Sustainable strategies for monitoring in slab track
WP43. Implementation in new structures
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Sustainable strategies for monitoring in slab track

Contents

• Motivation, Goals and Tasks
• Identification of Monitoring Needs
• Analysis of Market Available Technologies
• Selection of Technologies
• In-lab tests
• Installation procedures and guidelines
• Conclusions
Motivation

• The state of the rail infrastructure is mostly dependent on the age and local conditions (e.g. ground conditions, construction procedures, load, etc)
• These conditions affect the life expectancy and maintenance requirements
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Goal

• Development of a monitoring system embedded in the new concepts of slab track developed within C4R
• Based on market available technologies
• Features pursued:
  • Low cost
  • Easy and rapid to implement during the construction of the infra
  • Easy or none maintenance
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Tasks for the development of the monitoring system

- Identification of monitoring needs (what to monitor) and requirements (how to do it)
- Analysis of market available sensors and communication technologies
- Selection of most suitable technology according to the main constraints
- In-lab tests
- Drafting of installation procedures
- Deployment at real pilot at CEDEX laboratory
### Identification of Monitoring needs

**WHY TO MONITOR SLAB TRACKS?**

*Continuous monitoring may not be necessary because:*

- Slab tracks have **very low failure rates**.
- **Track geometry is quite stable** (one of the main advantages of slab track)

**But... we need to monitor because:**

- In case of failures, repairs are very costly. The early detection of failures could derive in **lower cost repairs**.
- In C4R we aim at **enhancing the infrastructure capacity**. We should avoid track possession booking for inspection.
- In C4R we aim at **improving the competitiveness of railways**. As construction costs in ballastless tracks are high, monitoring is a key factor **to reach the limit of infrastructure utilisation with proper safety**.
- **A better knowledge of track condition** will allow the extension of the life span of the infrastructure and supporting harmful traffic demand, such as higher axle loads, longer trains or mixed traffic.
### Sustainable strategies for monitoring in slab track

#### Identification of railway infrastructure monitoring needs

<table>
<thead>
<tr>
<th>WHAT CAN WE MEASURE?</th>
<th>WHERE DO WE WANT TO MEASURE?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Infrastructure condition</strong></td>
<td>AT CRITICAL SECTIONS, such as transition zones, high embankments, shallow phreatic level, low radii curves...</td>
</tr>
<tr>
<td>• Track geometry</td>
<td></td>
</tr>
<tr>
<td>• Rail defects</td>
<td></td>
</tr>
<tr>
<td>• Structural health of the concrete slab and bearing layers</td>
<td></td>
</tr>
<tr>
<td>• Drainage</td>
<td></td>
</tr>
<tr>
<td>2. <strong>Operation of rail services</strong></td>
<td>AT CONTROL SECTIONS</td>
</tr>
<tr>
<td>• Train detection</td>
<td></td>
</tr>
<tr>
<td>• Train speed measurement</td>
<td></td>
</tr>
<tr>
<td>• Train direction</td>
<td></td>
</tr>
<tr>
<td>• Axle counting</td>
<td></td>
</tr>
<tr>
<td>• Weighing in motion</td>
<td></td>
</tr>
<tr>
<td>• Unbalanced loads</td>
<td></td>
</tr>
<tr>
<td>• Wheel flat detection</td>
<td></td>
</tr>
<tr>
<td>• Single vehicle identification</td>
<td></td>
</tr>
</tbody>
</table>
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Identification of monitoring requirements (How to measure)

HOW TO MEASURE?

