Automating Track Inspection through the use of Automatic Machine Vision Systems
SBB – Lotschberg Case Study

The Lötschberg Base Tunnel

- Length: 21.5 miles
- Twin Tube, single track...one tube complete
- 110 trains per day
  - 30 passenger ≤ 250 km/h
  - 80 freight ≤ 160 km/h
- Single track
- Basic Visual Inspection made impossible by intense traffic

*First world example of a fully integrated and automated infrastructure inspection system*
Why use an Automated Inspection System?

**FAST AND PRECISE MEASUREMENTS. QUICK AND MORE EFFICIENT IDENTIFICATION OF PROBLEMS**

- Automated Track Vision allows consistent, objective inspection of a large number of different track components.
- **Reduction of measuring time and increase of inspection frequency**: Automated Inspection Systems mounted on a train can inspect up to 200 km per hour compared to a maximum of 10 km per day with a Basic Visual Inspection.
- Serious defects could be detected in a preliminary stage when a preventive maintenance action is possible (i.e. Headchecks are detectable with a resolution of about 0.15 mm).

With an automated system are not only faster but also incredibly more accurate.
Diagnostic Vehicle
ROGER 1000 SBB

Track geometry measurement
Track gauge, alignment, cant, twist, longitudinal level

Rail profile measurement
Rail profile, rail wear, wheel/rail contact geometry

Rail corrugation measurement
Short-, medium- and long-wave components

Track measurement and inspection
Condition of rail fastenings, rail running surfaces, sleepers, ballast bed and signalling equipment on the track

OHL measurement and inspection
Inspection of contact wire position and wear, structures, droppers, clamps, cables, contact wires and insulators

Voltage and rail return current metering

Video inspection
Overview video from the perspective of the driver
## Defect Severity Levels

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
<th>Possible Effects &amp; Maintenance Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Defects</td>
<td>Defect that pose either an immediate or near-term hazard to safe and efficient operation.</td>
<td>They represent a potentially severe condition such as a track buckle. These types of defects are what preventative maintenance and periodic track inspection are intended to prevent.</td>
</tr>
<tr>
<td>Relevant Defects</td>
<td>Defects that cause sub-optimal track structure conditions but do not present an immediate hazard to train operations.</td>
<td>Usually a relevant Defect could become critical, in some environmental condition, if it occurs along an extended portion of track. A periodic Inspection could detect a relevant defect in a early stage and prevent more serious problems</td>
</tr>
<tr>
<td>Symptomatic Defects</td>
<td>Symptomatic defects do not necessarily represent deficiencies per se, but they may be indicators of a possible problem.</td>
<td>These are not defects, but they indicate possible hidden issues in rail infrastructure. Through the collection of many inspection data, these symptomatic defects could be correlate between them and suggest a better maintenance action</td>
</tr>
</tbody>
</table>

Every defect could have a different level of severity that requires a different approach to inspection and maintenance
## 3PS (3 Point Scan) Track Geometry Measuring System

### Parameter | Accuracy
--- | ---
Gauge | ± 0.8 mm
Crosslevel (Cant) | ± 2.5 mm

**Twist**

| Base length |  
|---|---
| < 5.5 m | ± 1.5 mm / Base length
| 5.5 m < BL < 20 m | ± 3.0 mm / Base length

**Longitudinal Level (right and left rails)**

| Wavelenght |  
|---|---
| 3 m < λ < 25 m | ± 1.0 mm
| 25 m < λ < 70 m | ± 3.0 mm
| 70 m < λ < 150 m | ± 5.0 mm

**Alignments (right and left rails)**

| 3 m < λ < 25 m | ± 1.5 mm
| 25 m < λ < 70 m | ± 4.0 mm
| 70 m < λ < 200 m | ± 10.0 mm

Using the latest in no-contact optical technology the 3PS system takes measurements from the real rail profiles, applying the chord principle and providing the most accurate information.

Fully EN-13848 compliant

Typical sampling distance: 25 cm
RAIL PROFILE Measuring System

The system measures both horizontal and vertical rail wear. By means of the analysis software, it compares the worn profile to the original, allowing your maintenance team to detect areas with problem.

