FINAL PUBLISHABLE SUMMARY REPORT
(Section 1 of the Final Report)

Grant Agreement number:	SCP8-GA-2009-234040
Project acronym:	INTERAIL
Project title:	Development of a Novel Integrated Inspection System for the Accurate Evaluation of the Structural Integrity of Rail Tracks
Funding Scheme:	FP7

Period covered: **from** 1st September 2009 **to** 31st March 2013

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INTERAIL

"Development of a Novel Integrated Inspection System for the Accurate Evaluation of the Structural Integrity of Rail Tracks"

SCP8-GA-2009-234040

Document reference: INRAIL/ISQ/FR-PS-27-v1	**WP/Task:** WP I
Revision number: 1 **N. pages**: 46	**Deliverable no:** D17
Documents included:	**Level of Dissemination (PU/CO):** PU

Document Title: Project Final Publishable Summary Report		
Company: ISQ		**Distribution List**: *EC* *All partners*
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Abstract:
The present document presents the objectives and project context as well as the main S&T results achieved, its potential impact and dissemination activities.

Notes:
This document corresponds to the Final Publishable Summary Report included as Section 1 of the project Final Report.
This document is a revised version accordingly with the comments received from the PO.

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1. FINAL PUBLISHABLE SUMMARY REPORT

1.1 Executive Summary

Rail infrastructure managers have been showing strong interest in the development of novel techniques for the reliable and accurate evaluation of rails and faster inspection operations which will lead to the improvement of the efficiency of preventative maintenance and reduce the need for reactive maintenance to the lowest possible level.
Inspection systems based on conventional ultrasonics probes will remain the main rail evaluation method in the foreseeable future. Nevertheless, currently employed rail inspection methodologies do not achieve the highest level of reliability and cost effectiveness objectives required by the industry.

INTERAIL (Development of a Novel Integrated Inspection System for the Accurate of the Evaluation of the Structural Integrity of Rail Tracks, was a collaborative FP7 project under SST.2008.5.1.1: "Advanced and cost effective infrastructure construction, maintenance and monitoring", funded by the European Commission comprising 13 partners from seven European countries. INTERAIL aims to minimise the occurrence of rail failures through the implementation of a novel integrated high speed inspection system.

An integrated high-speed system which combines automated visual inspection, with electromagnetic sensors and conventional ultrasonics supported by a central control data unit and data treatment software, is able to offer a more efficient and reliable method for inspecting rails in the short to medium-term. Advanced manual defect verification techniques, as ACFM (alternating Current Field Measurement), UT phased array and High Frequency Vibration, were also researched for faster and more reliable inspection of structural integrity of rails.

The INTERAIL project produced a railway automated on-line inspection prototype system which showed with success the reliability of inspection which has been fully supported by manual verification techniques.

The successful implementation of INTERAIL results and future commercialisation of the prototype or inspection services availability, offers to the railway industry several technical and economic advantages, increasing the reliability of inspections, optimisation of maintenance operations and thus to railway safety and availability.

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1.2 Summary description of the project context and objectives

The technological advances in train design during the last years have enabled the construction of more high-speed rail lines and the broader use of high-speed trains as an alternative and environmental friendly means of travel, which offers fast and reliable transportation of passengers and goods between hundreds of cities across the European continent. The increasing trend for the industry's business is forecast to continue in the forthcoming years, since rail transport is steadily becoming a more attractive option over other means of transportation for the public. This is due to the fact that train travel is generally cheaper than using a car or an airplane, and very often the fastest option to reach a destination. It is also inherently safer and far more environmentally friendly in comparison to car travel, without compromising passenger convenience.

Today, rail networks across Europe are getting busier with trains travelling at higher speeds and carrying more passengers and heavier axle loads than ever before. The combination of these factors has put considerable pressure on the existing infrastructure, leading to increased demands in inspection and maintenance of rail assets due to the higher risk of catastrophic failure.

The successful implementation of the INTERAIL system delivers a step change in rail inspection practices currently employed by the rail industry through the development of a novel inspection approach integrating in a single vehicle different advanced techniques, leading to higher levels of reliability and safety.

Figure 1 – The Hatfield Rail Track Site following the accident [2]

[2] Grassie, S. L. **"**Rolling Contact Fatigue on the British railway system: treatment,Wear", 2005, 258, 1310-1318.

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The INTERAIL project aimed at the development and implementation of an integrated high speed inspection system based on a modular design, which will enable a faster and more reliable inspection of rail tracks at faster speeds compared to the available ones.

INTERAIL presented the following major objectives:

1) To overcome the limitations of current inspection procedures of rail tracks through the successful implementation of an integrated high-speed inspection system based on automated visual, Alternating Current Field Measurement (ACFM) and ultrasonics techniques, combined in a single architecture as shown in the figure presented.

2) To develop advanced verification and evaluation procedures of the defects detectable by the high-speed system based on ACFM, ultrasonic phased arrays, and high-frequency vibration analysis equipment.

3) To achieve higher levels of Probability of Detection (PoD) of rail defects leading to the substantial improvement in the actual reliability of the European rail network.

4) To decrease inspection times and associated costs by up to 75% through the integration of three different rail track evaluation techniques that will complement each other as part of a functional single high-speed NDE.

5) To develop the required software and intelligent control unit to enable automatic and real-time analysis of the defects detected and minimise human subjectivity during the interpretation and analysis of results.

6) To contribute to the harmonisation of inspection procedures and network reliability across Europe.

The INTERAIL system combines the use of automated visual inspection with ACFM and ultrasonics probes into a single high-speed inspection vehicle. Each module provides information for different aspects of the condition of the rail track. For example, the automated visual inspection module provides information on levels of corrugation, rail head profile, rolling contact fatigue damage, missing bolts, and defective slippers. The ACFM module detects and quantify RCF damage including head checks, squats and wheelburns, while the ultrasonics module detects and evaluates any internal defects that may be present in the rail. Integration of the three aforementioned modules will allow the full assessment of the condition of the rail track in a single run, resulting in a noteworthy reduction of inspection times when compared with existing state of the art high-speed NDE systems. Furthermore, by fusing and analysing the data obtained through the different inspection modules, it is possible to minimise the occurrence of false defect indications leading to further reductions in inspection times, cost and personnel effort, while rail track reliability is optimised.

The high-speed INTERAIL system was complemented through the development of manual defect verification and evaluation techniques which was applicable for the inspection of welds, switches and crossings. Welds, switches and crossings are particularly difficult to inspect with existing equipment due to the technical limitations involved. The consortium developed three different

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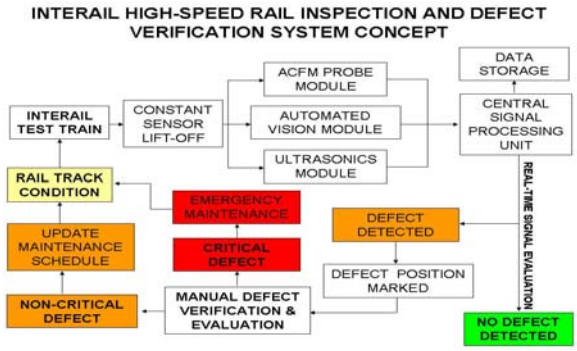
techniques for this purpose, including ACFM for the evaluation of surface-breaking defects, ultrasonic phased arrays for detection and assessment of internal defects and high-frequency vibration analysis for the inspection of welds, switches and crossings.

The schematic in Figure 2 shows a simplified outline of the concept of the INTERAIL inspection platform. The successful implementation of the INTERAIL inspection system will offer to the European rail infrastructure managers the opportunity to harmonise their inspection procedures and bring the realisation of a Pan-European rail network closer.

The successful integration and validation tests of the INTERAIL high-speed rail inspection system, defect verification and evaluation techniques was followed thoroughly planned field trials and demonstration of the system's capability at the consortium railway operators, REFER and STIB.



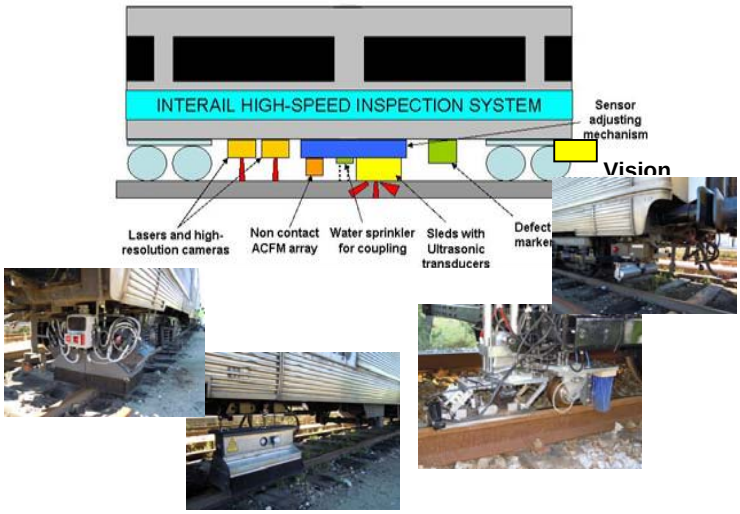


Figure 2 – Project Concept and involved NDT inspection modules.

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The major results achieved in the project were:

- High speed Automated Inspection equipment integrating several NDT techniques installed at REFER dedicated inspection vehicle.

- Intelligent software and control unit;

- Manual inspection equipment for faster and efficient inspections;

- Reduction of costs, time and accident probability;

- Increase of POD and reduction of POF;

- Training of operators and follow up for certification procedures.

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1.3 Description of the main S&T results/foregrounds

This section describes the main results obtained and demonstrated in INTERAIL project. The section will be divided according the main group of results which are:

- ***High Speed Inspection system:*** This subsection includes the different operating inspection modules and the central unit
- ***Manual Inspection Verification Techniques:*** This section includes the different manual techniques developed to validate the high speed inspection system

1.3.1 HIGH SPEED INSPECTION SYSTEM

The main result of INTERAIL was the development of an automated High Speed Inspection System which combines three inspection modules in a single vehicle, ultrasound, ACFM and Vision Module. The inspection speed can vary according the number of modules simultaneously active. These modules were adapted in a rail vehicle through the development of a mechanical fixing and moving device named High Speed deployment system. The data from the different inspection modules is combined in the Central Processing Unit.
This section will present the five main results obtained in the High Speed Inspection system: Deployment System, Ultrasound Module, ACFM Module, Vision Module and Central Processing Module.

1.3.1.1 Deployment System

A sensor adjustment mechanism was developed in order to control and adjust the lift-off and position of the ACFM and ultrasonic sensors.

The frame is composed by 120x60x8 mm structural beam profiles (Figure 3). It was attached to the inspection vehicle at four points by the wheel axles. The longitudinal beams have a lubricated slider box which compensates for small variations in distance between the axles. The sensor adjustment mechanism is located in the transverse beam, being vertically and transversely positioned by mean of actuators. The following figures show an overall view of deployment system.

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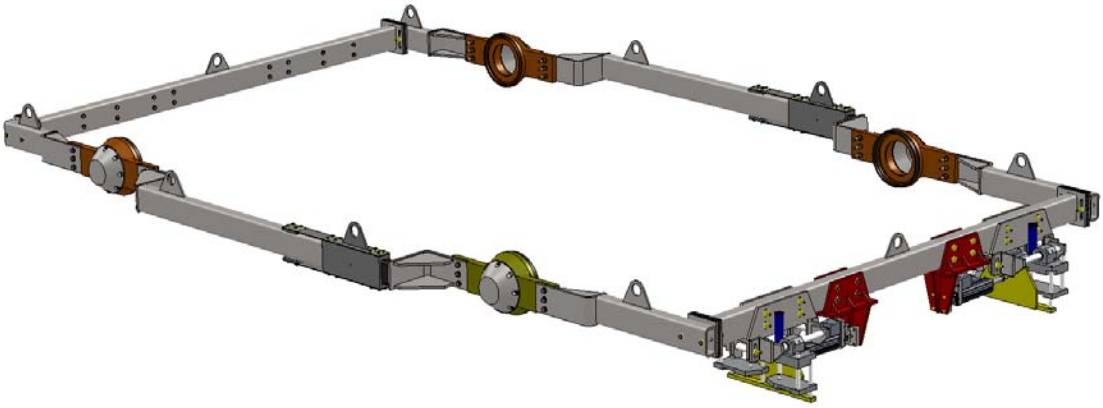

Figure 3 – Deployment system mechanical frame.

