IRIS 320 is a global concept inspection vehicle, merging engineering and R&D tools for infrastructure maintenance

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Abstract
IRIS 320 train set, the new generation of SNCF’s Railway infrastructure inspection vehicle, offers digitised measurement systems, Network, Information Technology and flexible facilities, to perform Engineering Data production and R&D experiments, leading to a merged production and innovation context, for Railway Maintenance.

Along 25 years of high-speed transportation with TGV trains in France, it became obvious for SNCF, in charge of Infrastructures’ Maintenance, that inspection vehicles would someday have to be renewed.

At the beginning of operation, there was no wear evidence yet available on the recently built High speed lines; it seemed possible to postpone such a considerable investment for a high speed inspection train set. But as years passed by, some defects of unknown types appeared; some equipments had to be replaced before the expected lifetime period, theoretically deduced from Conventional lines experience. High speed lines had to be inspected differently from what was done on Conventional lines, for instance in the track domain, by combining track geometry data to accelerations analysis, recorded at commercial speed, in order to encounter and measure similar defects as those felt by commercial train sets, and decide of appropriate Maintenance operations, given these new collected data.

As a first move to apprehend high speed defects, the Melusine coach was built, and inserted every fortnight within a commercial train set to collect at high speed the acceleration data which were missing.

But on the analysis side, a lot of time and paperwork was still needed, and as inspection vehicles produced anyway only paper outputs, it appeared impossible to work without printed matter and to start on board looking closely at the measurements with an on-board computer, while the vehicle was still running. Real time computation was not only out of reach because technology was not there; it was not even requested to perform such railway parameters inspection.

With the digital sampling revolution in the measurement domain, together with a global reduction of cost process, it appeared that next generation vehicles would have to meet the specific and more severe requirements of the high speed context, to provide more precision, and to bring radical changes in the adopted measurement techniques and on-board context offered for expertise, through Computer Science and Electrical Engineering.

Significant tradeoffs in favour of R&D works and Maintenance-oriented innovations were therefore included in the scope assigned in 2002 to the Project team, in charge of designing a new measurement vehicle concept - namely the IRIS320 Comprehensive high speed measurement train in effective production since 2006. The vehicle expected as output of this project had to be transverse, providing data for Track, Signalling, Catenary, and Telecommunication domains, but also designed in transverse mode with the corresponding expertise contributions of all the railway engineering departments.
Except for the Melusine coach, mainly in charge of Acceleration measurements at high speed, most of the existing measuring vehicles in France were initially designed for Classical lines, limited in speed by Rolling stock characteristics and constrained by robust but basic solutions adopted for data acquisition.

Concerning these now-aging vehicles, being stated that:
- all operate and localise data independently one from another; each of them is dedicated to focus on specific domain analysis, with a limited number of measurement systems; no run can be strictly identical to another one in terms of environment, with unavoidable impact on run outputs;
- they can provide, for sure, acceptable data for high speed lines, to guarantee security comfort, and reliability, but acquisition conditions are somewhat different from those truly encountered by commercial trains running at higher speed, because of their different dynamic behaviour, leading to blind transposition with the help of some virtual transfer function;
- they can not be inserted in-between commercial trains, because of different operational conditions; they have to be programmed during periods normally reserved for maintenance field operation;
- maintenance experts are aware of limitations, do claim for technical improvements, but with years have got used to their outputs as results appear as more secure when data are transmitted as paper charts; Real Time Information systems are considered as more complex to use, since they require an additional knowhow to proceed with the railway domain expertise, which is true;

But since minimal profit can be done from collected data, difficulties may sometimes be encountered for identification of the appropriate maintenance operation to be driven; some may lead to a radical change in the chosen maintenance strategy, as a workaround, if ever troubleshooting should require attempts of unusual cross-compilation of data.

In the meantime, since SNCF’s R&D Departments are constantly trying to find out ultimate ways to obtain a better description of Infrastructures, they legitimately claim for regular access to measurement runs, in order to perform true data acquisition. Their goal is to confirm applicability of suggested theories, or to discover, during their experiment runs, something significant out of intuition-driven combinations of both usual measurement data and others obtained from new sensors.

But single-coach measuring vehicles simply can not provide enough room for such occasional R&D teams on-board installations, without endangering their own data production; such one-shot attempts have indeed proven to be costly, unproductive and unreliable.