<table>
<thead>
<tr>
<th>Parameters Measured</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical wear</td>
<td>Up to ± 0.2 mm</td>
</tr>
<tr>
<td>Horizontal wear</td>
<td>Up to ± 0.2 mm</td>
</tr>
<tr>
<td>45° wear</td>
<td>Up to ± 0.2 mm</td>
</tr>
</tbody>
</table>

Features

- Typical Sampling Distance: 25 cm
- Measuring Speed: From 0 to 360 km/h
RAIL CORRUGATION Measuring Systems
Chord based Rail Corrugation Measuring System

<table>
<thead>
<tr>
<th>Rail Corrugation Wavebands</th>
<th>Reproducibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Waves [10-100] mm</td>
<td>± 10 µm</td>
</tr>
<tr>
<td>Medium Waves [100-300] mm</td>
<td>± 30 µm</td>
</tr>
<tr>
<td>Long Waves [300-1000] mm</td>
<td>± 100 µm</td>
</tr>
</tbody>
</table>

Features

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Distance</td>
<td>Up to 5 mm</td>
</tr>
<tr>
<td>Resolution</td>
<td>5 µm</td>
</tr>
<tr>
<td>Measuring Speed</td>
<td>From 0 to 160 km/h</td>
</tr>
</tbody>
</table>

Based on the chord principle, the measurement system is a no-contact optical chord based rail corrugation measuring system.

Real time functionality include data acquisition, storage and diagram visualization in all the three wavelengths.
# V•CUBE
## TRACK INSPECTION SYSTEM

<table>
<thead>
<tr>
<th>Features</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Horizontal Resolution</td>
<td>0.8 mm/pixel</td>
</tr>
<tr>
<td>Typical Sampling distance</td>
<td>1 mm</td>
</tr>
<tr>
<td>Measuring Speed</td>
<td>From 0 up to 200 km/h</td>
</tr>
</tbody>
</table>

---

**Features**

- **Typical Horizontal Resolution**: 0.8 mm/pixel
- **Typical Sampling distance**: 1 mm
- **Measuring Speed**: From 0 up to 200 km/h
# V•CUBE

Track Measurement System

<table>
<thead>
<tr>
<th>Features</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Transversal resolution</td>
<td>0.73 mm/pixel</td>
</tr>
<tr>
<td>Typical Sampling distance</td>
<td>6 mm</td>
</tr>
<tr>
<td>Measuring Speed</td>
<td>From 0 up to 180 km/h</td>
</tr>
<tr>
<td>Functional feature</td>
<td>Acquisition of the transversal 3D track profile</td>
</tr>
</tbody>
</table>

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**Typical Transversal resolution**

**0.73 mm/pixel**

**Typical Sampling distance**

**6 mm**

**Measuring Speed**

**From 0 up to 180 km/h**

**Functional feature**

**Acquisition of the transversal 3D track profile**
V•Cube - Linear Rail Surface Defects
Rolling Surface Analysis

Linear Rail Surface Defects

- **Defects Description:**
- **Defects Detected:**
  - Cracks on Rolling Surface
- **Technical Features:**
  - Minimum thickness: from 0.5mm to 1mm
  - Minimum length: 20 mm
V•Cube - Linear Rail Surface Defects

Rolling Surface Analysis

Detection and Estimation of Joint Gap

- **Description:**

- **Defects Detected:**
  - Joints are automatically detected and the system can provide an estimate of minimal and average distance between rails.
  - Defects are reported if joint gap is too narrow or too wide.
  - Rail temperature measurement can be associated.

- **Technical Features:**
  - Accuracy can vary from 0.25mm to 1mm.
### V•Cube - Missing Fastening and Rotated or Missing Clips

**Fastening Check**

#### Description:
- Defects Detected:
  - Missing Fastening
  - Rotated Clips
  - Missing Clips

#### Technical Features:
- Analysis based on Optical Modeling
- Real time analysis
- Detection Rate: 99.92%
- False positive/km as low as 5 for every rail.

<table>
<thead>
<tr>
<th>Type</th>
<th>Automatically extracted Fastening Image</th>
<th>Fastening features extraction (in red)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W 14</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>
**Symptomatic Defect**

**V•Cube - Shifted Rail Pads**

**Fastening Check**

**Missing or Rotated Fastenings**

- **Description:** If the fastening is not well fixed, the pad could move from its originally position. This defect could be an index of poor pressure fastening/rail foot and can compromise rail insulation.