The deployment system was attached to the inspection vehicle by four points, each one on the extremities of the axles of one of the bogies.

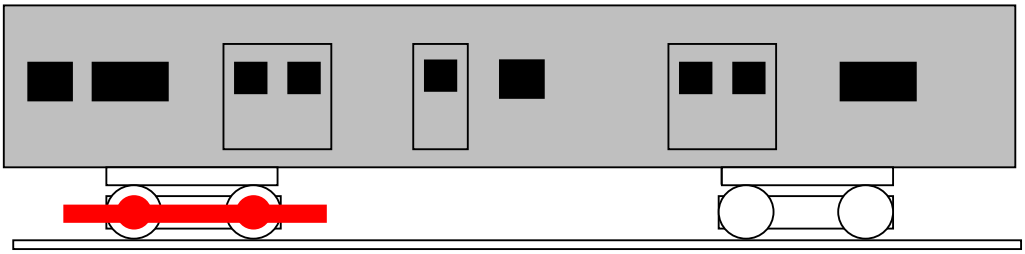

Figure 4 – Deployment system location in the inspection vehicle.

The sensor adjustment mechanism is composed of two probe mountings which will receive the ACFM and ultrasonic systems, two vertical actuators, one horizontal actuator and horizontal and vertical sliders for movement guidance.

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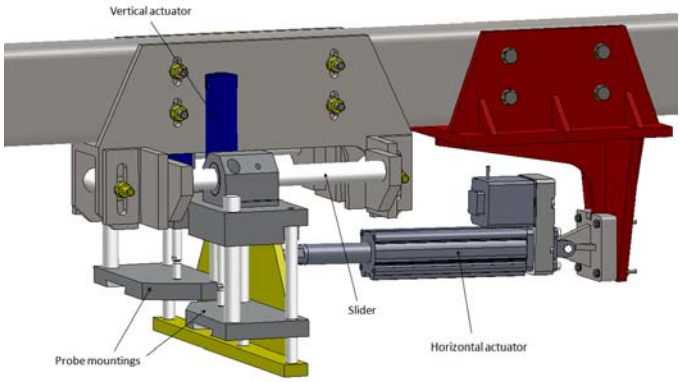

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Figure 5 – Sensor adjustment mechanism.

The positioning system of the ultrasonic and ACFM systems is independent in the vertical direction, which makes it possible to use only one of the systems for inspection if desired, resulting in greater flexibility.

The two major general capabilities of the deployment system are the following:

- Mechanical fixing and moving device to be attached in the inspection vehicle minimising the changes in the vehicle bogie
- Modularity and flexibility to adapt other inspection modules if necessary

1.3.1.2 Ultrasound Module

1.3.1.2.1 Hardware

The High Speed Ultrasound module was the responsible for the inspection of internal defects in the rail volume and is one of the modules attached directly to the deployment mechanism.

The ultrasonic wheel mechanism used in the INTERAIL system is basically identical to any wheel mechanism. It consists of a plastic tyre that, thanks to two bearings, rotates around an axis and maintains contact with the rail top surface. The wheel, filled with a coupling liquid to allow transmission of the ultrasounds in the rail material, encloses the ultrasonic probes at fixed positions and angles while rotating and moving along the rail.

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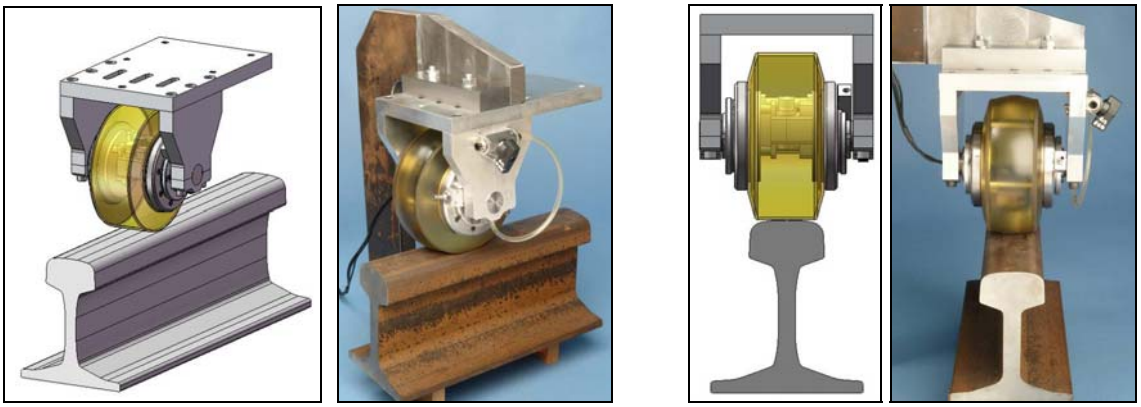

Figure 6 – UT Wheel schematics.

Because of the physical space available in the wheel, the maximum number of probes that can fit is limited to three. One wheel has been designed and covers the main important angle of inspection which are 0^0, 35^0 and 70^0 but pointing only to one direction of travel. As proof of concept that is sufficient enough to perform the trial runs and to demonstrate the technique.

The plastic membrane that the tyre is made of, is a robust but flexible polyurethane which has been specifically designed for the inspection of rail. The flexibility of the plastic allows the tyre to conform to the rail geometry and thus ensuring a good contact between the wheel and the rail surface and therefore ensuring a good transmission of the ultrasounds into the rail.

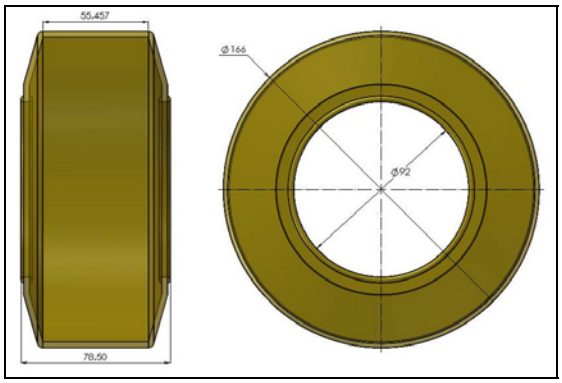

Figure 7 – UT Wheel

The wheel probe is attached to the deployment mechanism that was developed within the project. The question of having an additional suspension system for the wheel has been raised. This was investigated while the dynamic tests are running. Due to the flexibility of the plastic tyre, the wheel mechanism was able to overtake some of this vertical movement and therefore was not necessarily need a separate suspension system.

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In addition, the system needed a brush that will clean any debris in front of the wheel to avoid any interference and damages, as well as a water sprinkling mechanism to wet the rail surface in front of the wheel to maximise the transmission of the sound in the rail.

The probe selection was based on different inputs:

- The frequency: between 3Mhz and 5Mhz.
- The dimensions: small enough to fit three probes in the wheel.
- The crystal size: the ultrasonic beam for the 0° and 35° probes has to be small enough to get the maximum energy going through the width of the rail web, and for the 70° it has to be big enough to cover the full width of the rail head.
- The availability on the market: checking through vendors catalogue to find adequate probes.

Some modelling was carried out to evaluate the performance of these probes in terms of beam propagation and defect response, as is presented in the next figures.

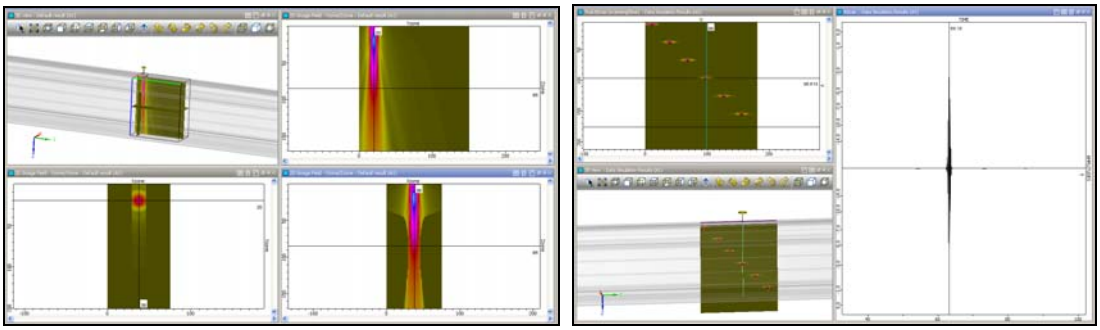

Figure 8 - Modeling for the 0° probe: Beam Modelling and defect response

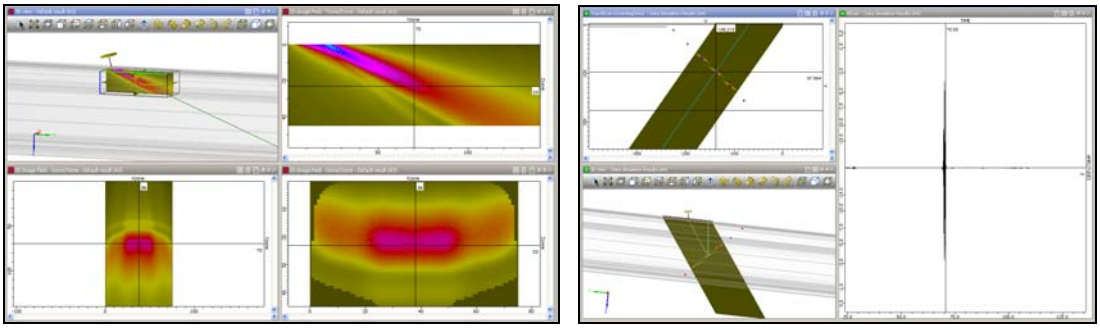

Figure 9 - Modeling for the 35° probe: Beam Modelling and defect response

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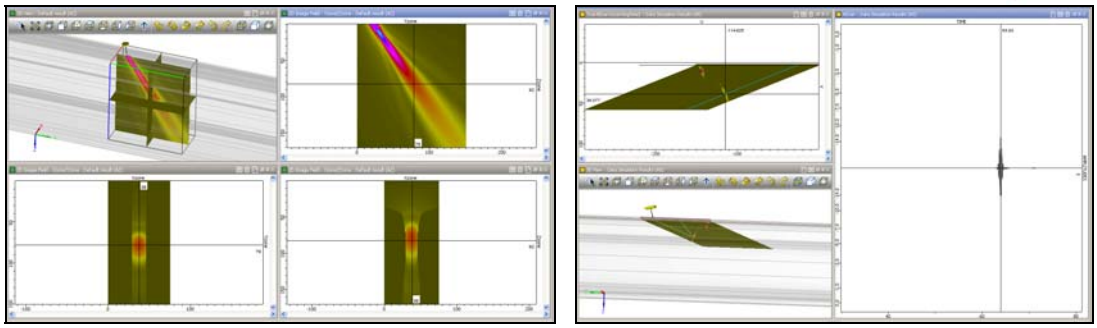

Figure 10 - Modeling for the 70° probe: Beam Modelling and defect response

Accordingly with the modelling results the final choice implemented in the wheel was therefore the following:

- For the 0° and 35° probes: standard immersion Panametrics V382-SU (3.5MHz, 13mm)

- For the 70° probe: Accuscan Paintbrush Panametrics A331S-SU (3.5MHz, 38mmx6mm)

The ultrasonic wheel was filled up with a liquid which permits the propagation of ultrasounds from the probes to the rail. This liquid is a mix of propylene glycol and water with a mixing ratio of 2 to 5 (40% of glycol). The use of this mix is double. Firstly, the velocity of sound achieved is really close to the velocity of sound of the plastic tyre, so there is almost no loss of energy from the liquid to the plastic membrane. Secondly, the addition of propylene glycol to the water increases the range of temperature the liquid could be used at. Typically, the temperature of operation ranges from below -40°C up to 100°C which is really convenient for the purpose of the project as inspection can happen in freezing conditions.