Therefore people expected much more than a simple federation of elemental systems from IRIS320:
- a combo of high-tech measurement coaches, crew facilities and comfort coaches to compose a revolutionary global concept train, dedicated to infrastructure metrology, cost-efficient, as well as graceful insertion in the commercial high speed traffic, on the basis of a week journey;
- a unified process of data localisation and database storage, relying on a precise kilometric point (PK) track indexation, to offer, at last, versatile uses of the collected digital samples;
- opportunities, given by the above mentioned database, to compare some data collected during the current run to equivalent data collected from same reference or former run;
- an operator’s ‘maths toolbox’, to establish evidence of correlation between a selection of data, sent by independent measurement systems, for a better behaviour understanding;
- an on-board programmable video matrix, to take advantage from localised pictures to extract useful environmental information by imaging processes and tracking features, results to be later examined by experts, together with other contents of database;
enough room and desks in vehicle coaches to provide opportunities for R&D teams to install on-board mock-ups or experimental sensors, and leave equipments where they are, to be free to come back as much as necessary, to reach the required accumulation of neat runs performed under similar conditions, to conclude with some evidence;

- other working rooms for maintenance experts who would wish to visualise and analyse in real time the data measured on the infrastructure, in case particular points or the consequences of maintenance operations would be of some interest.

Figure 1: The IRIS 320 train set during a measurement run on high speed line

Choice of both digital sampling and nowadays powerful computation, driven by common localisation and data collection through high data rate network, makes possible all Real Time automated processes and semi-automated operations, which may be useful for expertise during runs.

With such an incentive and flexible processing tool, Engineering and R&D works can merge and bring substantial progress in Maintenance inspection throughout the life cycle of this train, for all concerned domains of infrastructure:

- by starting, while still on board, validation of data and analysis which was formerly considered only as a post-run decisional process,
- by feeding specific treatments with raw data to generate automatic alarms with the use of predefined thresholds for determine from flow, exceeding values,
- by using of prediction algorithms to enable a true wear trend identification, whenever possible and fruitful in terms of spare parts procurement anticipation,
- by regularly upgrading the SNCF’s asset management database.
The following parts propose examples that illustrate how Engineering for data production and Research programs have to overcome new difficulties but take significant advantages from the new IRIS 320 Concept.

I – Example of Engineering for data production

The former loaded track geometry measurement system on “Mauzin” cars was reliable and working very well, but was limited in speed operation at 220 km/h, because of its pure mechanical concept; it could not be transposed directly on IRIS320. Its outputs had proven to be satisfactory for maintenance decisional process, so there was a big challenge in choosing a new principle, not deriving from the former measurement principle, obtain measures by use of some completely new high tech contactless measurement devices, committed to end up, still, with an identical deliverable output, acceptable by the maintenance teams on the field. Nothing similar had been operated before in France: Lasers, cameras, inertial package, digital sampling and computation would be involved, to produce on-board real time displays and digital data frame transmissions.

The design risks were obviously very high, but the real milestone was to specify how such a complex system would be validated at the end of the development process, and would for sure meet the requirements in all production contexts.

The new track geometry measuring system, nicknamed "Geo_V", which was officially declared as available for data production service in 2007 required the definition of this new, modified procedure validation, in order to prove the system would be coherent with itself and also that it would be well-consistent with the existing (Mauzin) system, given the fact that the same parameters are supposed to be measured by both types of vehicles.

Reasons to focus on a new validation procedure

It is not the complexity of the design architecture that is exposed hereafter, since it was and still is the manufacturer’s responsibility and intellectual property which is involved there, but rather the method used for the validation of this new track geometry measuring system, arising with its high tech difficulties but also a lot more potential features and evolution capabilities than the previous measuring systems.

Since the wavelength of the defects measured can be as long as 200 m for alignment, and because the possible measuring speed ranging from 10 to 320 km/h, these system’s characteristics have made necessary specific validation tests, to ensure that the system would be fully compliant with its specification documents.

Another special requirement was the overall comparison ability with the measurements delivered by the current "Mauzin" measuring car; therefore, specific test runs were planned to obtain the necessary data to proceed with such a comparison.

Some details are given here on the procedures used to validate the system, illustrated by examples of malfunctions at measurement and system level, which have been revealed, then troubleshooted. Some significant improvements of the system were finally added to the product.