- **Defects Detected:**
  - Shifted Rail Pad
V•Cube - Shifted Rail Pads
Fastening Check

Released Base Plates
- **Description:** The consequence of a released base plate is a change in color between tie and base plate.
- **Defects Detected:**
  - Shifted Base Plate
  - Subsided Base Plate
Fastening Markings Detection

- **Description**: For each type of fastening, for each side (left / right), the phenomenon may occur in two different ways (mkg-up and mkg-down): if the fastener, on both sides, doesn’t correctly press on the rail foot, the could be a shift in either direction causing the clips to leave a mark on the rail foot. The marking has a different morphology depending on the type of fastener, the direction of displacement and the magnitude of the displacement.

- **Defects Detected**:
  - Markings on rail
**V•Cube - Missing Bolts Detection**

**Fastening Check**

- **Description:** V-Cube automatically recognizes the model of the analyzed fastenings. Bolts presence is automatically checked even on the shoulder plate.

- **Defects Detected:**
  - Missing Bolts

---

**Fastening Missing Bolts Detection**

- **Description:** V-Cube automatically recognizes the model of the analyzed fastenings. Bolts presence is automatically checked even on the shoulder plate.

- **Defects Detected:**
  - Missing Bolts
Fastening Tightening Measurement

- **Description:**
  Fastening tightening can be evaluated by measuring the height of the upper bolt surface with respect to the rail foot, or the height of the fastening clip with respect to the rail foot. Fastening position and model is identified automatically, for each measured fastening one or two values are reported in graphical form.

- **Defects Detected:**
  - Unscrewed Bolts
  - Fastening Position
Symptomatic Defect

Rail Anchors displacement in time

- **Description:**
The distance from the centre of the nearest fastening is calculated for each detected.
In the subsequent acquisition of the same track the same processing can be performed and compared to the previous (stored) pincer distance from the fastening.
The comparison of the two data will provide the eventual displacement of the pincers.

- **Defects Detected:**
  - Rail Anchors Displacement
Concrete Sleeper Crack Detection

**Description:** When the system finds a concrete sleeper, the image is analyzed to search for cracks.

**Defects Detected:**
- Concrete Sleepers Cracks

**Technical Features:**
- Minimum crack Thickness value is 1 mm
- Typical minimum crack length is 50 mm
Iron Sleepers Crack Detection

- **Description:** V-Cube is able to automatically recognize steel sleepers and consequently detect cracks in the sleepers.

- **Defects Detected:**
  - Steel Sleepers Cracks

- **Technical Features:**
  - Minimum Crack Thickness can vary in a range from 0.5 mm to 1.5 mm
  - Typical minimum crack length is 50 mm
V•Cube - Sleeper Type Recognition and classification

Sleeper Check

Sleeper Material Recognition and classification

- Description: V-Cube can recognize sleeper material. The extracted parameter is a statistical report of the mixture: how many concrete or wooden or steel sleepers in the analysed zone.
V•Cube - Excess or Lack of Ballast

Track Bed Check

Ballast defect detection

- **Description:** The level of ballast is measured with reference to the rail foot height. The excess or lack of ballast is defined by taking the difference between height of ballast level and rail foot against user defined limit.

- **Defects Detected:**
  - Ballast Excess
  - Ballast Leakage
Mud and Dancing Sleepers Detection

**Description:** Ballast optical analysis permits identification of excess of dry mud and dancing sleepers phenomenon. This two events can be used to understand health of the track bed underground.

**Defects Detected:**
- Moving Sleeper
- Mud on Ballast
**V•Cube - Eurobalise detection and check**

**Track Bed Check**

**Eurobalises detection and check**

- **Description:**
  The beacon devices have to be checked to avoid the possibility of wrong positioning. The system is able to automatically check the maximum height of the devices with respect to the rolling plane and distance from the rail longitudinal axis.

- **Defects Detected:**
  - Eurobalise Detection
  - Eurobalise Measurement
**V•Cube - Signaling beacons detection and measuring**

**Track Bed Check**

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**Beacon detection and position check**

- **Description:**
  The beacon devices have to be checked to avoid the possibility of wrong positioning. The system is able to automatically check the maximum height of the devices with respect to the rolling plane and distance from the rail longitudinal axis.

