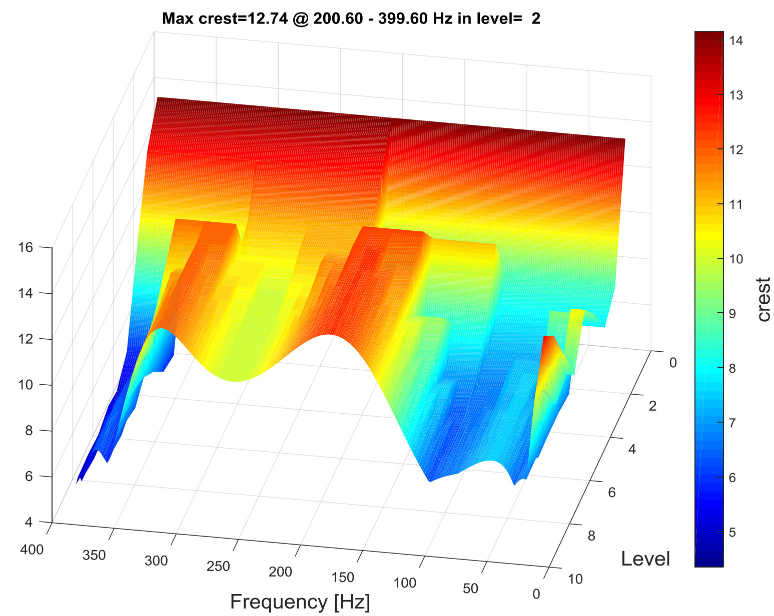
- Displacement data in mm
- Using a bandpass filter and double integration for displacement
- Consistency in number of wheels passed
- Consistency in the displacement level

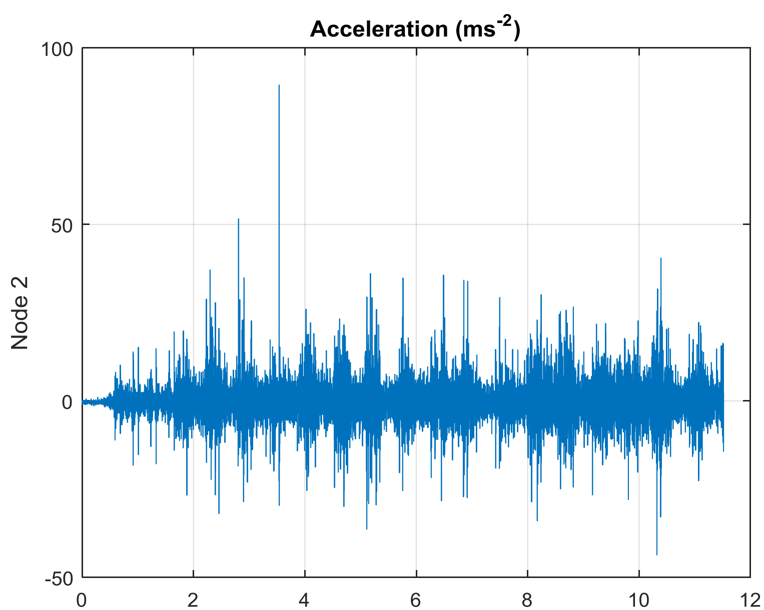
Data available live on UoB [webserver]

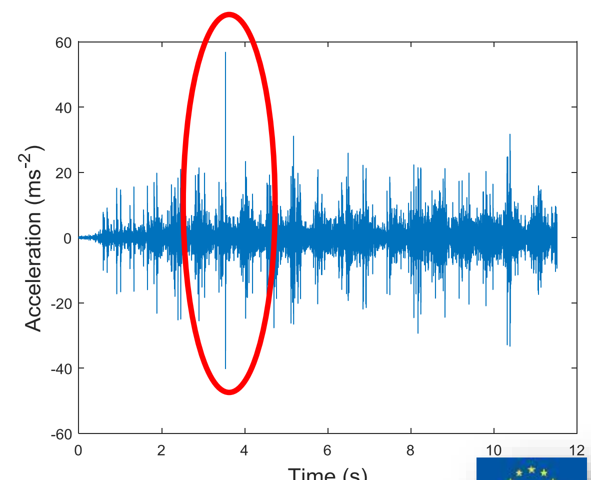


Data Analysis

- Freight train – Peak analysis
- Crest factor spectrom
- Load monitoring and wheel impact