- **Requirements for the integrated monitoring system components**
  - Sensor nodes shall be **low-cost**
  - Sensor nodes shall be **energetically autonomous** (battery-free or energy harvesting methods for self-recharging)
  - Sensor nodes shall be **embedded** in the infrastructure elements (i.e. below some centimetres of concrete)

- **Requirements for the Communications systems**
  - **Wireless**
  - **Accuracy** and **precision**
  - Avoidance of **Interferences**

Both **MUST BE compatible**
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Analysis of market available technologies

- Study and analysis of wireless communication applications
  - Wi-Fi
  - Wi-MAX
  - GSM/GPRS
  - 3G
  - 4G
  - BLUETOOTH
  - ISM-band
  - IEEE 802.15.4
  - EPC 18000-6C
  - RFID active
  - RFID passive

- Specifications
  - Range of measurements
  - Consumption
  - Data rate
  - Response time
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Analysis of market available technologies

❖ Study and analysis of wireless communication applications
  ▪ Wi-Fi
  ▪ Wi-MAX
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  ▪ RFID passive

❖ Specifications
  ▪ Range of measurements
  ▪ Consumption
  ▪ Data rate
  ▪ Response time
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Analysis of market available technologies

- **Admissible levels for the studied features**
  - **Range** of measurements: a short distance is good enough (- -)
  - Data rate: Not continuous monitoring a low data rate is good enough as only few bytes (-)
  - **Consumption**: as lower as possible (---)
  - Response time: not a major constraint (---)

- **Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Wi-Fi</th>
<th>Wi-MAX</th>
<th>Mobile</th>
<th>BLE</th>
<th>IEEE802.15 .4g</th>
<th>Passive RFID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>-</td>
<td>+++</td>
<td>+++</td>
<td>-</td>
<td>++</td>
<td>- - -</td>
</tr>
<tr>
<td>Data rate</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Consumption</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>-</td>
<td>-</td>
<td>- - -</td>
</tr>
<tr>
<td>Response time</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>- - -</td>
</tr>
</tbody>
</table>

To avoid **interference** with railway infrastructure communication, the reading distance in RFID should be kept below 12 meters.
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Selected technology: RFID (Radio Frequency Identification-Systems)

- **RFID includes:**
  - Readers
  - Labels or **tags**

- **Different ranges of frequencies:**
  - **Low** frequencies: 125-134.2 kHz
  - **High** frequencies: 13.56 MHz
  - **UHF:** 868-956 MHz
  - **Microwave:** 2.445 GHz

- **Passive or active**
  - **Active:** requires a battery installed in the Tag
  - **Passive:** power supply is based on the electromagnetic field emitted by the antenna
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**RFID (Radio Frequency Identification-Systems): Active or Passive systems**

- **Passive RFID (battery free)**
  - Limited read range
  - Discrete measures
  - Able to be embedded in the concrete
  - Low cost

  Research and demonstration within C4R

- **Active RFID (battery)**
  - Higher read range
  - Ability for continuous monitoring (e.g. accelerations)
  - Medium cost

  - **Rechargeable battery**
    - Able to be embedded in the concrete
  
  - **Non-rechargeable battery**
    - In a plug & play monitoring box

  - **Energy harvesting**
    - Inductive charging with electromagnetic-fields already existing in the railway track

Research but not demonstration within C4R “Vision 2050”
Selected technology: Passive RFID technology

- **Limitations of Passive RFID technology**
  - Do **not** allow continuous monitoring → discrete values for record parameters
  - **Not all devices or sensors** are compatible with RFID communications → research on relevant sensors
  - **Interferences** need to be taken into account

- **Compatible sensors with passive RFID**
  - **Needed** of obtaining relevant parameters for Structural Health analysis
    - Accelerometers (relevant for modal analysis) are **not possible** – they requires continuous or longer times of monitoring
    - **Other critical parameters** must be considered: strains, moisture, temperatures...
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Market available RFID technology and strain gauges

- **Strain Gauges**
  - **Strain** measurements
  - **Widely spread** in industry
  - High level of **reliability** and **accuracy**
  - Great **number of different applications**

- **Operating principles**

  - **Tension causes resistance increase**
  - **Bonded strain gauge**
  - **Gauge insensitive to lateral forces**
  - **Comression causes resistance decrease**
  - **Resistance measured between these points**
Market available RFID technology and strain gauges

- **Strain Gauges**
  - **Strain** measurements
    - Strain/deformation in the reinforcement bars of the concrete slab