- **Defects Detected:**
  - Signalling Beacon Detection
  - Signalling Beacon Measurement

- **Technical Features:**
  - Positioning Tolerance Range provided by the signalling rules
Switches, Crossing, Check Rails Detection & Classification

Description: This is made in order to:
- Prevent False alarms from fastening and sleepers check
- Correct the localisation info, if database available
- Measure distance from the track
Axle counters detection and position check

- **Description:**
  Axle counter (wheel detectors) can be automatically detected and measured by TSMS. The devices have to be checked to avoid the possibility of wrong positioning. The system is able to automatically check the maximum height of the devices with respect to the rolling plane.

  This feature is Model Based, each model requires a dedicated development.

- **Defects Detected:**
  - Axle Counter Detection
  - Axle Counter Measurement

- **Technical Features:**
  - Positioning Tolerance Range provided by the signaling rules
**Unknown objects detection**

- **Description:**
  Unknown objects that occupy volume close to the rail can be automatically detected and measured. Every no permanent way object is analysed, if the object volume is over a parameter threshold, V-Cube system shows it as a potential defect.

- **Defects Detected:**
  - Unknown Object Detection
  - Unknown Object Measurement
**Base Plates (slab track) Crack detection**

- **Description:** Slab track crack detection is applied on ballast less tracks. TSIS automatically activates this function when a ballast less section is identified by TSMS.
- **Defects Detected:**
  - Base Plate Crack Detection
  - Base Plate Crack Measurement
- **Technical Features:**
  - Minimum Crack thickness is 125% of the sampling step: typical value is 1mm;
  - Typical minimum crack length is 100mm
Excess of vegetation

- **Description:**
  Excess of vegetation is automatically detected and defect extension area is reported.

- **Defects Detected:**
  - Excess of vegetation Detection
  - Extension Area Measurement
Level Crossing Detection & Level Measuring

Description: This is made in order to:
- Prevent False alarms from fastening and sleepers check
- Correct the localisation Info
- Average level respect to rail top surface can be calculated
# Head Check Detection

<table>
<thead>
<tr>
<th>Features</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition frequency</td>
<td>≈ 222 kHz</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.15 mm</td>
</tr>
<tr>
<td>Sampling distance</td>
<td>0.15 mm</td>
</tr>
<tr>
<td>Measuring Speed</td>
<td>From 0 up to 120 km/h</td>
</tr>
</tbody>
</table>

A unique laser illumination system, developed by MER MEC is used to illuminate the rail.

The system is able to determine crack with size from 0.15, their angle, length and frequency.

Head check is so identified in early stage, when correction is still possible by means of light grinding.
OHL Geometry and Contact Wire

Parameters Measured | Accuracy
--- | ---
Wire Stagger | Up to ± 10 mm
Wire Height | Up to ± 10 mm
Wire Wear | Up to ± 0.2 mm

Features | Details
--- | ---
Number of detected wires | Up to 8
Sampling distance | Standard 20 mm
 | Customizable to Client’s needs
Measuring Speed | From 0 to 360 km/h

MAIN FEATURES
- Laser based system
- High resolution / High speed Line Scan Cameras
- Very short integration time of 50-100µs eliminates blurring at high speeds
- Measurement rate up to 5,000 measurements per second (every 20mm @ 360 km/h)
- Cleaning and conditioning subsystems
- High immunity to environment light

* All measured parameters are with reference to the rolling plane, independent of the vehicle’s spatial position.
Pantograph/Catenary Interaction

<table>
<thead>
<tr>
<th>Parameters Measured</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact pressure on the pantograph</td>
<td>&lt; 1% of the applied force</td>
</tr>
<tr>
<td>Vertical contact strip accelerations</td>
<td>&lt; 1% of the max measured acceleration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Features</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling distance</td>
<td>25 cm</td>
</tr>
<tr>
<td>Measuring Speed</td>
<td>From 0 to 320 km/h</td>
</tr>
</tbody>
</table>

The measuring system is based on mechanical contact technology using accelerometers and load cells. It provides both static and dynamic measurements of interaction forces and vertical accelerations, with a dynamic sampling frequency of up to 2kHz at speeds of up to 320 km/h.
Electric Parameters Measuring System

The system acquires, in all environmental conditions, the electrical parameters that can be processed in order to identify the characteristic of the electric power drained from the contact line. Using onboard software with real time data analysis, the system can measure both the voltage and the traction current at speeds of up to 320 km/h.