The water sprinkle mechanism to facilitate the coupling between the rail head surface and the ultrasonic wheel membrane was implemented in the inspection vehicle using its own water container which ensures, by gravity, the necessary pressure to feed the wheel probe area.

1.3.1.2.2 Control and Software

The implemented UT acquisition unit is based on a high performance and compact industrial computer, with high capacity RAM, solid state disk driver (SSD), USB ports, parametric interface, and able to house NDT Automation AD-IPR-1210 UT boards, which consists in a 12 bit analogue to digital converter with an integrated high performance 300 Volt (400 Volt Optional) pulser/receiver module. In addition the system can house up to four AD-IPR-1210 UT boards, thus providing up to 4 UT channels. The PC contained three AD-IPR-1210 UT boards and was remotely operated via an Ethernet cable and a laptop.

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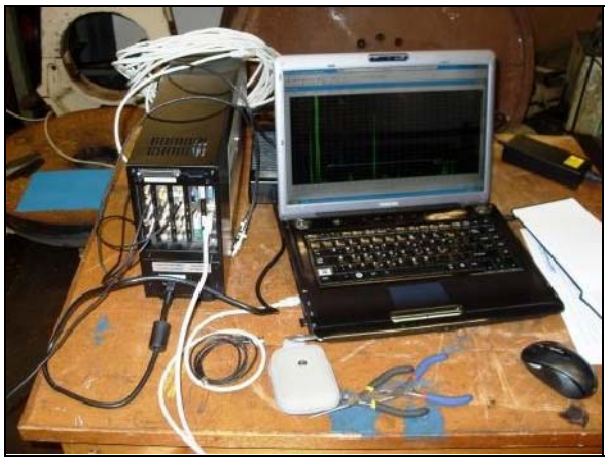

Figure 11 – UT data acquisition.

The interfacing was made with UTwin real-time acquisition software controlled through remote access. The interface allows the user to define the UT acquisition settings which can be programmed and set on demand at any time of the UT condition monitoring. The settings used were the following: 380mm width with 160mm delay at 100MHz sampling rate with two gates (G1 and G2) and only feature monitoring of the thickness and the amplitude.

The wheel probe was mounted in the deployment mechanism. The following figures presents the wheel assembly mounted in the wagon and an example of the acquisition software developed.

Figure 12 - UT wheel assembly mounted on the wagon and acquisition software

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1.3.1.3 ACFM Module

1.3.1.3.1 Module Electronics

This module will detects the surface and subsurface cracks at high-speed. The ACFM technique uses an alternating magnetic field to induce a current on the surface of the rail. If this current encounters a crack, it is forced around and beneath the cracks. This change of direction of current, modifies the magnetic field at the surface. The change in magnetic field is detected by small sensor coils held a few millimetres from the surface of the rail. These changes are measured and used to locate the ends of the cracks, and to determine the depth.

The current ACFM instrumentation is called “Amigo”. It consists of circuits to drive the field generation coils, and circuits to measure voltages from the sensor coils; this measurement requires careful amplification and filtering to ensure accurate results. This part of the Amigo has been completely redesigned as part of the project. Its analogue circuits have been replaced by a Digital Signal Processing (DSP) chip that has been programmed in-house.

The algorithm run on the DSP chip accurately mimics the functions of the analogue circuits in the previous board. This has the advantage of speed and flexibility, as its inputs can be modified by software. The figure below shows the software, written by TSC, and the development boards used in the project.

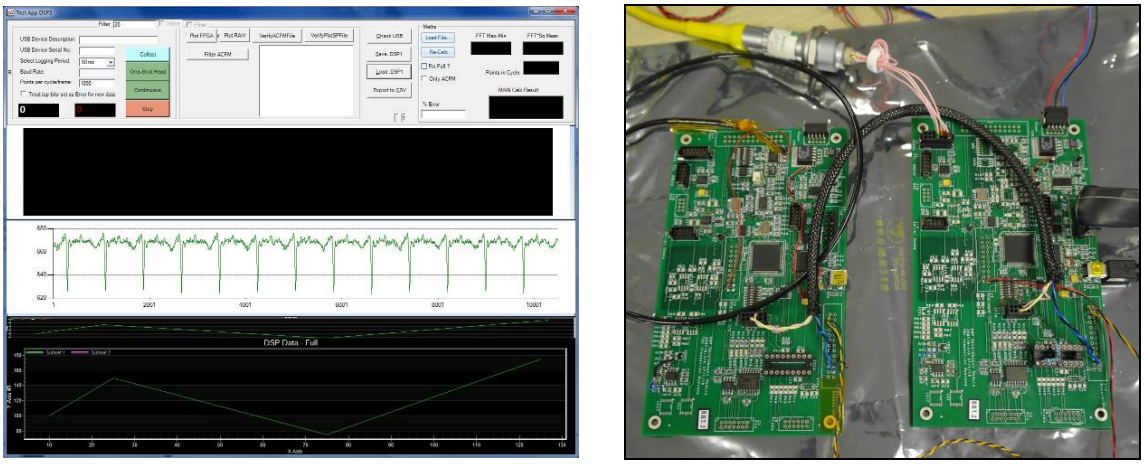

Figure 13 – ACFM Module electronics and software.

1.3.1.3.1 Rail interface and probe design

The INTERAIL project includes an ACFM probe that is able to inspect the rail at 100 km/h. The probe as well as the suspension system, where the probe was attached, were designed and

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manufactured within the project. The ACFM probe was attached to a sled, and the sled was assembled into the suspension system.

Several limitations were faced during the sled development related with the design itself and material to be used. The sled must be strong enough to protect the probe when it hits a leading edge of a rail, this would suggest a relatively large sled. However, the sled must be electromagnetically invisible, which would suggest a small lightweight sled. The challenge was to design a sled that is strong enough to withstand the impacts, but remain electromagnetically invisible.

After some modelling the final solution for this sled is shown in the following figures.

The final version, totally designed and developed in the project, of the ACFM high-speed probe consists of four sensor coils. Each sensor has its own set of instrumentation, rather than multiplexing. This parallel processing massively increases the speed of data acquisition, which is necessary at high speed. The following figure shows the internal construction of the high-speed probe.

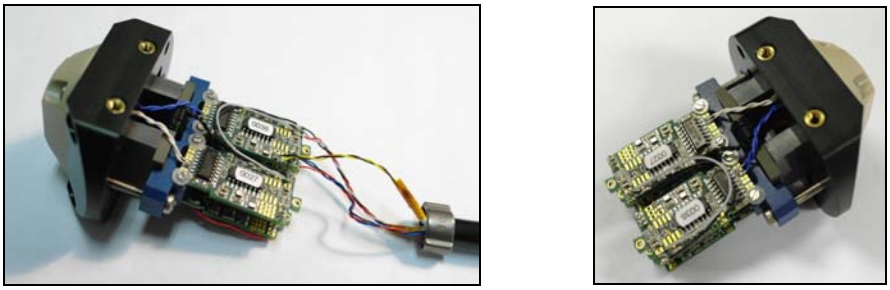

Figure 14 - Internal construction of the high-speed probe

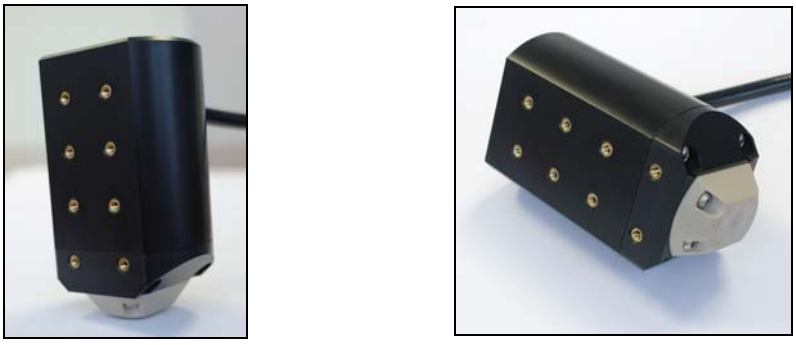

Figure 15 - Completed final probe

The high-speed deployment system consists of two ACFM probes mounted side by side and two laser displacement systems, which are used to monitor any lift-off between the sled and the rail. Accelerometers were added to the sled, along with thermocouples to monitor the vibration and temperature, respectively.

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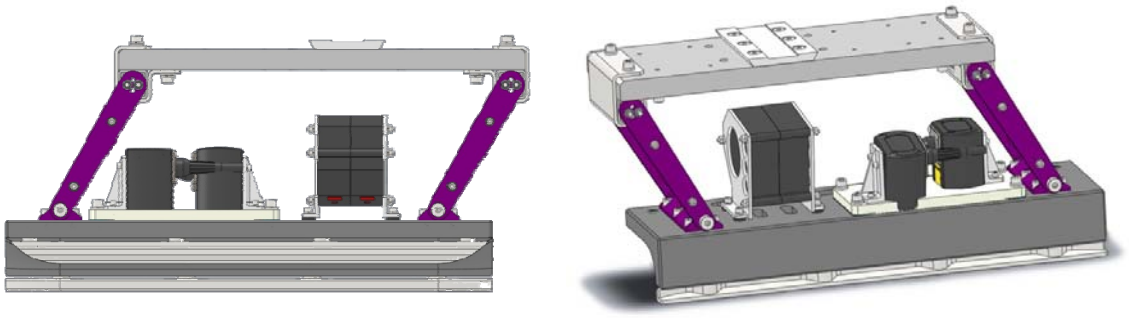

Figure 16 - High speed ACFM sled to attach in the deployment system

A parallel linkage mechanism was used to ensure the system always ran parallel with the rail, while rubber bushes were used for suspension. Pneumatics was used to lower the system onto the rail, and to maintain the necessary downward force required to deploy the system correctly. Stainless steel skids were mounted into the peek plastic body for wear resistance. The heat was dissipated from the stainless steel skids through cooling fins (not shown). Vibration was monitored using vertical and horizontal accelerometers, while the temperature of the stainless steel cooling fins were monitored by thermocouples. The data from all probes were monitored within the inspection vehicle in real time.

The ACFM system was mounted behind ultrasonic wheel-probe. Both systems could be deployed together or separately. Both systems were mounted below the inspection train, as shown in the following figures.

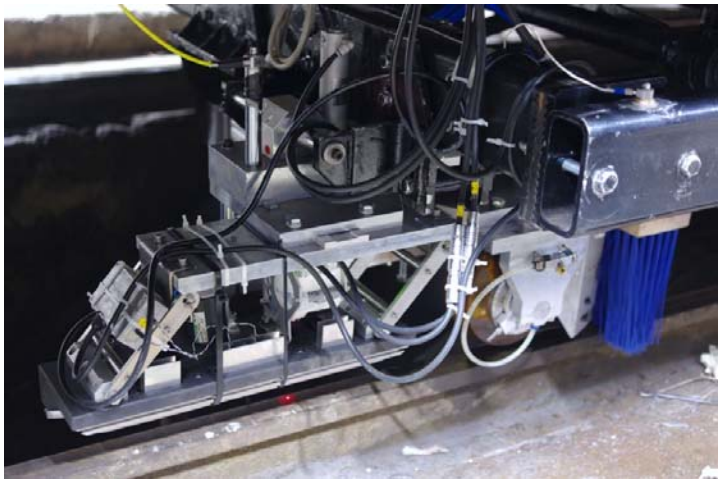

Figure 17 - System mounted below inspection wagon

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1.3.1.4 Automated Vision Inspection Module

This section is divided in two parts. The first one presents the conception of the high-speed vision system and the second part is dedicated to the laser measurement system.

