Novel monitoring techniques for preventive maintenance of railway tracks

Rolf Dollevoet

BCRRA 2017 Athens
Railway Engineering
Contents

- Railway Engineering Group
- Education
- Research / monitoring
- Cases workshop BCRRA 2017
  - CTO train
  - Vibration
  - Axlebox accelerations
  - Remote sensing
Group: Railway Engineering, TU Delft

1949 - 2006 chair: Van Veen, Cuperus, Van Bilderbeek, Van Witsen, Esveld
2006 - 2012: Chair vacancy...

2012 > chair: Dollevoet (part-time TU Delft and ProRail (Dutch infra manager Railway))
Challenge and focus: more for less money, and interfaces research

Group: 13 staff members, 18 PhD’s, 1 PDEng, 4 Postdoc’s, 6 guest researchers


**Education: knowledge for craftsmanship**

- Academic research
- Practical validation and experience
- Adult education

---

**TU Delft**
New talents at MSc-level

- Attrack young students (BSc)
- 11 new blended courses
- Specialisation Railway Systems
Professional Doctorate PDEng

- Pure focus on innovation
- From talent to specialist in 2 years
- Practical themes of Rail practice
Professional Education

- Long life learning
- Modular program, part-time
- Actual issues to be engineered
Worldwide on demand

- New online courses, MOOC Rail
- Focus on System approach
- Starts in October 2017
Online platform RailaHead

- Enthuse students early
- Knowledge centre
- International connections
Research: real-life-lab

- CTO measurements
- Modeling
- Wheel-rail test rig
Wheel-Rail Contact

- Slippery track
- Noise and vibration issues
- Preventive maintenance
Smart Materials

- Digital elastic materials
- Self healing
- CO2 reduction and durability
Sensors / Monitoring

- Measurements on board
- Predictive maintenance
- Vehicle behaviour / Big data
Operations and design

- 'Choice' vision
- Less switches and levelcrossings
- Robust System
Door to Door

- Twizy D2D100%EV
- Passenger Journey
- Station of the Future (Delft Zuid)
Energy

- Rolling pantograph
- Recuperation brake energy
- 3kVolts project, the Netherlands
Crowd Sensing

- Social Awareness
- Rush hour questions
- Sensors = passenger
Virtual Reality

- Serious Gaming
- Education and training
- Costs efficient; easy plan process
Operations Control

- ERTMS
- ATO
- Monitoring platform = train
TU Delft Express

- Innovation = proven technology
- Running lab and class-room
- Testing of knowledge in practice
Cases: BCRRA Workshop Rail CTO

- Railway test platform for rail society
- For **free** (inclusive students....)
- Today: 8 companies work with CTO and TU
Vibration reducing underground constructions

Measure in the propagation path
4 types of underground constructions

- **Barrier Coated barrier**: < 4 dB
- **Sheet piles**: < 14 dB
- **Ditch or trench**: < 3 dB
- **Coated barrier**: < 14 dB
Rolling Stiffness Measurement Vehicle

Simulated axle load 30 ton
Frequency 0-20 Hz
Lateral 15 ton

Measurement speed: 40 km/h
Dynamic load: < 50 Hz, < 60 kN
Static axle load: 180 kN
Measuring

Vibrating mass at different frequencies
Data fusion / big data & understanding the physics

Combinations of:

- Location
- Geo Radar
- Image
- Substructure
- Soil info
- Stiffness
- Phase difference
- etc.

TU Delft
ABA: axlebox acceleration monitoring

- "baby" Squats detection: 80% hitrate at operational trainspeed
Remote Sensing: Microwave

- **Microwave** → in all weather
- Centimeter wavelength → millimeter measurement precision

<table>
<thead>
<tr>
<th>Wavelength (λ)</th>
<th>Used by satellite-borne radar</th>
<th>Used by airborne radar to see below Earth’s surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.7 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>700 nm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1st pass
At time $t_1$

**Satellite measurement:**
- **Amplitude** – record the ground target reflection
- **Phase** – record the location/motion of the ground targets $[-\pi, +\pi]$
Satellite measurement:

- **Amplitude** – record the ground target reflection
- **Phase** – record the location/motion of the ground targets $[-\pi \, +\pi]$ 

$\phi^{1,2}$

→ calculate the phase difference between $t_1$ and $t_2$ -- the settlement value is obtained

Satellite Radar Interferometry (InSAR) techniques
Q: Can these satellites observe every ground object in railway infrastructure environment?

Train
Rails
Embankment
Poles
Catenary
Sleepers
Squat
Grass
Tree ...
Q: Can these satellites observe every ground object in railway infrastructure environment?

- Train
- Rails
- Embankment
- Poles
- Catenary
- Sleepers
- Squat
- Grass
- Tree ...

☑️
Good to know....

- Radar satellite delivers data in **all weather**, since **1992**, some medium-resolution data are **free**

- Radar satellite data are
  - in **millimeter-estimation** precision
  - **routinely** updated
  - **wide-scale**, e.g. ~100 km swath
  - used for railway infrastructure **permanent settlement/deformation** monitoring, not for railway dynamic deformation monitoring
Nation-wide rail-deformation

Readability for non-InSAR people

Radarsat-2 data [2010.06 – 2015.08]
New-built tracks, Lelystad area (Hanzelijn)

Total differential deformation between this new-built track and the adjacent old-built track is up to \(~50\) mm in [2010/2015].

\[\text{Radarsat-2 data [2010.06 – 2015.08]}\]

\[\text{('risk' to be defined by end user)}\]
Example
Risk-map

Legend
Warning flag
-10mm/yr
>+8mm/yr
railway

Gas field

Radarsat-2 data [2010.06 – 2015.08]

(‘risk’ to be defined by end user)
LOS-vector decomposition

Rotation matrices:

\[ R_1 = \begin{bmatrix} \cos \beta & \sin \beta & 0 \\ -\sin \beta & \cos \beta & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad R_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \gamma_s & -\sin \gamma_s \\ 0 & \sin \gamma_s & \cos \gamma_s \end{bmatrix}, \quad R_3 = \begin{bmatrix} \cos \gamma_t & 0 & \sin \gamma_t \\ 0 & 1 & 0 \\ -\sin \gamma_t & 0 & \cos \gamma_t \end{bmatrix} \]

\[ d_{geo} = R_1 R_2 R_3 d_{track} \]
\[ d_{track} = [d_T, d_L, d_N]^T \]
Q: How do we turn this into ‘information’?
Linking the satellite reflections to assets.

Using laser scanning data, link every satellite measurement to a specific asset.
Linking the satellite reflections to assets
Using laser scanning data, link every satellite measurement to a
Miss InSAR space
Dr. Ling Chang, TU Delft
2 – 5 years
5 – 10 years
20 years
50 years
Thanks to my COLLEAGUES!

TU Delft