For both measurements, the overhead line voltage can be correlated with the current drained by the vehicle.

### Tension Measurement Main Features

<table>
<thead>
<tr>
<th>Technology</th>
<th>Line drained current: up to 3 KA peak DC or 400Arms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Parameters</td>
<td>Overhead Line Voltage: (DC) up to 4.5 Kv and (AC) up to 30 kVrms</td>
</tr>
<tr>
<td>Measuring Speed</td>
<td>0 - 320 km/h</td>
</tr>
<tr>
<td>Sampling Frequency</td>
<td>10 kHz</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 1%</td>
</tr>
<tr>
<td>Visualized Graphs and Data</td>
<td>• Line Voltage: DC or AC • DC or AC Lined Line voltage harmonics content • Singular points • Vehicle speed</td>
</tr>
<tr>
<td>Processed Parameters</td>
<td>Time domain frequency analysis</td>
</tr>
</tbody>
</table>

### Drained Currents Measurement Main Features

<table>
<thead>
<tr>
<th>Technology</th>
<th>Electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Parameters</td>
<td>Line drained current: up to 3 KA peak DC or 400Arms</td>
</tr>
<tr>
<td>Measuring Speed</td>
<td>0 - 320 km/h</td>
</tr>
<tr>
<td>Sampling Frequency</td>
<td>10 kHz</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 0.5%</td>
</tr>
<tr>
<td>Visualized Graphs and Data</td>
<td>• DC or AC Lined drained current • DC or AC Lined drained current harmonics content • Singular points • Vehicle speed</td>
</tr>
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<td>Processed Parameters</td>
<td>Time domain frequency analysis</td>
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</tbody>
</table>
OHL Defect Detection

The main purpose of the system is to inspect the overhead line in order to detect defects on its infrastructure components.

This inspection is carried out by means of two “field of views”:

**Longitudinal Structure Inspection (LSI)**

made by a 4000 pixel linear camera

**Transversal Structure Inspection (TSI)**

made by a 10 Mpixel matrix camera
OHL Defect Detection
Detection and Recognition of Objects of Interest and Defects
OHL Video Recording

MAIN FUNCTIONS
- OHL infrastructure video recording
- Catenary video recording
- Analogic/digital recording of the images
- Sending of critical images via wireless connection
## Clearance Profile Detection & Tunnel Walls Inspection System

### Features

<table>
<thead>
<tr>
<th>Measurement speed</th>
<th>0 - 200 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature range</td>
<td>-15°C to 50°C</td>
</tr>
</tbody>
</table>

#### Clearance Profile Measurement

- Filed of view: circle with 1.5 m – 8 m radius from the track center
- Acquisition frequency: up to 1000 gauge profiles per second
- Measured points: 5000 points/profile
- Sampling step: 3 mm – 70 mm (10 mm at 30 Km/h)
- Azimuth Resolution: 2 mm -10 mm depending on “circle radius”
- Measurement Accuracy: between 1 mm and 10 mm depending on the distance

#### Tunnel Wall Inspection System

- Filed of view: tunnels up to 9 meters wide from track center
- Acquisition frequency: up to 4000 Hz
- Sampling step: 0.7 mm – 13 mm (2 mm at 30 Km/h)
- Image Resolution: 0.5 mm/pixel - 3 mm/pixel depending on tunnel wall distance
Clearance Profile Detection & Tunnel Walls Inspection System
Detection and Recognition of Areas of Interest and Defects
MAIN FUNCTIONALITY
- Track video recording
- Sideways video recording
- Driver view video recording
- Night vision
- Analogic/digital recording of the images
- Sending of critical images via wireless connection
Why use an Automated Inspection System?

PERFORMANCE & RISK OPTIMIZATION IN MAINTENANCE

- A Study case with an important conventional railway shows the importance of automated inspection in particular and dangerous environment such as tunnels
- Around 110 trains a day run through a base tunnel 34 km long and for this intense traffic Basic Visual Inspection is impossible
- Thanks to Automated Inspection Systems signalling devices and fastenings in the tunnel are inspected every 15 days without affecting network traffic

Automatic inspection systems guarantee:
- Longer term predictive assessment of the health of track
- Increased availability of network
- Increased Safety in Operations
Thanks for your kind attention