1.3.1.4.1 High Speed Vision System

1.3.1.4.1.1 Linear camera and field of view for vision inspection sub-system

The sub-system used the 2D images in grey levels data to inspect the track. The image is a reconstruction of data issue from line scan camera. The line scan camera has a capability to acquire one line of pixel with short integration time to minimize the blur. The kind of camera has two functionalities. The first is the free running, in this case, the camera automatically deliver one line for each µs according to the internal parameters. The second solution, used in our project, is the synchronisation on trig to uniform the image independently of the speed of the train. The acquisition software reconstructs the 2D image by the association of one by one line delivered by the camera

In our case, the camera is synchronized by the encoder LENORD&BAUER GEL 291 TX / 2000 impulses installed on the EM120 REFER vehicle. With this encoder and the 120 km/h max speed, the high accuracy resolution is 1 mm for each pulse due to the number of pulse by revolution.

The line scan camera is associated with the bespoken lighting system in order to acquire a uniform image along the field of view. In our case, the field of view is determined by the kind of fasteners installed on the track and the best compromise is around 800 mm to cover fasteners and sleepers support.

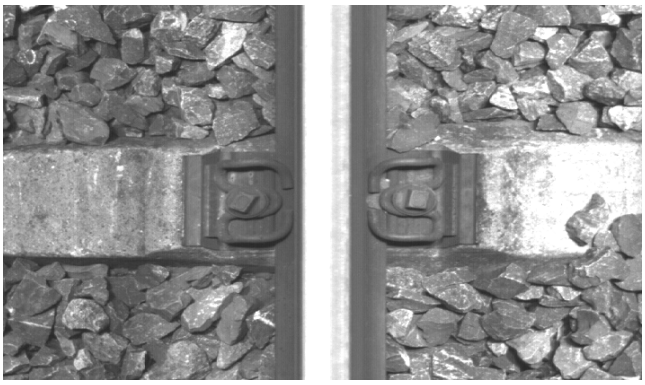

Figure 18 - Typical Image Acquired from vision inspection sub-system.

In this example above, you can see that the three parts of the image can be used. The middle of image is used to analyse the head of rail, the both sides near the rail are employed to analyse the fasteners and the outside area to control the sleeper.

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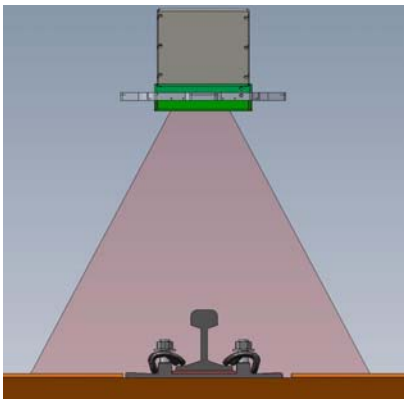

Figure 19 - 2D Field view

1.3.1.4.1.2 CMOS camera and field of view for 3D laser inspection sub-system

The sub-system used a combination between CMOS camera and laser beam to create the 3D information data to inspect the track. Inside the camera, the processing delivers from each image a profile of the laser beam and generates a line of data as a line scan camera. With the same approach, the 3D area scan camera has a capability to acquire on image with short integration time to minimize the blur. The kind of camera has two functionalities. The first is the free running, in this case, the camera automatically deliver one line for each µs according to the internal parameters. The second solution, used in our project, is the synchronisation on trig to uniform the image independently of the speed of the train. The acquisition software reconstructs a false 2D image by the association of one by one line delivered by the camera. The level of pixel corresponds to the value of Z axis.

In our case, the camera is synchronized by the encoder LENORD&BAUER GEL 291 TX / 2000 impulses installed on the EM120 REFER vehicle. With this encoder and the 120 km/h max speed, the high accuracy resolution is 1 mm for each pulse due to the number of pulse by revolution.

According to the max frame rate and the synchro pulse at the max of the speed (120 km/h) , the longitudinal resolution (line sampling step in the direction of the run) is 7 mm. With the same field of view as B1W camera (800 mm) for 1200 pixels in the sensor, the cameras resolution on transversal running way is 0.7 mm.

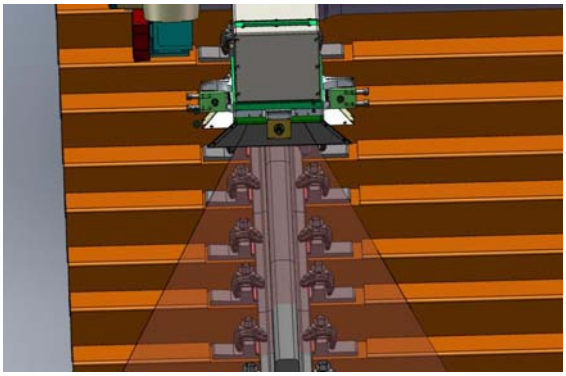

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Figure 20 - 3D Field view

The acquisition system is composed on PC architecture with acquisition board and connexion for control board (laser on/off, triggering, temperature ...). With two dedicated link for each camera, the software acquire the data of camera according to the speed of the train. This part is managed by an odometer that it receive the synchro pulse from the encoder and deliver another synchronisation to the system (1 pulse by mm for any speed of vehicle between 0.3 km/h to 120 km/h)

1.3.1.4.1.3 Acquisition Software and Interfacing

The acquisition system is composed on PC architecture with acquisition board and connexion for control board (laser on/off, triggering, temperature ...). With two dedicated link for each camera, the software acquire the data of camera according to the speed of the train. This part is managed by an odometer that it receive the synchro pulse from the encoder and deliver another synchronisation to the system (1 pulse by mm for any speed of vehicle between 0.3 km/h to 120 km/h)

The system acquires the line scan camera and generates a 2D image with RAW format. All data are saved on the hard disk with index. In the same time, the system acquires the information form the odometer system and the control unit of odometer to apply for each index the real value of the location on the track. In this case, during the processing, the system can identify all defect along the track from the index table.

In this example below, you can see that false 2D image (colour to see the Z value) and a reconstructed image.

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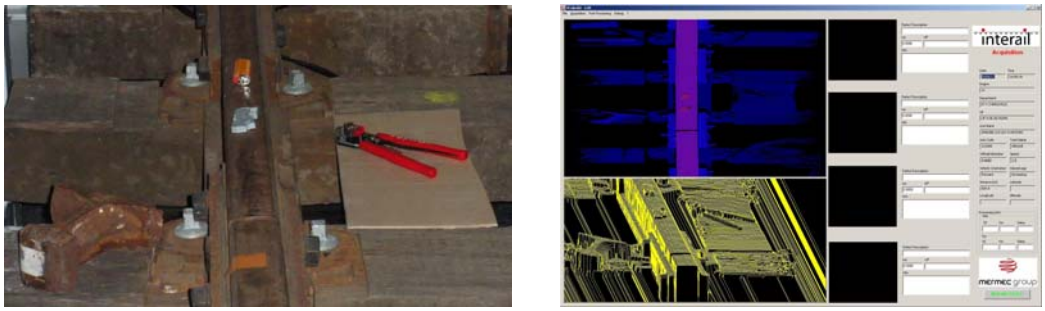
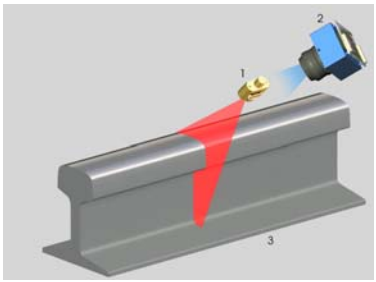
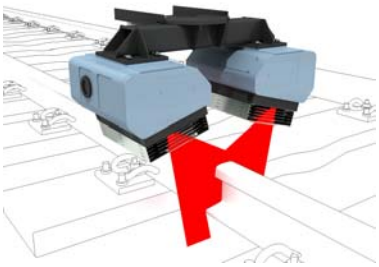


Figure 21 - Man Machine interface and 3d profile compared to real data.

1.3.1.4.2 Laser Measurement System

The Rail Profile monitoring system is designed to measure the rail profile both for high speed lines as well as for conventional and metro lines. In all cases top performances and accuracies can be guaranteed thanks to proprietary CMOS camera system able to acquire up to 500 frames/sec at high resolution. All sunlight interference and blooming effects have effectively been almost completely removed thanks to different protection systems (camera technology, pulsed laser and camera acquisition synchronized, interferential filters and software filters). The main purpose of the monitoring system is to give integrated indications to the track maintenance responsible for planning the interventions for the short and long term. The system is able to detect and quantify all the key WEAR PARAMETERS describing the qualitative status of the infrastructure (vertical wear, transversal wear, multi-point wear, gauge,). As a consequence, by applying data analysis and comparison procedures, it becomes possible to optimize track maintenance plans, periodically checking and keeping under control rail degradation due to mechanical wear.





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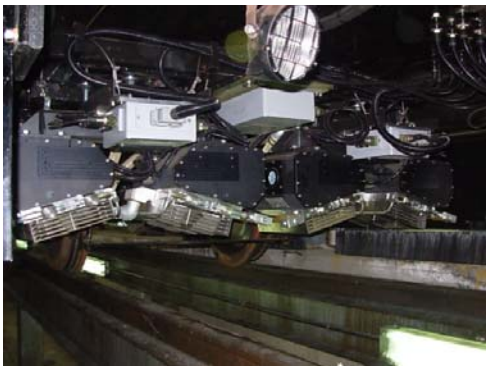

Figure 22 - Rail Profile : triangulation concept layout and real installation

For the rail corrugation the European Norm that deals with is the EN13231-3. The Rail Corrugation measurement System fully respects this European Norm, i.e. the measurement process is done according to this norm. The RCMS for grinding purposes can be used as an approved instrument for the acceptance of rail grinding works: the certification of the RCMS as an approved instrument, according to Annex B of EN13231-3, is not part of the standard supply and has to be expressly required. The measurement can be done at speed up to 160 km/h, with the train travelling both directions and for all the weather conditions.

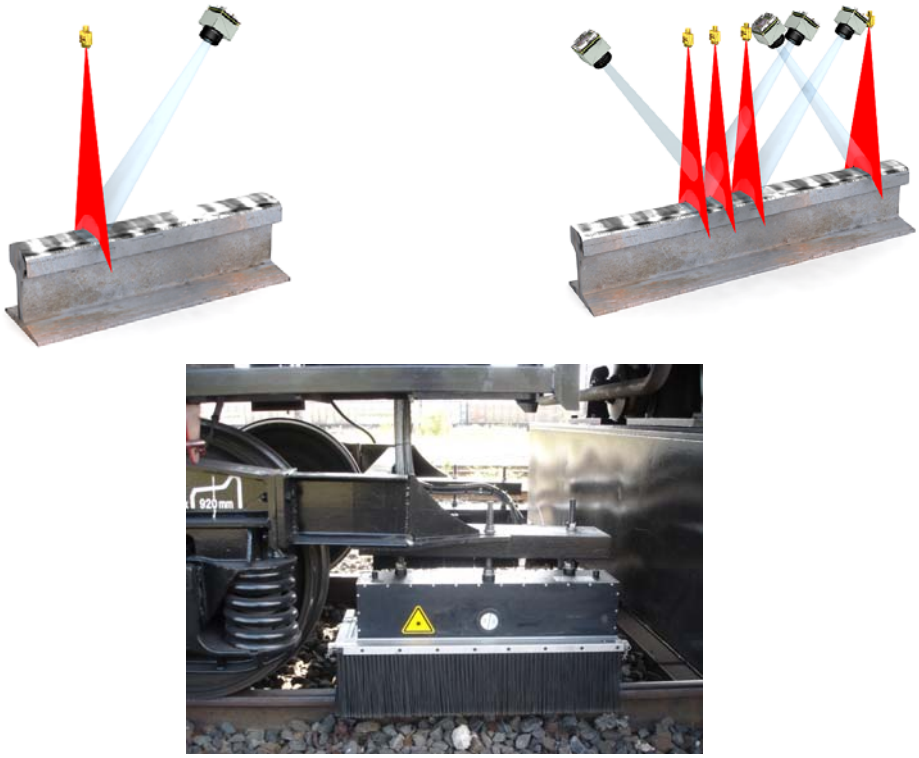

Figure 23 - Rail Corrugation : triangulation concept layout and real installation

1.3.1.4.2.1 Laser Measurement System Interface

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The RPMS used for Maintenance operations calculates the wear by a series of operations that permit automatically to detect the rail inclination and calculate the absolute reference of the rail (foot and web) to overlap the acquired profile with the template used. The wear is then calculated as difference between the two profiles (real vs. ideal).