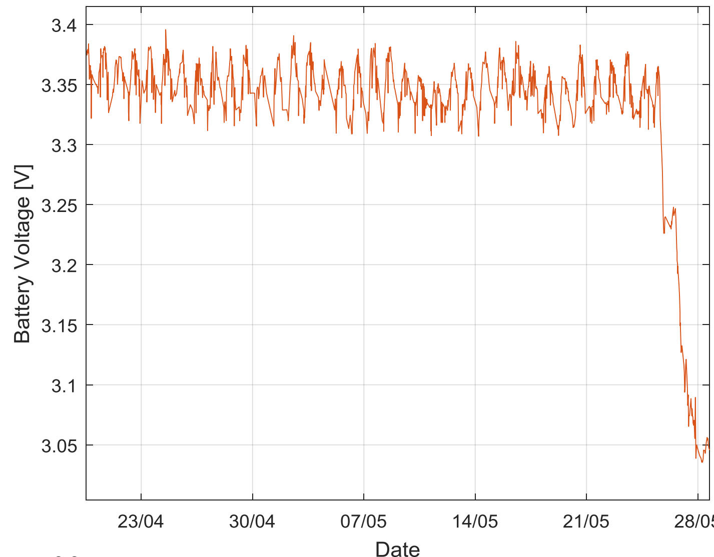




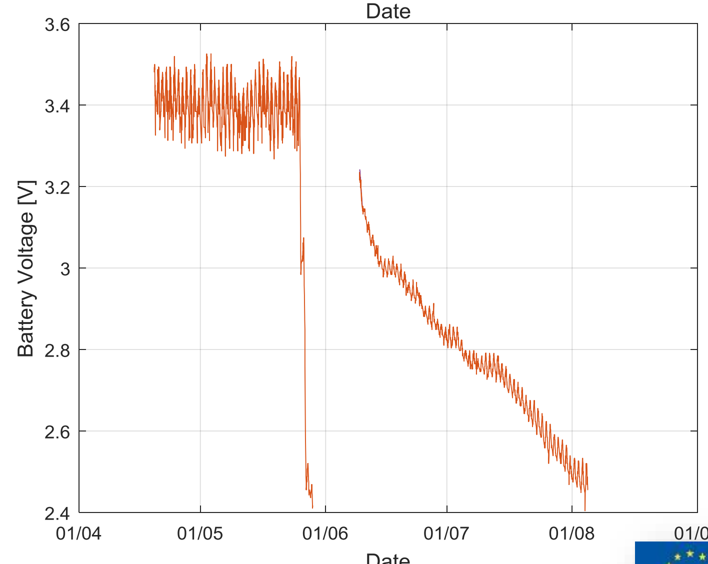


System performance

- Waking up every 200ms
- Log maximum 11 seconds if there is a train
- Estimated to work for two months at 25˚C

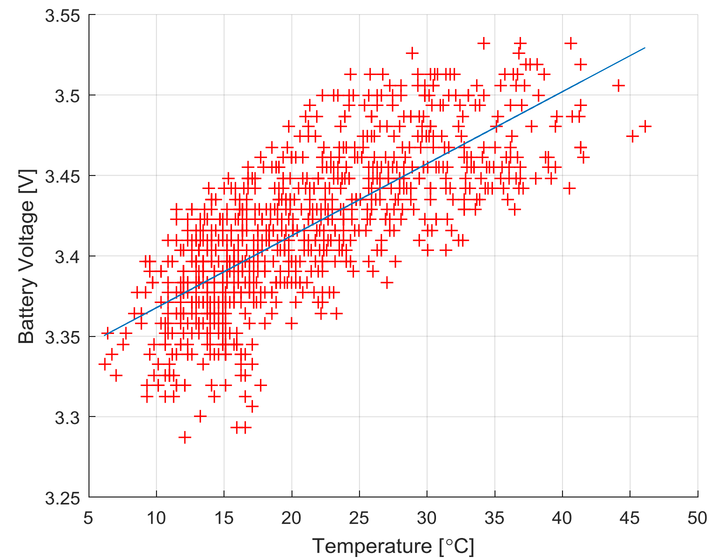


- Replaced battery after 40 days
- Difference between industrial and commercial batteries
- Triggering to be improved