From the strain determination in the reinforcement bars and through the use of FEM models it is possible to identify the state of stress in a slab or in a beam.
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Market available RFID technology and strain gauges

- **RFID Strain Gauges Restrictions**
  - Needed of Voltimeter to read results → Vmeter RFID
  - Embedded in the concrete block
  - Connection between strain gauges and voltmeter are required
  - Wireless communication system to send results is a prescription of the system

- **Vmeter-DCLV10**
  - Low voltage DC metering
  - Voltage range: 0V to 1.5V
  - Voltage resolution: from 1.5mV (Gain=1) to 1.5μV (Gain=1000)
  - Price: 10.11€ (>500 units)

- **Passive tag**
  - Price: 14.50€ (>25 units)
  - Price: 3.00€ (>30 units)

Material cost less than 35€ /Passive tag
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Market available RFID technology

- Other RFID compatible sensors
  - **Temperature** measurement
    - Changes in concrete behaviour
      - (sensor embedded in the concrete slab)
  - **Moisture** measurement
    - Detection of possible cracks or failures in the slab (embedded in concrete)
    - Failures in the performance of the drainage system

All of RFID devices require a *interference assessment analysis* in reinforced concrete (RC) elements.
Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS**

A number of in-lab test were performed in order to study the behaviour and performance of passive RFID in real environment.

- **Purpose of tests:**
  - Analysis of signal attenuation: due to concrete, steel and PVC coating
  - Different technologies of antennae: fixed and handheld.
  - Comparison with active RFID

- **Parameters analysed**
  - Power of antenna
  - Thickness of concrete
  - Detection distance
  - Maximum reading distance
  - Influence of PVC coating and steel
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Development of the sustainable monitoring system based on RFID technology

- IN-LAB TESTS

- Attenuation signal analysis
  - Different concrete thickness
  - Possible steel interferences
  - PVC coating for RFID sensor
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Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS**
- **Different technologies of antenna**
  - Fixed antenna: directional and cylindrical
  - Handheld mobile RFID reader

<table>
<thead>
<tr>
<th></th>
<th>Directional antenna</th>
<th>Cylindrical antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>860 – 970 MHz</td>
<td>860-960 MHz</td>
</tr>
<tr>
<td><strong>Gain</strong></td>
<td>6 dBi</td>
<td>6 dBi</td>
</tr>
<tr>
<td><strong>E-plane beam width</strong></td>
<td>60°5°</td>
<td>67°5°</td>
</tr>
<tr>
<td><strong>H-plane beam width</strong></td>
<td>74°5°</td>
<td>69°5°</td>
</tr>
<tr>
<td><strong>Nominal read distance</strong></td>
<td>8 m</td>
<td>5 m</td>
</tr>
<tr>
<td><strong>Polarisation</strong></td>
<td>Directional</td>
<td>Cylindrical</td>
</tr>
</tbody>
</table>
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Development of the sustainable monitoring system based on RFID technology

❖ IN-LAB TESTS

❖ Summary of test campaigns

- 1\textsuperscript{st} campaign ➔ Passive RFID + Fixed antennae
- 2\textsuperscript{nd} campaign ➔ Passive RFID + Handheld antenna
- 3\textsuperscript{rd} campaign ➔ Active RFID

Objectives:

- IN-LAB TESTS

1\textsuperscript{st} campaign: Passive RFID + Fixed antenna
2\textsuperscript{nd} campaign: Passive RFID + Handheld antenna
3\textsuperscript{rd} campaign: Active RFID
## Development of the sustainable monitoring system based on RFID technology

### IN-LAB TESTS

### Test campaigns

<table>
<thead>
<tr>
<th>Passive RFID + Fixed Antennae</th>
<th>Concrete</th>
<th>Steel</th>
<th>PVC coating</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Passive RFID + Handheld Antennae</th>
<th>Concrete</th>
<th>Steel</th>
<th>PVC coating</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Active RFID</th>
<th>Concrete</th>
<th>Steel</th>
<th>PVC coating</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
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</tr>
</tbody>
</table>
Development of the sustainable monitoring system based on RFID technology