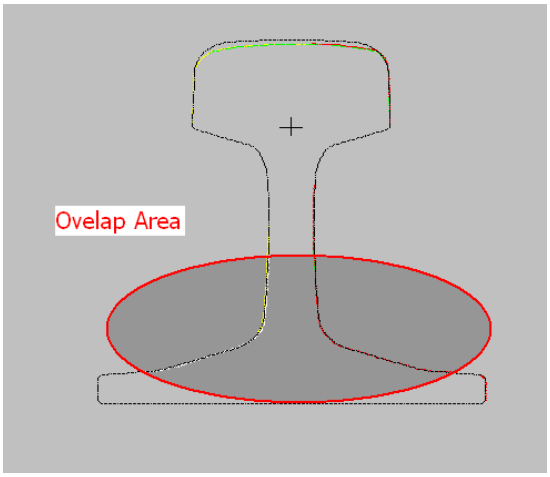

Figure 24 - Example of Overlap between the real Profile (coloured) and the template (black).

The RPMS is able to recognize automatically the template used in the line by choosing between a list of template contained in a database. To perform the automatic recognition we have to be sure that there is an appreciable difference between the templates.

The inclination of the template for maintenance operation is chosen to 0° to permit the best match with the real profile. With this configuration the system reduces to maximum the error caused by match operation.

The wear are calculated in certain point. Usually must be considered the position at

A. -14mm (gauge point)
B. 45° tangent point (corner)
C. rail inclination tangent (of the template) to calculate the wear in a vertical position.

As shown in the following picture there is the possibility to choose also other positions in the template to have a better coverage of the wear tendency over the head and the RPMS is able to perform other type of measure different from the wear. Hereafter some examples of the graphical interface of the RPMS is presented.

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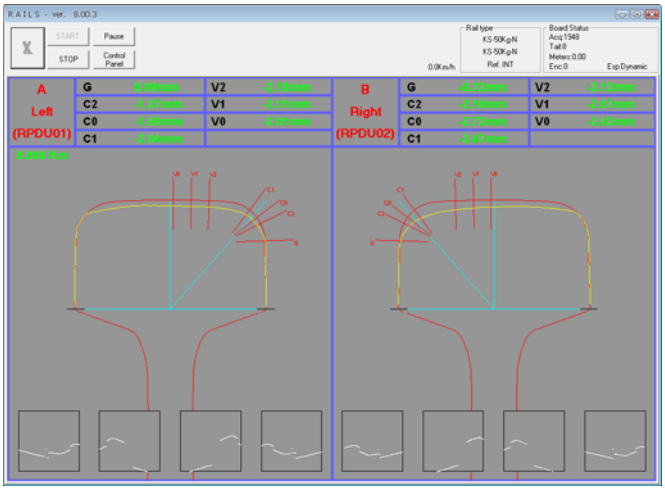

Figure 25 - Example of Full Rail Profile graph compared with reference profile

Regarding the corrugation module, an interfacing program was developed, to acquire the data, post-elaborate the results and setting the parameters of the RCMS. This tool can be used in two working modes:

- locale, stand alone: all the commands are given by the operator using the graphical interface
- remote, by supervisor: all the commands are given by the operator using a supervisor software connected via network with the corrugation program.

The figures below present some screens of the GUI (Graphical User Interface) of this module.

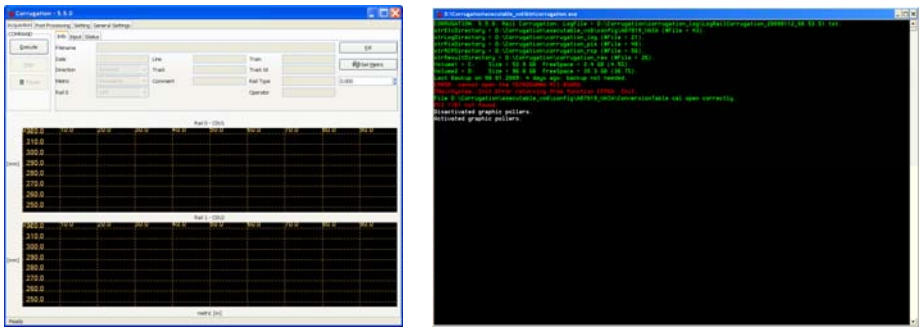

Figure 26 - Acquisition window and Console

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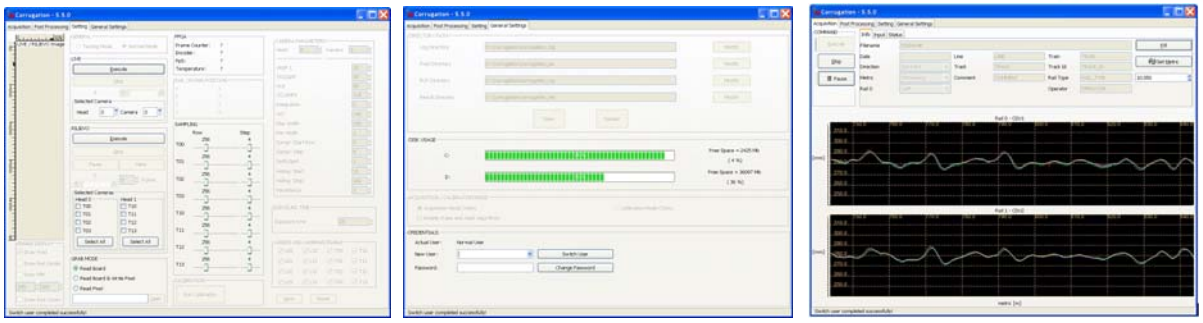

Figure 27 - Setting, Post Processing and Acquisition s windows

The final installation of the three modules is presented in the following figures, as well as some final results of the data acquires.

Vision Module | Rail Corrugation Module | Rail Profile Module

Figure 28 – Automated vision inspection modules

1.3.1.5 CENTRAL PROCESSING MODULE

The INTERAIL software suite is responsible for the alignment, long-term storage, and display of the data gathered by the various inspection systems on the vehicle; this is reflected in the following objectives:

- The software suite should be able to integrate the data streams from the various inspection systems involved in INTERAIL (namely the automated vision, ultrasonics and ACFM modules) this will be performed off-line based on timestamps inserted into the data streams as they are collected.
- The software suite will be able to store the data gathered by the inspection systems in such a way that information on defects/changes in the infrastructure over time at a location can be monitored at a later date.
- The software suite will serve as the sole man-machine interface (MMI) to the INTERAIL system; as such it must be capable of not only providing access to the raw data as gathered by the individual inspection systems, but also of detecting and reporting events in a manner that is appropriate for use by maintenance workers.

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In order to meet these objectives, a set of three modules that together comprise the INTERAIL software were produced; the modules are:

- A pre-processor that will take data streams as provided by the inspection systems on the demonstration vehicle, align them in time based on markers inserted into the streams during the recording of data, detect events such as rail cracks and write that information into the project database.
- The project database, which will store the individual data series recorded by the inspection systems, annotated with any events detected during the demonstration.
- The project MMI, which will present data in a range of forms as appropriate for different railway stakeholders.

1.3.1.5.1 Pre-Processor

The pre-processing module is responsible for taking the individual data streams as produced by the on-board inspection systems, and combining/aligning them ready for storage in the project database.

The general flow of information through the pre-processor can be described as a two-step process; first the GPS data from a journey is examined, for each GPS data point a series of checks is made to determine whether or not a record for that latitude and longitude already exists in the database, and if so what its key/ID value is.

If there is no existing record, then the GPS data point is added to the database. Once key values are available for all the GPS data locations recorded during the journey, the second phase of pre-processing, where the individual streams from the inspection systems are aligned, can begin. For each data stream in turn, the software first checks whether raw data is available, or whether the system only reports events.

If the system being processed is event-only then the events are simply assigned to the appropriate GPS point and checked against the database to determine whether they have already been detected by another inspection system, if so the existing event is expanded, if not the new event is written to the database along with the IDs of any existing data points recorded at the same time by other systems that are not already noted in the event.

If however the system being processed records both events and raw data, the situation is more complex; in this case, the software must first assign a timestamp to the data point by interpolating between the markers inserted into the data stream as it was recorded, next it must identify the GPS data recorded immediately before and after the data, and use these values to perform a second interpolation to determine an approximate position.

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The calculated position must then be checked against the key list & database to determine whether or not the GPS position already exists as a record, and if not it must be added.

Finally, the record for the aligned (by timestamp and position) data point can be added to the database. Any events raised by the inspection system are then added in the same manner as for the event-only data streams.

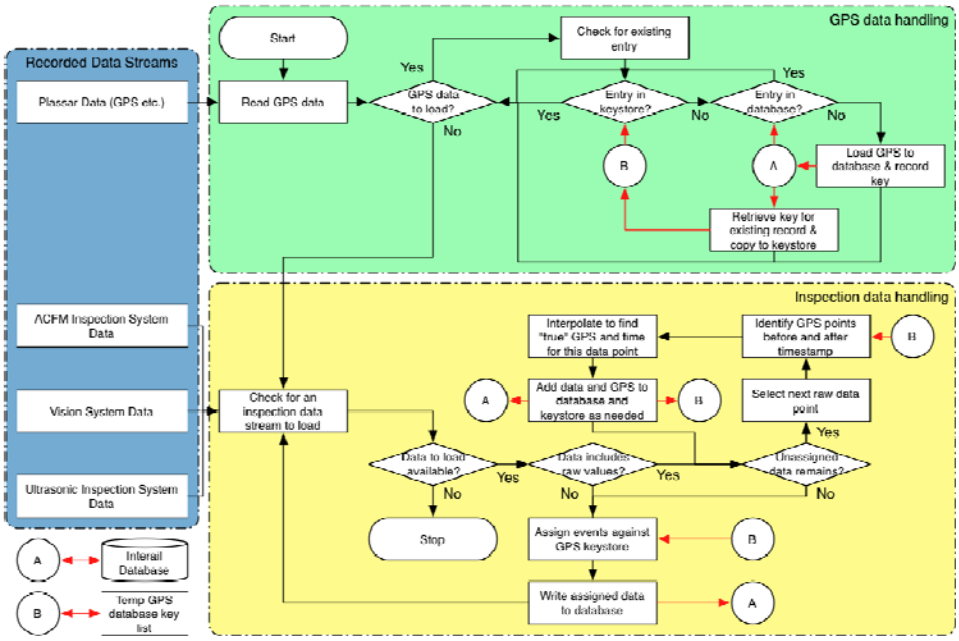

Figure 29 - Flowchart showing the alignment operations performed by the pre-processing module

1.3.1.5.2 Database

The project database is designed to allow rapid access to event data (facilitating highly-responsive user interfaces) while also serving as a repository for the detailed inspection data that will be produced by the various systems and may be required for later, less time-critical analysis work such as trending towards failure.

To that end, the database consists of two key concepts; the trial data object and the event object. Trial data objects represent a single point of data from an inspection system; each object contains the data item itself (the payload) along with a timestamp and a GPS position at which the data was recorded.

Since GPS data will be received much less frequently than the data from the inspection systems, there is also a flag to indicate whether the GPS location included in each data item is recorded data, or whether it has been interpolated based on the GPS information that immediately surrounds it.

GPS location data is held in a separate, referenced table for both efficiency of storage and to facilitate more rapid searching by location should this functionality be required. Trial data objects

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are grouped together (by reference) into data series; a data series represents a collection of data that belongs to a single probe or inspection system.

Each data series has an associated platform object, which describes the physical platform (for example a vehicle or a piece of lineside equipment) that the inspection system is mounted on. Data series are then grouped together (again, by reference) into trials, where a trial represents a particular project.