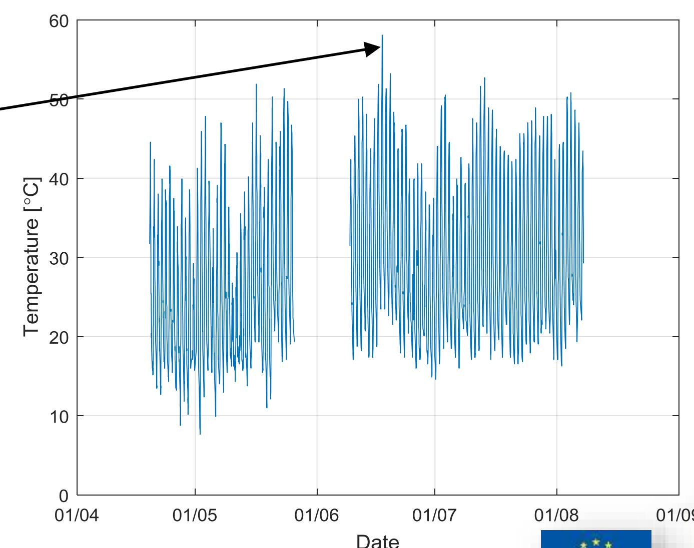


System performance

- Temperature effect on the batteries of the nodes
- No significant change in battery voltage within a month



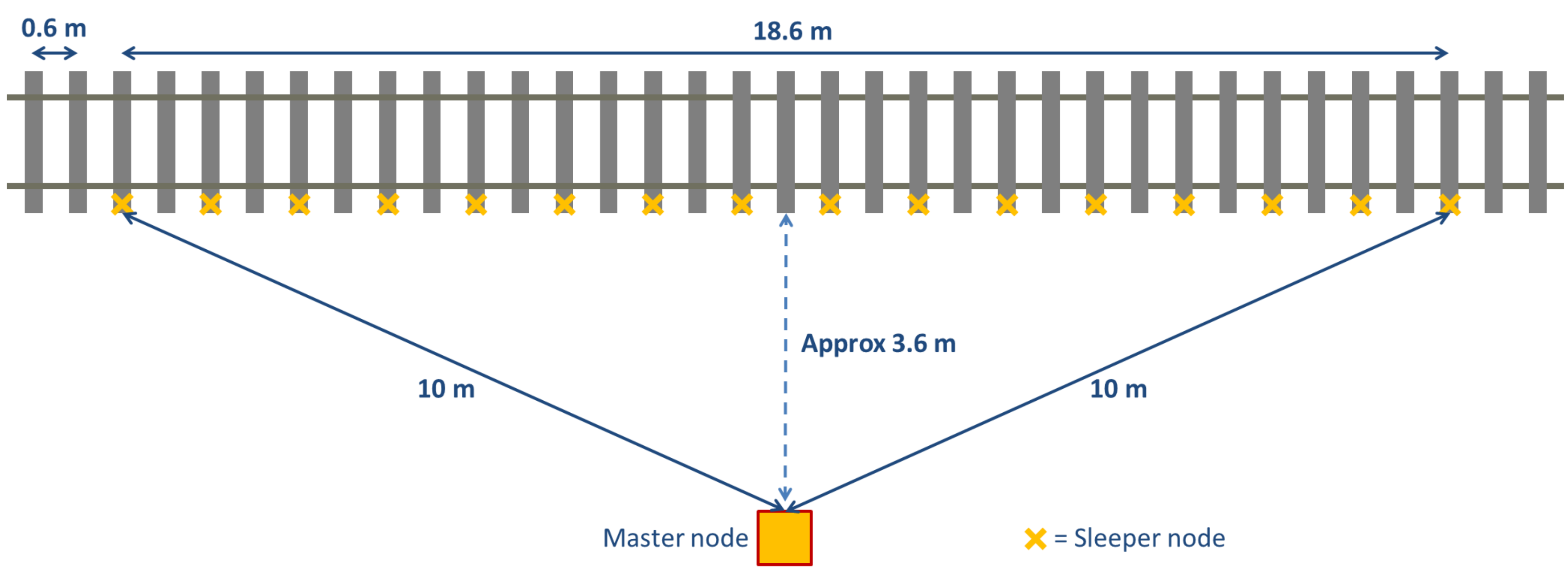
- Temperature monitoring
- Max temp about 60˚C
  – Lost network connection
- Data stored locally
- Connection retrieved after a couple of weeks



Instrumentation plan – NR HS, UK

Capacity for Rail

- 16 wireless nodes
  - 14 battery powered
  - 2 solar panels and battery
- Vibration and temperature monitoring
  - Lateral acceleration - 4 nodes
  - Vertical acceleration – 12 nodes