The sampling for the rail profiles is done every 25 cm of railway line; maximum operating frequency of cameras is 400 Hz, which makes possible a geometric data description at 320 km/h.

The following track geometry parameters are measured in accordance with the European EN 13848 standards series: longitudinal level, alignment, twist, cross-level and gauge.

Digital filters have been developed and applied to the Geo_V measurements to deliver the same outputs as the ones which are produced by mechanical characteristics on board of the Mauzin cars.

The Geo_V system can therefore supply compliant results with EN13848 series and also parameters identical with those described in SNCF’s track geometry standards.

The characteristics of the Geo_V system, whose domain of measured wavelengths extends from 3 to 200 m, with speed ranging from 10 to 320 km/h, lead to define special and very strict
validation procedures, since they must also include a part dedicated to comparisons with the "Mauzin" measurements in order to ensure continuity in the exploitation of results.

There is no existing reference standard, no "standard track", against which loaded track geometry measuring systems can be tested and validated, precisely because these are made to provide a dynamic assessment of the track under the load of a vehicle, whereas a so-called reference measurement can only be obtained in static conditions, which would imply an unloaded track. This fact generates measurement differences which can be quite substantial, especially for the short and medium wavelengths, which happen to be closely tied to safety conditions.

Thus, the specific method was developed to validate the measuring system on the basis of two basic tests and applying different criteria to be respected for each of them.

- **Repeatability test**: this test is performed to check that two successive measurements made under the same conditions give equivalent results within the acceptable tolerances.
- **Reproducibility test**: since the loaded track geometry is considered as an assessment independent from the speed of the vehicle, this test is performed to check that two successive measurements, made under different conditions, e.g. speed of measurement or vehicle orientation, provide equivalent results within the acceptable tolerances.

These tests runs were made and the following criteria were applied to the collected data:

- A **statistical analysis** focusing on the difference between the synchronised signals obtained in two successive runs; this analysis allows to highlight abnormal single samples and any variation of the signal zero offset.
- **A frequency analysis**, which may help reveal differences in the overall system’s behaviour occurring during any of several runs, due for example to two different recording speeds. This was very useful to identify any speed dependency, which should not occur.

The tests were applied to each of the output parameters, in order to consider the largest possible domain of all the characteristics of the measuring system; the test runs were made on tracks of different geometric quality, from very good (selected from high-speed lines) to mediocre. Also, different measuring speeds, ranging from 320 to 50 km/h, were tested to check that performance of the system would be equivalent under any circumstance of traffic, and on any type of line.

On each of the lines which was used for the tests, a complete comparison with the parameters delivered by the Mauzin car was also made, obtained from a true “Mauzin” car which had performed its run recently, using the same, statistical and frequency criteria. Such comparisons are essential because they ensure that the track maintenance field engineers will be able to use the results, either from the new technology Geo_V system set on IRIS 320, or those obtained from one of the still operational Mauzin cars, with great confidence of reliability in both cases.

Moreover, some additional cross-validation tests (for internal coherence) have been made, since some measured parameters are not independent, they must therefore be consistent in the frequency domain as for example the difference in alignments between two rail strings and the gauge, which are necessarily linked. This is done to ensure that the digital processing of the raw signals from the sensors is error-free, in particular where the software filterings and calculations are concerned.

In addition to the comparison made, since the very long wavelengths higher than 70 m can be measured by the Geo_V system on IRIS 320 but can not be taken into account by the “Mauzin” car, a topographical survey of about 10 km long was made to compare the field data to the measured data and check their validity.

**Expected results**

Different types of defects have been revealed by the tests described above, namely:

- Single-sample or “punctual” anomalies, by examining the maximum value of the difference between the signals from two different runs, environmental conditions may be the possible causes, such as the direct sunlight on the rail misunderstood as being part of the laser beam, generating therefore a wrong rail profile description, defects also occur when running over a special track feature such as a switch, since the systems loses the rail profile suddenly and concludes to a sudden variation of gauge, leading to false alarms generation;
- defects stemming from particular alignment conditions, when looking continuously at the mean value of some parameters;
- the measurement system setting itself and/or adjustment errors, by means of the frequency analysis, the possible causes being poor synchronisation or inappropriate filtering of the signals.
- A slight error in the zeroing process of the inertial package in lab conditions, before delivery.