The event data object is structured based on two main criteria; firstly, that event data must be easily, and above all quickly, accessible in order to enable the creation of responsive MMIs, and secondly, that a single event may involve data from multiple inspection systems.

In order to meet the second of these criteria, it was necessary for the event table to have as small a footprint as possible; as such the event table itself contains only the metadata necessary to describe the event from an operators point of view (the event type, severity and detailed description) along with an indicative timestamp and GPS position that can be used when populating MMIs.

The event table is then associated with a number of trial data objects via a double-referenced table, allowing trial data objects to be attached to the event regardless of the data series that they belong to. This structure also allows the trial data items for an event to be obtained relatively quickly (by searching a indexed columns) if the data is needed for display in the MMI.

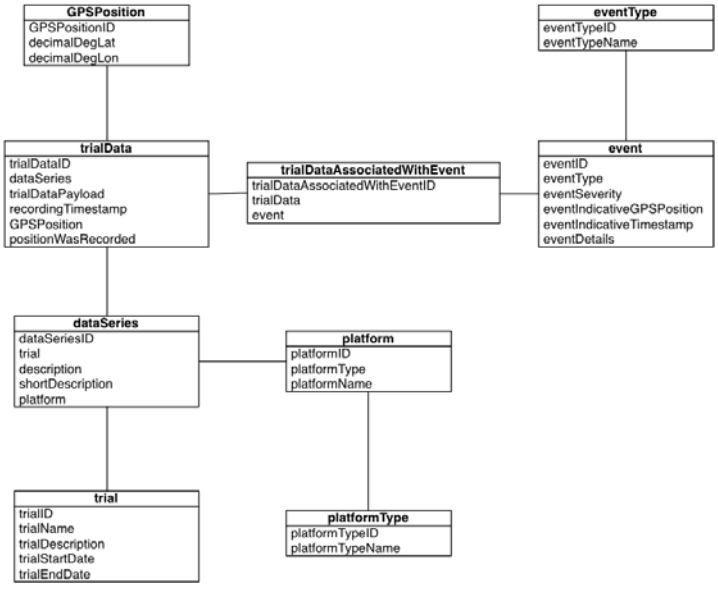

Figure 30 - Schematic representation of the project database

1.3.1.5.3 Man-machine Interface (MMI)

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The prototype INTERAIL project MMI uses the event table of the project database to create a graphical representation of issues identified by the various inspection systems being used in the project.

The interface is based around the events list in the bottom right-hand corner of the screen (see figure 31); as the list of events is expected to be quite long, particular date ranges of interest can be specified using the calendars immediately above the list.

Events that have been selected in the list are shown as markers on the map screen, allowing them to be related to features in the infrastructure such as bridges or switches and crossings (S&C).

Clicking on the marker for an event causes a pop-up to appear that contains further information on the event, such as the indicative GPS position (as latitude and longitude values). When a single event is selected, the raw data associated with it (if available) is displayed in the windows in the lower-left portion of the screen.

The prototype MMI is designed to be accessible from anywhere in the world via the web, and as such has been built using JAVA Server Faces (JSF) technology.

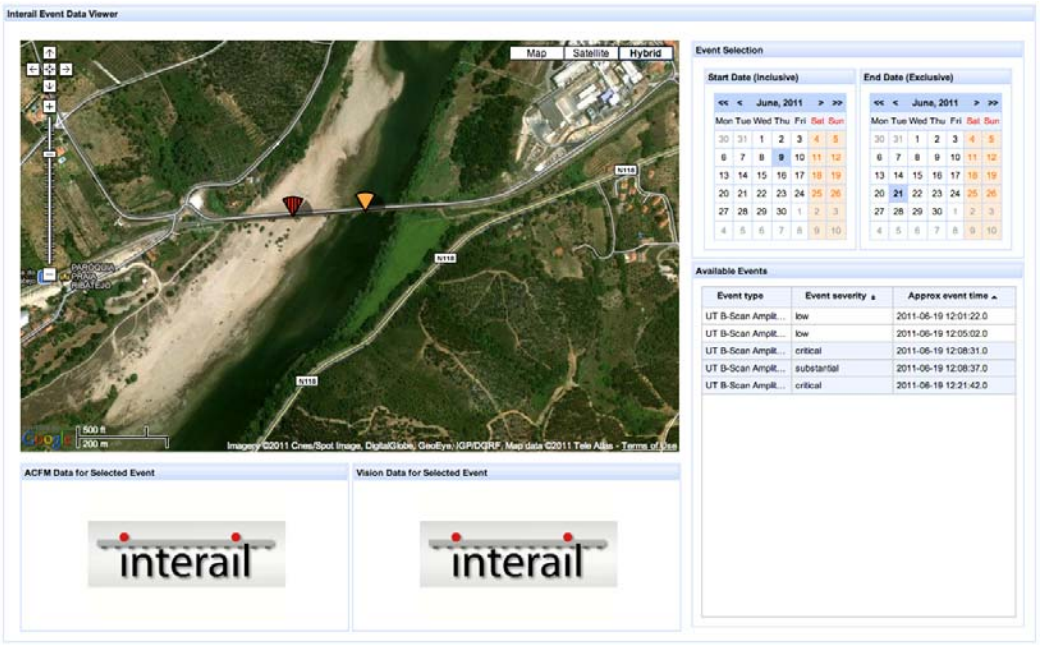

Figure 31 - Prototype for the back-office version of the INTERAIL MMI

In order to allow end-users with different roles to access the INTERAIL project data in ways that best supports their jobs / functions, a number of different interfaces to the system have been developed. These include a web-based system for office use by planners and infrastructure managers, a mobile system deployed on an Android tablet PC for maintenance workers with access to a 3G internet connection, and a PDF export that can be printed out and taken to areas with little or no mobile data coverage. Events in all three of the interfaces are presented as clusters in order to

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reduce the number of markers, to average out the effects of outliers (unusually high or low results) and to allow trending to be performed on the severity of the defect over time, enabling the use of just-in-time maintenance techniques. Clusters of events are defined based on a combined metric that takes into account geographic position (handled as a radius from the averaged position of the cluster) and vehicle heading (events only form part of the same cluster if the vehicle detects them is heading in the same direction).

1.3.1.5.3.1 Office-based system

The web interface is designed to allow office-based workers, for whom high data rates are not an obstacle, to have the most flexible access possible to the inspection data. This includes the ability to review all event clusters, to limit the available events by date and geographical location, and to select the event clusters to view based on frequency of occurrence, severity and the type of event. The web interface is also the point from which PDF exports can be obtained, with the contents defined by the event clusters selected at the time of export. Event clusters are displayed on a map of the area (in the case of the prototype system, this is provided by the Google maps API), clicking on a flag brings up additional information about the event cluster, including the dates and times of the first and last events in the cluster, and the indicative position of the cluster. Selecting a single event cluster in the list allows the various inspection results associated with that cluster to be reviewed, be they graphs of numerical data (see example) or images from the vision system.

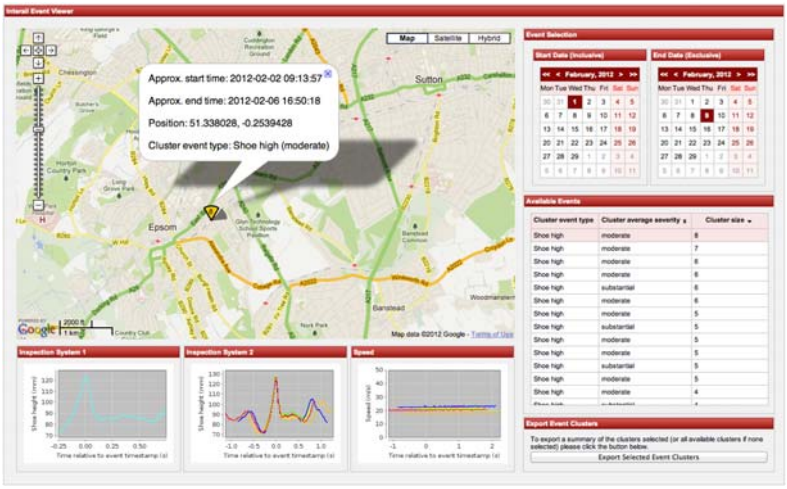

Figure 32 - Web interface to the INTERAIL integrated inspection data (data shown is laser data from South East of England as INTERAIL demonstrations are yet to take place at time of writing).

1.3.1.5.3.2 Mobile tablet system

As with the web interface, the INTERAIL tablet application is centred around the display of event clusters on a map. The different interaction styles permitted by the tablet as opposed to the web

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interface do mean that some compromises in functionality have needed to be made; the ability to refine the clusters displayed on the map is limited to “selection by severity” on the tablet application and it is not possible to export a PDF file, however, most of the remaining functionality remains, including the ability to review the underlying data responsible for an event.

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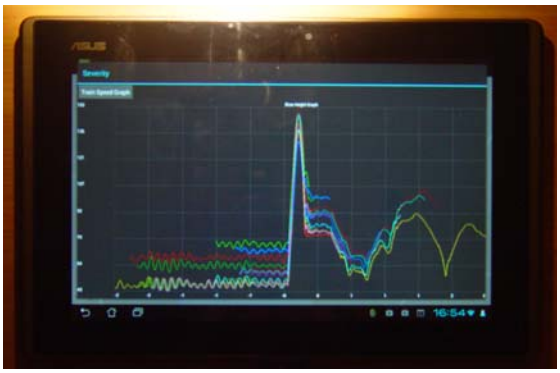
Tablet interface to the INTERAIL integrated inspection data showing the map view (data shown is laser data from South East of England as INTERAIL demonstrations are yet to take place at time of writing)



Tablet interface to the INTERAIL inspection system showing a raw data view (data shown is laser data from South East of England as INTERAIL demonstrations are yet to take place at time of writing

Figure 33 – Tablet information display.

1.3.1.5.3.3 Paper reporting system

While the least high-tech of the interface options available, the PDF export / printable report is the one preferred by the maintenance workers the developers have spoken to. Tailored around the provision of the bare minimum of information about a cluster necessary to allow its categorisation and subsequent identification on the ground, the printable report replaces the larger route map with a set of coordinates for the cluster, an aerial image showing the surrounding area, the raw data to enable diagnosis, and any trending information available. Each cluster is presented as a double-page spread of A4, meaning that multiple clusters can be exported in a single document that can represent a single day's work while navigation is as easy as flipping to the correct page. An example double-page spread for an event cluster can be seen in Figure 34.

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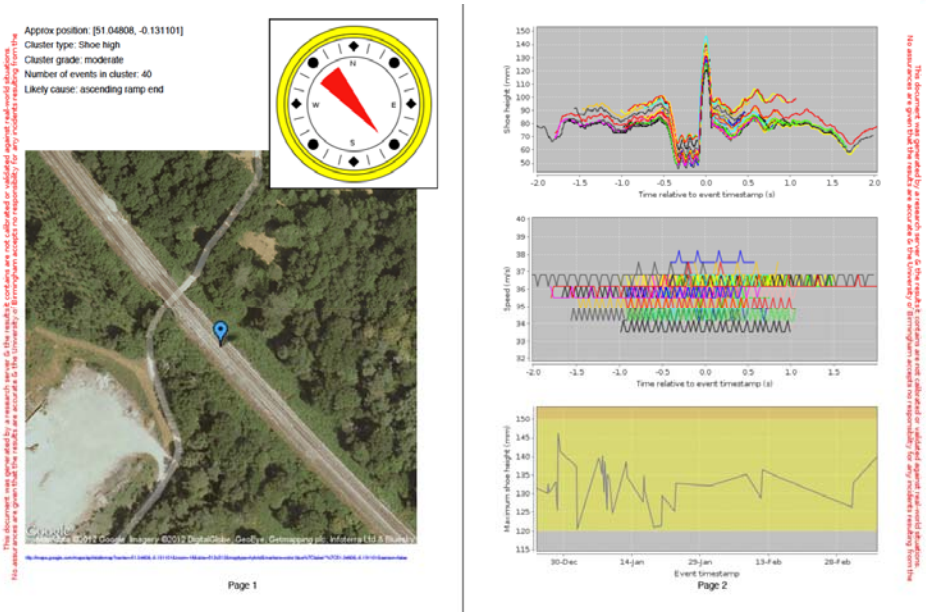

Figure 34 - Paper report for an event in the INTERAIL integrated inspection data (data shown is laser data from South East of England as INTERAIL demonstrations are yet to take place at time of writing)

1.3.2 MANUAL INSPECTION VERIFICATION TECHNIQUES

This section will present the second group of results obtained within INTERAIL project. These results are related with the manual verification techniques developed to validate the High Speed Inspection system. The section is divided according each technique developed, manual ACFM module, Ultrasonic Phased Array module and High Frequency vibration analysis module.