Network Rail High Speed - Kent

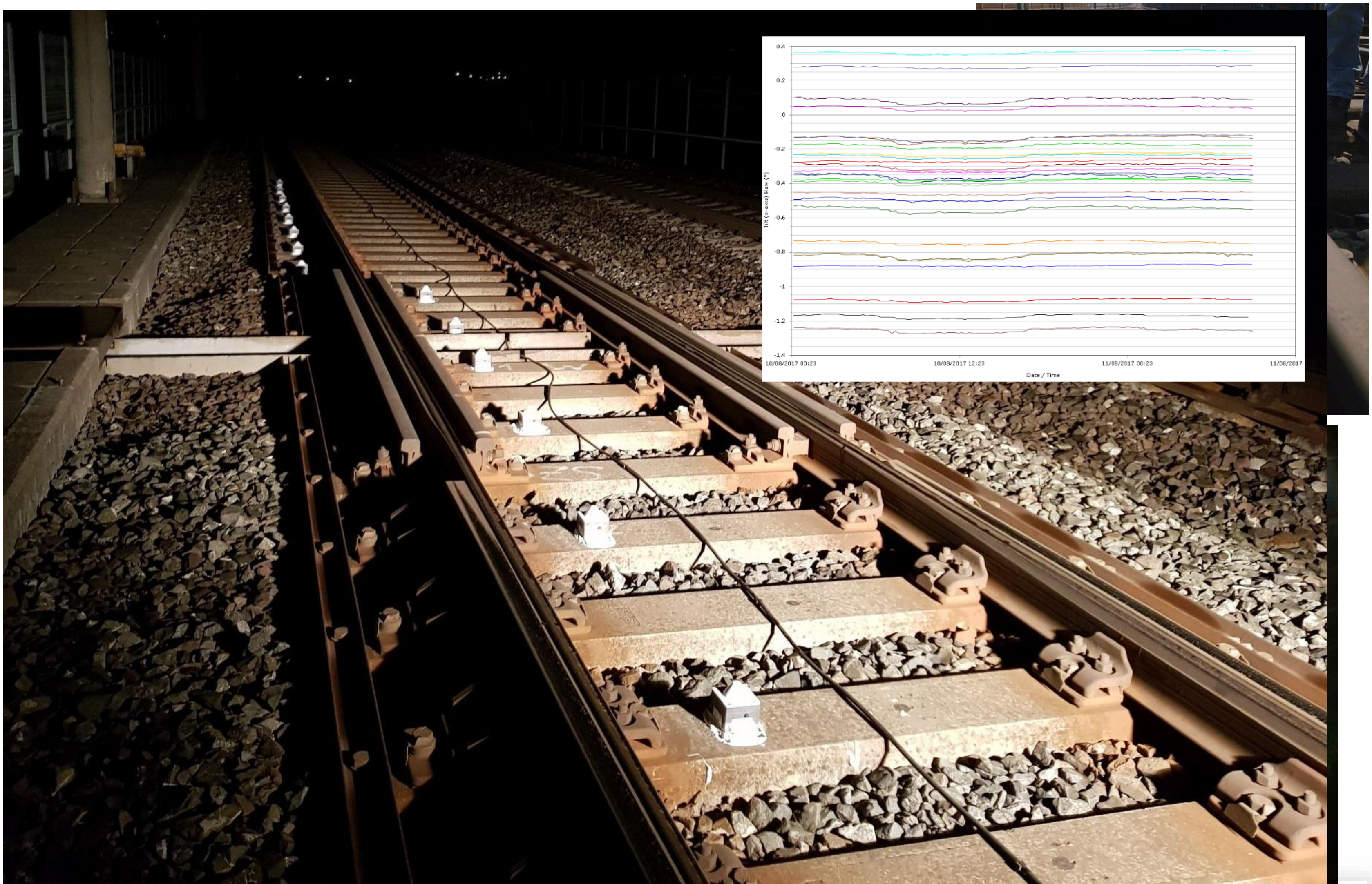
- Location identified by NR HS
- Ballast issues
- Nodes installed
- Solar panel
- Access for UoB staff visit to be granted

Solar panel

Wireless nodes

DB Demonstrator

Capacity for Rail



Conclusions

- Sensing technologies introduced including their key parameters for evaluation
- Field test demonstrations of a range of technologies
  - Extends laboratory testing
  - Demonstrates integration of technologies
- Monitoring system design comprising of:
  - Low cost system
  - Energy harvesting
  - Low power electronics and sensing technologies
  - Short range wireless methods and LTE networks
  - Distributed data collection and processing network
  - Data processing and condition monitoring techniques
- Demonstrates interactions / trade-offs between technologies in whole system development

Thank you for your kind attention

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