The comparison with the measurements made by the “Mauzin” cars has demonstrated that the requirement as to the delivery of "Mauzin signals" was overall fulfilled, in the frequency domain, and also for isolated defects.

Without the methods above detailed, it would have been difficult to precisely identify the origins and reasons for the problems which have been encountered. Troubleshooting is indeed difficult on such testing train sets because it is impossible to perform an adjustment or some deep monitoring on signals or calculations from modules which are not within the coach, but underneath it, on the bogie, and all defects can not be reproduced once back to the workshop.
**Potential for implementation**

The method was not only applied in the measuring system acceptance phase but also during all the system development and fine-tuning phases. Right from the start, it helped to identify various problems such as the one concerning signal digital filtering. In that case, the frequency analysis helped to determine the origin of the malfunction and to quickly ask for corrections and the following validation run.

Generally speaking, level of tests procedures can vary when appears the necessity to check parts, sub assemblies or the complete system, depending whether it corresponds to a routine maintenance operation or a major modification in the concept. The exact content and context of tests to be made in the latter case must be examined and specified according to the specific modifications made.

For instance, a modification on a sensor or transducer will require more tests on isolated defects while a major software modification may require more attention to be spent on the system's frequency behaviour and non regression checking.

**Impact of such a new geometry measurement system on Railway business**

Generalisation to other measuring systems of the validation procedures described will allow, ultimately, to have systems being validated according to identical criteria and offering an identical behavioural performance, in terms of measurement "quality" and traceability. As time goes by, these validation criteria will be identified as the elements making easier to compare the geometric quality of different rail networks.

**II – Example of a Research program**

In the catenary domain, until recently, most of measurements were done by systems relying on contact techniques, at relatively slow or very slow speed. Pantograph's dynamic behaviour was monitored by direct visual observation, this type of investigation being the only efficient method of defects detection, due to the complexity of the catenary equipment.

The Melusine coach in charge of acceleration measurement was also providing a roof observation point, in order to check for arcing, excessive stagger or contact difficulties of pantograph with powered overhead line, but all collected data were based only on human observation.

A research program driven by Research department from SNCF led to a significant progress in defect detection when was set on the roof of the Melusine coach an experimental mock-up, including a linear camera transversally oriented, in charge of recording as a continuous ribbon the catenary equipment.

When lines assembled produced pictures of equipment, the picture could be compared to template pictures, to determine if it looked alike, meaning that the equipment seemed normal, or if it could not be matched, possibly meaning that there could be some defect, to be confirmed, later on by some catenary expert, during post-run analysis in the offices of the suspect pictures.

The system worked, but unfortunately could not operate, at such an experimental stage on a real time basis, Melusine being included into a commercial TGV and committed to run at commercial speed on the inspected High speed lines.

For the new IRIS 320 train set, roof observation points have also been included in the design, to offer equivalent possibility to inspect pantograph behaviour and arcing.

From there, experiments are made with pictures from cameras set inside the roof observation point, to monitor the dynamic behaviour of the pantograph, in order to provide information such as stagger and height, available for analysis in conjunction with gauge instrumentation set on the pantograph, providing accelerations, efforts, and movement description.
The research program, started on Melusine, will continue with a new generation of equipment, this time more industrialised to have the system work as long as possible in any weather conditions, during the lifetime of IRIS320. Development phase of this program will lead to set on the roof an illuminating system composed of laser diodes, a transversal linear camera, and a longitudinal matrix camera to offer a two axis recording, which was not available on the former system.

From the recorded images, image analysis strategy consists in (i) locating the catenary sections between two supporting arms, and then (ii) extracting all surrounding elements such as the contact wire, the carrying wire, the supporting arms, the simple droppers, the droppers with electrical connection. The implementation of the solution is based on the following steps:

**Preprocessing step:** the main goal here is to binarize the image in order to separate catenary from background. On the basis of the observation that structures to extract are clearer or darker than their environment, morphological operators like “top hat” and “bot hat” are applied. These operators resulting from the theory of mathematical morphology allow to extract peaks from intensity image.

**Detection step:** this step is made up of two successive processing steps. The first one (based on Radon transform) aims at detecting contact and carrying wires. The second one aims at detecting the other elements by vertical projection. From the vertical projection, regions of local maxima are determined by looking for downward zero-crossings in the first derivative.

**Classification step:** after catenary element regions have been detected, feature vectors are constructed for each element. A classifier is then trained and used to classify catenary elements according to the classes of element described above.