- IN-LAB TESTS: 1st CAMPAIGN. FIXED ANTENNAE
  - Results for maximum range (*maximum measurement distance*)

- PVC encapsulation of RFID tag resulted in decreases of around 10% in maximum range
- Directional antenna offers notably better results (increases of more than 70% for both conditions)
Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS: 1st CAMPAIGN. FIXED ANTENNAE**
  - Results for detection distance (*distance at which reader recognize the RFID tags*)

- PVC encapsulation of RFID sensor does not show any effect on the detection distance
- The contact with a steel plate shows a high level of attenuation in the signal
- Directional antenna shows a better performance
Development of the sustainable monitoring system based on RFID technology

- IN-LAB TESTS: 1st CAMPAIGN. FIXED ANTENNAE
  - Results for maximum range for different concrete thicknesses – 2, 4, 6 and 8 cm)

- The greater the power, larger distances no matter concrete thickness
- 2 cm (a usual covering for reinforced concrete) allows measuring at reasonable distances
- For the maximum power – RFID is able to be read through 8 cm of concrete.
6. ADVANCED MONITORING SYSTEM BASED ON RFID TECHNOLOGY

- IN-LAB TESTS: 2\textsuperscript{ND} CAMPAIGN. HANDHELD ANTENNA
  - Results for maximum range in different environment
  - Without obstacle (air) – PVC coating

- Maximum range with/ without obstacles and PVC coating
- Maximum ranges are around 25\% lower than the obtained with fixed antennae but lower power
- Handheld reader is able to measure through more than 5cm thickness of concrete at a total distance of 10-15cm
Development of the sustainable monitoring system based on RFID technology

- IN-LAB TESTS: 3RD CAMPAIGN. ACTIVE RFID
  - Comparison w.r.t. passive RFID
  - Maximum range for different concrete thickness

<table>
<thead>
<tr>
<th>Direction</th>
<th>Unidirectional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>30-50 m indoor</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>RF Output Power</td>
<td>0 dBm</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>-85 dBm</td>
</tr>
<tr>
<td>Data rate</td>
<td>1 Mbps</td>
</tr>
</tbody>
</table>
Development of the sustainable monitoring system based on RFID technology

- **IN-LAB TESTS: 3rd CAMPAIGN. ACTIVE RFID**
  - Results for the different concrete thicknesses (0, 2, 4, 6, 8, 14, 21 cm)

  ![Graph showing Maximum range vs Concrete cover](image)

  - Results were as expected:
    - Able to read at much **larger distances**
    - Attenuation dependent of inverse square distance
Development of the sustainable monitoring system based on RFID technology

- **ASSEMBLY OF SYSTEM**
  - Prototypes SP1

**Monitoring System**
- Strain Gauge
- Passive RFID
- Encapsulation

**Reinforced Concrete Element**
- Rebar
- non-metallic fastening
- passive RFID
- strain gauge
- wire
Development of the sustainable monitoring system based on RFID technology

Connections

\[ \varepsilon = \frac{\Delta R}{R} \]

\[ \Delta R = \frac{4RV_m}{V_R - 2V_m} \quad \text{Where } V_m := V_{IN-} - V_{IN+} \]
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Testing of the monitoring system

Test: puntual stressing of strain gauge
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Deployment at real pilot at CEDEX laboratory

INSTALLATION AND TESTS IN PROTOTYPES SP1
AT CEDEX INTEROPERABILITY RAIL LABORATORY (MADRID, SPAIN)
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Summary

• Development of a monitoring system for the slab track concepts developed within C4R

• Based on Passive RFID technology

• Shows adequate performance especially in relation to measurement distance and energy consumption

• Signal attenuation and interference with other infrastructure communication system analysed

• Low cost (less than 35 € per tag), easy deployment, no maintenance
Thank you for your kind attention

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