1.3.2.1 MANUAL ACFM MODULE

The automated manual ACFM inspection system has focused in the following aspects:

- A prototype ACFM was developed in order to verify and evaluate surface defects previously detected with the high-speed system.
- Special software incorporating the improved ACFM signal analysis algorithms was also implemented to enable the automatic quantification of the surface size and depth of the defects under evaluation.
- A special acquisition unit was used to log the signals obtained and ACFM data processing algorithms will be used to enable data processing in real time.

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The final low speed system used exactly the same probes and instrumentation as the high-speed system, as each was designed to be software configurable. This was to improve exploitation potential, as the system could be used for either application. Only the deployment system and software change from one application to the next. The slow-speed deployment frame is shown below.

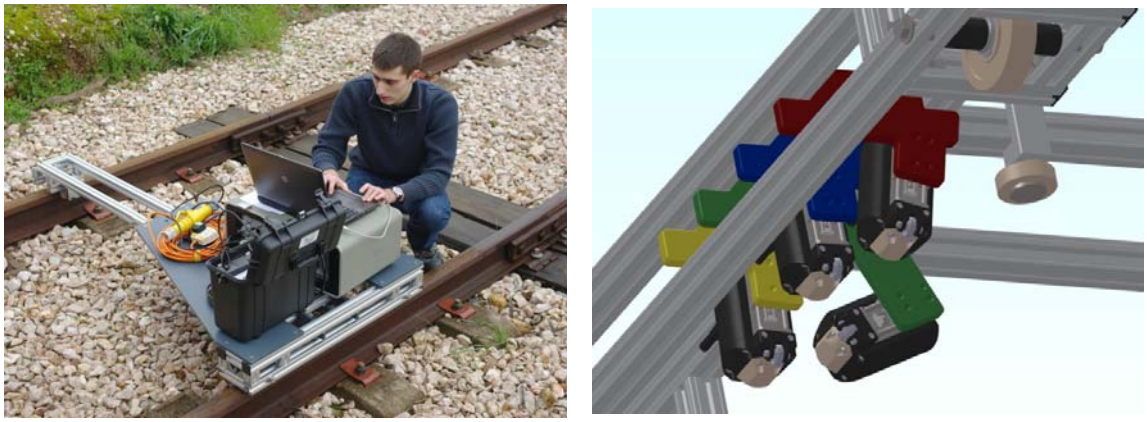

Figure 35 - Low-speed deployment frame

Four probes can be used with the system, each probe contains two pairs of sensors (one pair is required to measure defects in that region of interest). The probes are arranged around the rail to cover the whole RCF region, as shown above. One of the probes inspects the top of the rail, with a very small lift-off, as shown below.

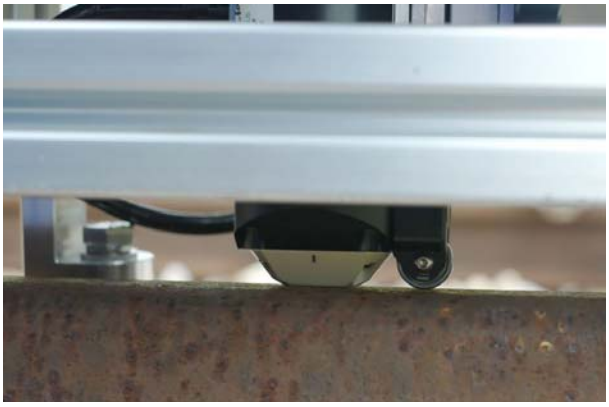

Figure 36 - ACFM probe on top of rail

1.3.2.2 ULTRASONIC PHASED ARRAY MODULE

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The Phased Array system is aimed at validating the results obtained by the High Speed System mainly concerning the Ultrasound high-module by additionally scanning rail areas that have previously been marked by these as defective.

During the tests the Phased Array system the objective is to scan a short section of rail where a defect had previously been reported by the high-speed system, giving additional information regarding the complete characterisation of the discontinuity.

The main purpose of the manual scanner is to be able to run along the rails and perform phased array acquisitions. Therefore, for this project we needed the scanner to have:

- Support for the phased array probes.
- Support for the portable computer.
- Balance in the top of the rails.
- Accessibility to be transported and assembled easily in other places.
- Low weight and proper height to be pushed.

The Phased Array system used comprises a set of four probes performing six electronic setups, which are represented in the following table. As a whole they guarantee a full coverage of the main areas of the rail structure, namely the head, the web-head fillet radius, the web and the web-foot fillet radius.

Both linear and sectorial electronic scans have been applied, as well as beam focalization at different depths and angles, in order to maximize probability of detection and amplitude of response in all areas.

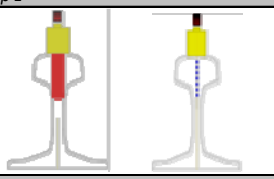
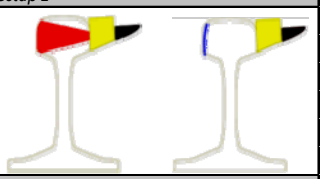
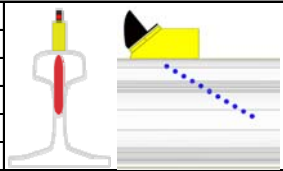
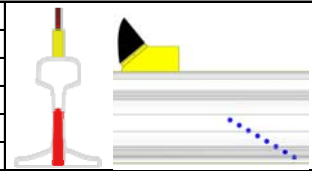
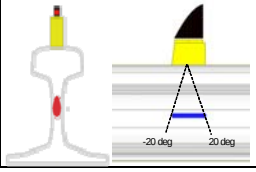
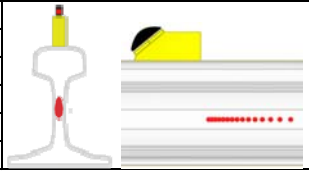
Setup 1			*Setup 2*		
Type of scan	Electronic		*Type of scan*	Sectorial (-15 to 15º)	
Active elements	Variable		*Active elements*	32 (unisequential)	
Probe axis	Normal to rail axis		*Probe axis*	Normal to rail axis	
Wedge	Straight, 38mm-high		*Wedge*	Straight, 38mm-high	
Wave type	Longitudinal		*Wave type*	Longitudinal	
Angle	0º		*Angles*	-14 to +14º	
Setup 3 (3.1, 3.2 and 3.3)			*Setup 4 (4.1, 4.2 and 4.3)*		
Type of scan	Electronic		*Type of scan*	Electronic	
Active elements	See table		*Active elements*	60 (unisequential)	
Probe axis	Longitudinal		*Probe axis*	Parallel to rail axis	
Wedge	39.5º		*Wedge*	39,5º	
Wave type	Shear		*Wave type*	Shear	
Angles	37, 60 and 70º		*Angles*	37 and 60º	
Setup 5			*Setup 6*		
Type of scan	Sectorial (-20 to 20º)		*Type of scan*	Sectorial (37 to 65º)	
Active elements	60 (unisequential)		*Active elements*	60 (unisequential)	
Probe axis	Parallel to rail axis		*Probe axis*	Parallel to rail axis	
Wedge	39.5º		*Wedge*	39.5º	
Wave type	Shear		*Wave type*	Shear	
Angles	-20 to +20º		*Angles*	37 to 65º	

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Figure 37 - Phased Array setups

1.3.2.2.1 ULTRASONIC PHASED ARRAY SCANNER

The Phased Array system is embodied in a manual scanner which incorporates four probes, two straight and two angular. The angular probes are mounted opposite to each other to cover simultaneously the forward and backward directions.

The two wheels at the extremities of the scanner provide stability during data acquisition, preventing the scanner from slipping down the rail.

The system also incorporates an encoder to register position coordinates that help quickly locate any reflection the operator may come across.

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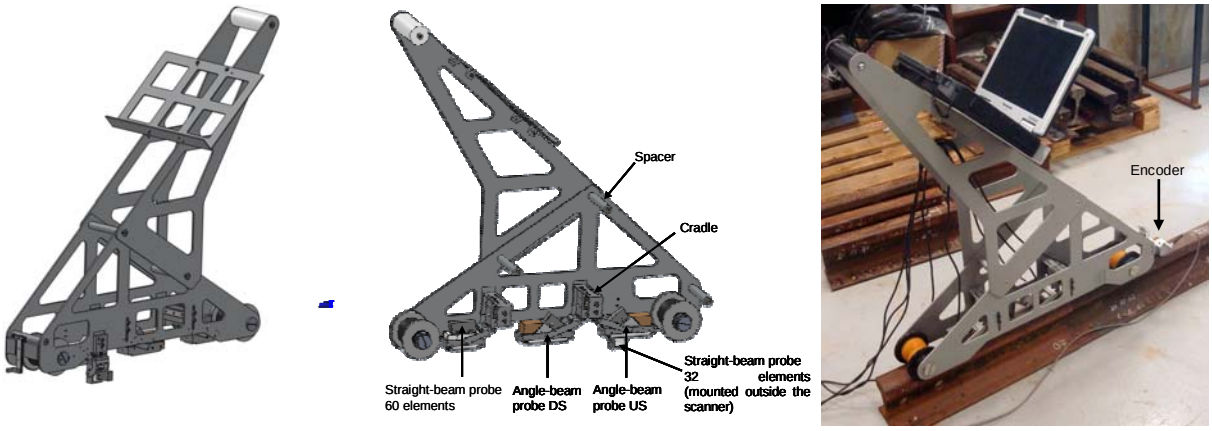

Figure 38 - Configuration of the Phased Array scanner

As main result a manual ultrasonic Phased Array module was developed with the following capabilities:

- Total coverage of the ROI (Regions of Interest) areas with the different Phased Array probes
- Data record and data storage capabilities
- Capability of characterise in detail the defect location and size
- Autonomous modular scanner

1.3.2.3 HIGH FREQUENCY VIBRATION ANALYSIS MODULE

The High Frequency Vibration Analysis modules was developed for continuous monitoring of a rail with potential crack development or for detection of difficult to access faults (e.g. embedded track, switches, crossings). Variations in the high-frequency vibration spectrum up to 150 kHz are monitored and analysed, allowing the detection of small cracks.

1.3.2.3.1 System description

The high-frequency vibration system developed consists of an impact device and an acquisition system.

1.3.2.3.1.1 Excitation

For the high-frequency vibration measurement techniques, it is important to excite the device under test (DUT) with an impulse impact, containing an input spectrum at least up to 150 kHz. This is realized with a freely mounted, low-mass hard impact object. For the initial lab testing, the excitation was applied manually (left figure). Later on, automated excitation is used (right figure).

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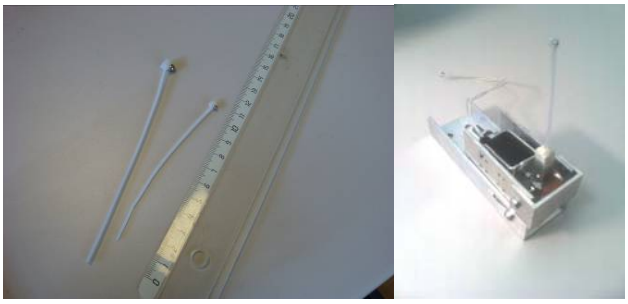

Figure 39 - Impact hammer

1.3.2.3.1.2 Acquisition

For the data acquisition, a sensor technology with frequency range up to 150 kHz needs to be used. Several sensor technologies are available in this range: microphone, accelerometer, and displacement sensor. Based on laboratory tests, the accelerometer was selected for further use in the development of a monitoring system. Compared to the microphone, it has a higher sensitivity since it directly captures the vibration response on the rail instead of the radiated noise. Compared to a displacement sensor, it is more robust since it can be directly attached to the rail surface, without e.g. the use of a probe or without the need to maintain a specific offset distance.