Results of recognition are materialized in the image by colored bounding boxes according to recognized elements, as shown in figure 2. Tests on 12 catenary sections give the following results of recognition: 96% for contact wire, 72% for carrying wire, 92% for supporting arms, 60% for droppers with electrical connection, 97% for simple droppers.
The former experiment has provided significant experience in the interpretation and processing of the data obtained from the transversal linear camera, but the study starts from scratch with the additional matrix camera.

Future work
Such a system has been specified, and is now under design and manufacturing. It will be probably more difficult to set such a new system on the roof of IRIS 320, now that the high speed inspection train set has gone into regular production, and can not therefore remain very long in the workshop to have such complex systems mounted. Besides, if the work is not finished, partially mounted equipment can not remain in intermediate situation, it has to be secured because it will travel outside and because of the very high voltage, both requiring very strict conditions of installation and respect of procedures. Integration phase might take a long time and a lot of efforts from all contributors to have things set properly. But once the system will be operational, IRIS320 will offer the best ever known conditions to record a maximum of catenary equipments, enabling first the generation of a reference database, producing detection of defects, based on image processings followed by the GO/NOGO recognition principle.

Future work will deal with default detection on the basis of recognized catenary elements such as: broken and missing dropper, broken and missing electrical connection of dropper. Also, a new frame grabbing system will definitively be installed definitively in Iris 320 before the end of 2008. It will be made up of two frame grabbing sub-systems: the first one for inspecting longitudinal catenary on the same basis as the previous frame grabbing system but with better resolution and contrast, the second one for inspecting lateral supporting structures.

The recognised cases of defects will be analysed in conjunction of arcing detections, and dynamic behaviour of the pantograph; this will lead to an overall better understanding of
behaviour in cases of defects and generally speaking understanding of interaction between pantograph and overhead line.

Joint analysis can be done at two possible different levels: as a first move, some data produced by catenary measurement systems will be fed to the catenary defect detection system, in order to let it conclude to the defect type on an autonomous way, by its specialised algorithms. Then, if useful, the raw and calculated data extracted from the pictures could also be sent to the IRIS information system, to fill-in the database. Since Real time processing is not a key factor for the catenary domain, data can also be delivered to the ground information system, if treatment can not be done on-board.

Post processing will in that case be possible with other data coming from instance track measurement systems, to check that catenary defects are not induced or worsened by track defects.

The global aimed objective is to have on board of IRIS 320 all possible measurement systems for catenary, lead various experiments during runs, and see what can come out of it, in terms of automated catenary description, also true defects detection, to reduce the time to repair and avoid more sever problems when defects are left because unsuspected, but also what can be concluded as efficient for catenary preventive maintenance improvement.

**Conclusion on the current technical equipment and the production situation of IRIS 320**

After only one and a half year of operation, IRIS320 performs measurements equivalent to former following measurements vehicles: Melusine (Accelerations and GSM controls), Mauzin (Track Geometry), as well as Helene (Signalling). However the final scope is way ahead, since IRIS320 has been designed to operate for at least 15 years, during which new measurement systems will continuously be added, or upgraded.

This permanent enriching process will have a considerable impact on Infrastructure. Maintenance methodology, and has already brought significant railway business opportunities.

- On engineering side, Project team is in the process of integrating:
  - an imaging Rail surface defaults analysis system,
  - a Catenary overhead line dynamic analysis system with gauge instrumented pantographs, as well as pantograph's 2-axis movements with image tracking
  - a lightning [in terms of detection and duration] measurement system
  - various Signalling train-to-ground communication analysis systems
  - GPS output within data localisation process

- R&D research programs for Infrastructure will also soon be set on board (many others to come):
  - the imaging Catenary overhead line default detection system
  - a Real time analyser to experiment data treatments to recognise defaults from instrumented pantograph data
  - wheel / rail contact noise spectrum analysis for rail corrugation characterisation

- out of the Infrastructure’s scope, IRIS 320 also contributes to other R&D research programs, to help define what will be the Next generation TGV trains:
  - test of ceilings covered with optic fiber woven confection to provide better illumination conditions for passengers
  - characterisation of precise transportation conditions leading to sickness or refusal

Efforts were mainly focused on High speed lines. However, return-on-investment will also concern major electrified Classical lines, since half of IRIS320 year schedule will soon be spent running on these.