Figure 40 - High-frequency range microphone, accelerometer & displacement sensor

The figure presented below shows the complete measurement setup; a laptop PC with PCMCIA National Instruments data acquisition card is used. MATLAB software is written that acquires the impulse response.

Figure 41 - Complete data acquisition system for lab tests

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1.4 Potential impact (including the socio-economic impact and wider societal implications of the project so far)

The European Commission states that in order to maintain and further increase the current economic growth, mobility and co-operation within the region, it is imperative that the rail industry meets the socioeconomic and environmental demands and expectations of 21st century Europe. For that reason the EU Commission instructed the deep reforming of the European rail industry so as to put an end to its decline and instigate its gradual growth. One of the fundamental milestones in the deep reforms planned for the revival of rail transport is the significant improvement in the industry's safety records. The EU has set strict targets that seek to decrease the number of fatalities involved in rail transport to an absolute minimum by 2020. As a direct consequence of the rail industry's renewed growth, it is expected that the increase in the numbers of rail passengers and freight will also result in the significant reduction of road fatalities, as the traffic in European highways will gradually begin to decrease. The environmental benefits that can be achieved by maximising the efficiency of the European rail network and strengthening its growth are also considerable. Rail transport is far more environmentally friendly than cars, buses, trucks and airplanes and therefore, train travel is much more desirable if other means of transportation can be avoided. Rail transport has clearly the lowest CO_2 emissions in comparison to every other mode of surface transport apart from coaches, and also the lowest after maritime transport when in comparison with all the other main modes of transport. Furthermore, rail transport is as comfortable as air travel and far more comfortable than coach, bus and car travel.

The European rail industry is in a state of rapid transformation aimed at meeting the increasing safety, environmental, societal and economic demands set for modern rail transport. Rail interoperability, defined as the operational and technical integration of the different national railway systems in the European Union and the accession countries, is a key element in this transformation. Efficient transport and mobility are the lifeblood of the European economy and an indispensable factor in Europe's competitive and sustainable growth, enhancing communication, economic growth and social stability. As with any modern transport network, European transport must have, as a key component, a well coordinated, smoothly functioning international rail system. The main challenge for the European rail industry is to develop maximum passenger/customer value. Trains have to be safe, clean, reliable, and on time, both for passengers and goods. Improved services will give rail transport a huge competitive edge, making it the best way to combine low travel time with easy accessibility to both leisure and professional hubs while maintaining environmental impact to a minimum.

It is therefore expected that INTERAIL project results to have impact and contribute to the improvement of the following aspects:

a) safety record within the rail industry,
b) reliability of rail transport and
c) strengthened global competitiveness of European Railway Transport industry.

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INTERAIL will be a major component on the road towards achieving the safety and business targets set for the European rail industry and will help push forward the European rail research agenda further. Widespread application of the INTERAIL platform will decrease inspection times and associated costs whilst it will improve the reliability of the rail network. Inspection costs currently represent 15% of the direct overall maintenance costs. Due to the decreased accuracy offered by current techniques, the use of preventative and reactive maintenance is not efficient enough. A significant improvement in inspection reliability achieved through the application of the INTERAIL systems could result in a further 10% reduction in maintenance times to be achieved. This could potentially lead to an overall reduction in current maintenance times and costs of up to 20%. Moreover, can also promote the start-up and emergence of new high-tech SMEs in activities specific to transport processes and increase the level of employment, create new skills especially in the area of new inspection technologies and improve working conditions.

In addition, this project will significantly contribute to the improvement of punctuality in train travel times through the minimisation of the number of broken or severely damaged rails found each year on the European rail networks. Severely damaged and broken rails can cause substantial delays and disruption to train travel due to imposed emergency speed restrictions and the need to carry out emergency maintenance.

Therefore, INTERAIL project results contributes to the ERRAC Roadmap and Strategic Agenda mainly strengthening competitiveness through the development of higher speed maintenance technologies and improving safety and security due to higher reliability inspection methodologies.

1.4.1 – Strengthening Safety and Security

The INTERAIL project will therefore contribute profoundly in the improvement of the safety record within the rail industry by delivering the technology required in order to eliminate rail failures and derailments that result from them. By increasing the reliability of the rail network the infrastructure managers will be able to improve their maintenance strategies, minimise operating costs, improve their efficiency, increase public confidence in train travel, and use the financial resources recovered as a direct result of the reduction of operating costs for the improvement of existing rail infrastructure and the construction of new high-speed rail lines throughout Europe. The improvement in the efficiency of maintenance and operating procedures will play a significant role on the way towards harmonisation of European procedures and standards, as well as towards the implementation of a non-monolithic Pan-European rail network, which will satisfy the needs of modern Europe for optimised and environmentally friendly mobility of people and goods.

1.4.2 – Specific Societal Impact

1.4.2.1 Increasing Competitiveness

Through approaching the following objectives:

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- To increase public confidence in rail transport across Europe and optimise reliability of the European rail network.
- To enable the safe and reliable transportation of higher numbers of passengers across Europe.
- To improve train punctuality through increasing the railway availability, optimise travel times and increase the convenience of passengers.
- To support the increase in the number of available jobs in the rail industry in line with its economic growth.
- To decrease the number of fatalities associated with other forms of travel through the increase of passengers in rail transport.
- To contribute to the sustainable growth of mobility of people and goods across the European region.
- To minimise traffic congestion in European highways through the optimisation of the efficiency of the rail network.

1.4.2.2 Environmental

Through approaching the following objectives:

- To achieve the minimisation of environmental pollution through an increase in the number of rail passengers who would have otherwise used cars or aeroplanes to travel.
- To reduce environmental pollution by increasing the amount of goods carried via rail instead of aeroplanes and trucks.
- To decrease noise levels produced by trains by at least 10% through the reduction of rail corrugation and profile irregularities which produce excessive noise at the wheel-rail contact interface.
- To substantially reduce the probability of environmental pollution that may be caused due to derailment of freight trains carrying hazardous substances.
- To minimise carbon dioxide emissions related to train travel by optimising the efficiency and reliability of the European rail network.
- To eliminate the use of hazardous chemicals and substances associated with Magnetic Particle Inspection and radiographic techniques currently employed for the inspection of rails and welds.

1.4.2.3 Employment and labour markets

INTERAIL research contributed to the increase of productivity by enabling smarter/qualified working and more flexible inspections.

It also helped increasing the added-value of jobs in the railway industry.

1.4.2.4 Educational

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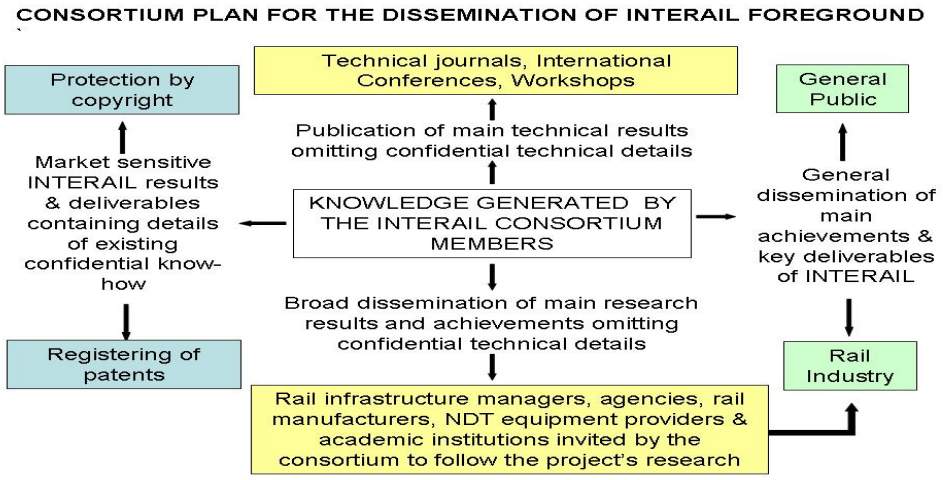
The INTERAIL consortium has promoted the results of the project in several events and published dedicated technical papers. This information is available in Section 2 of this report. The participation of universities in the project allowed to a wider education spread towards NDT railway inspection technologies.
Moreover, dedicated training provided to railway operators promoted the qualified training to technical staff.

1.4.3 Dissemination activities and Exploitation results

The dissemination mechanisms of particular use to the project included: dedicated meetings; seminars; trade fairs; workshops; infodays; interface with other projects; interface with technological platforms (ERRAC) and the project website (**www.interailproject.eu)** through the production of technical papers, presentations and other promotion and dissemination material. The website is being used as the hub of all dissemination activities, with all the project information being placed onto the site. The site itself has areas that are for public access and allows questions to be asked or comments to be produced by the outside public to the experts within the project as well as areas that are restricted to the consortium. The use of the website has been shown to have a number of benefits include acting as a central resource for all partners and providing some feedback as a measure of the success of promoting the project to a wide audience. All technical publications presented in public conferences as well as in technical magazines made by the consortium are available for download at the project website. This will further increase as additional information related with the project final developments and results is posted via this route.



The project promotion have been systematically carried out and updated through the project website during all project duration. Dedicated promotional material (leaflets), technical papers and posters have been distributed and presented in conferences as NDT 2010 (ECNDT), RCM 2011, BINDT 2011/2012 and Railways 2012 by some of the partners.

INTERAIL was present in other relevant Railway research and industrial events as WCRR (World Congress for Railway Research), TRA (Transport Research Arena) and INNOTRANS 2012 where specific publications of the project results were available to a wider audience.

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Other relevant technical papers were submitted to Journal of Transportation Research and in the Mechanical Systems and Signal Processing (MSSP) are under evaluation. An INTERAIL abstract has been submitted to the next TRA2014 to be held in April 2014 and has been accepted as a full paper for submission.

A Final Demonstration workshop was organised and held in Portugal in March 2013. A relevant audience has attended and on-train demonstration was carried out to the invited attendees. A dedicated video highlighting the main developments of the project was produced.
All project publications including the Demonstration workshop presentations and video are available at the project website and social networks as You Tube.

The INTERAIL project delivered an integrated high-speed rail inspection solution demonstrated through a prototype for the automatic inspection of railway tracks to meet the requirements of the European and global railway industry. The high-speed rail inspection system has been complemented through the development and implementation of advanced manual verification techniques based on ACFM, ultrasonic phased arrays and high-frequency vibration analysis. This prototype offers to the rail industry several technical and economic advantages which will increase the reliability of inspections and optimize maintenance costs.

The partners will be proactive in commercialising the INTERAIL system for the benefit of the railway industry and European economy. The commercialisation of the INTERAIL system will support the improvement of the reliability of rail infrastructure and railway operations, increasing cost-efficiency of maintenance activities and decreasing delays and disruption. The technology will be equally adoptable to any type of railway (tram, metro, urban, suburban, freight, or high-speed lines). The consortium estimates that evolution to condition based maintenance practice through the implementation of the INTERAIL technology will allow a significant reduction in overall operations and maintenance costs for railway infrastructure managers. This cost reduction is expected to exceed 10% in comparison to current expenditure. It is expected that the average delay times will reduced by at least 10% in comparison to current levels thus increasing profitability of railway networks with INTERAIL capability. The consortium will ensure that the improvement in rail inspection, maintenance and reliability is clearly visible to all railway industry stakeholders who will be potential clients of INTERAIL.

1.5 Address of the Project Public Website & Relevant Contact Details

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Email: mmpinto@isq.pt
Visit us at www.interailproject.eu

Partner contact details are available at the project website.

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