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Project RADIUS – Railway digitalisation using drones

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Abstract

Railway signalling assets monitoring is based on three alternative methods: a) human maintenance; b) wired solutions; c) monitoring trains. These methods impose severe limitations in terms of safety issues, initial investment and complexity, operating costs, limited set of the diagnostic data processed, and track occupation. The direct result of these limitations is that the maintenance activities of railway lines are suboptimal, resulting in preventable failures that require expensive and disruptive reparations that imply the temporal interruption of the service in the affected tracks.

RADIUS proposes to use Unmanned Aircraft Systems (UAS) or drones to execute a large part of the inspection and maintenance tasks of signalling assets that improve on the current methods but require compliance with aviation standards and regulation besides those existing in the railway environment.

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Nomenclature

BVLOS	Beyond Visual Line of Sight
DCF	Diagnostic Centre Facility
EGNOS	European Geostationary Navigation Overlay Service
EMI	Electro Magnetic Interference
GNSS	Global Navigation Satellite Systems
IAMS	Intelligent Asset Management System
ODM	Open-source Data Management
SBAS	Satellite Based Augmentation System
SORA	Specific Operations Risk Assessment
TMS	Traffic Management System
UAS	Unmanned Aerial Systems
UC	Use Case
VLOS	Visual Line of Sight

1. Introduction

IMs currently monitor their railway signalling assets using three methods:

- On-demand or programmed human maintenance activities.
- Wired solutions.
- Trains equipped with monitoring technologies.

Human maintenance activities demand high direct personnel labour costs and operational constraints. Maintenance teams comprise at least two or three people for safety purposes. In addition, maintenance activities require the protection of the affected trackside area from dangerous situations for the workers: train movements and speeds, power supply, etc. According to Eurostat (2020), during 2020 there were 31 deaths and 44 severe injuries amongst railway employees in EU-27 countries, some of them during inspections.

Moreover, monitoring of signalling assets based on diagnostic data acquired with wired solutions is expensive since it requires extensive and costly cabling. Because of the sometimes-limited bandwidth of the existing cabling solutions, they only allow the transfer of a limited set of diagnostic data from the peripheral posts to the centre, establishing a limit of the number of features monitored.

To overcome these limitations, some Infrastructure Managers have made significant investments for designing, developing, operating, and maintaining diagnostic trains. These trains acquire diagnostic data during their runs, which are later elaborated offline to discover trackside and signalling asset anomalies. However, diagnostic trains run at lower speed than commercial trains, thus implying temporary performance limitations on the assessed lines. In addition, these solutions involve substantial additional budgets to maintain and update the on-board equipment of the diagnostic trains, as well as to train staff.

Railway maintenance activities require special verification checks of the maintained areas before restoring the nominal operational signalling conditions. For example, depending on the maintenance activities performed, a train must run on that section to ensure that there are no obstacles left on the track and to verify that the track layout complies with the certified track layout. Track inspections must also be performed after important climatic events.

To overcome some of these limitations, RADIUS proposes to use Unmanned Aerial Systems (UAS) to execute a large part of the inspection and maintenance effort on-site, including tuning, re-calibration, activation of special functions, etc. SESAR (2016) acknowledges that using UAS could benefit the mobility sector through railway inspection. The RADIUS automation will also allow increased inspection frequency, defining a new paradigm for railway inspection and maintenance that limits the activities carried out by human teams and improves the global railway operational service in terms of availability, reliability, and performance.

The main benefits provided by UAS in inspection and maintenance activities may be:

- Overcome many of the limitations mentioned above in inspection and maintenance of signalling assets.
- Contribute to the digitalisation of the railway sector, recognised as a key trend by GSA (2019a).
- Replace most of the human maintenance and visual inspection activities.
- Increase the safety of the maintenance operations by requiring fewer people in the field.
- Reduce the complexity and the cost of maintenance activities using autonomous systems.

The following table summarises the major limitations of each of the asset monitoring alternatives compared to the RADIUS approach.

Table 1. RADIUS compared with existing solutions.

Inspection method	Initial investment	Operating costs	Track possession	Other issues
Human inspection	**Low**	Very high	Yes	Health & safety
Wired solutions	Very high	**Low**	**No**	Limited features
Diagnostic trains	Very high	High	No (but reduced capacity)	Staff training
RADIUS concept	**Low**	**Low**	**No**	Compliance with aviation standards and regulation

2. Objectives of the RADIUS project

The aim of the RADIUS proposal is to develop UAS-based technology:

- To perform inspection and monitoring for condition monitoring of both physical status and electronic functionality of both non-safety-critical and safety-critical railway signalling assets.
- To execute specific maintenance activities to pave the road to efficient and reliable unmanned activities.

The project will explore the following potential uses of unmanned aerial technology for monitoring and maintenance of railway signalling assets and other related ancillary systems and devices:

- **Condition monitoring of signalling assets**. Condition monitoring of signalling assets is one action an UAS can perform and covers monitoring of coatings of signalling racks, light intensity of line-side signals, track circuit key parameters, temperature, point machine key parameters, etc.
- **Identification of vandalism**. Detection of vandalisms against signalling assets and railway installations close to the tracks.
- **Detection of malicious and non-malicious radio frequency interferences**. The UAS can measure signals that are above given thresholds and have the capability of disturbing the signalling communications because of new radio transmissions, degradation of devices that cause emitting outside the usual spectrum, intentional disturbances, etc.
- **Wireless diagnostic data collection**. The UAS can get enough diagnostic data to perform a real-time preliminary analysis aimed at identifying the immediate maintenance actions (e.g., tuning of some key parameters) to restore the operational conditions.
- **Software updates of signalling assets**. Signalling assets incur in degraded functionalities because of aging and wearing of their parts. In most cases, an UAS can fine tune them, optimising their threshold

settings or performing firmware updates using wireless technology, considering the security risks inherent to firmware upgrades.
- **Clearance after human/mechanical intervention under track possession**. UAS can also contribute to increase safety by using the visual sensors to verify that a working site is clear from human and device presence before releasing track possession.

These potential capabilities go much beyond what is possible to do with the current wired solutions and diagnostic trains and compete favourably with human inspections, at a fraction of the cost and with increased safety.

2.1. Key Performance Indicators

Based on the objectives of the project, it is possible to quantify the following Key Performance Indicators for the industrialised solution:

Table 2. RADIUS Key Performance Indicators.

KPI	Target
Reduction of costs	• Reduction of 80% of human related costs for preventive maintenance • Reduction of 30% of human related costs for corrective maintenance
Increase of health and safety of workers	Increase of health and safety of workers by 70% in the long term by reducing their presence in dangerous working areas
Increase of railway reliability and availability	Increase of 20% in availability and 5% on reliability

3. Methodology

To achieve its goals, RADIUS will use the following methodology which is summarised in Figure 1:

- **System Specifications**: Identifying stakeholders' needs, priorities and constraints introduced by aviation and railway regulations and standards and to define the system requirements and architectural specification.
- **Communication, mission control and interaction with TMS**: Dealing with all the drones' flight management actions to perform asset monitoring and maintenance actions avoiding or limiting the railway possession.
- **Adaptation or redesign of signalling assets**: To facilitate the monitoring, inspection and maintenance activities using drones. A docking station to recharge the UAS will also be designed to increase the range of the solution.
- **Selection of drone and payload design**: Centred on the selection of the best UAS solution, including the changes required to existing UAS and design of the payload, including the sensing solutions.
- **Data management and analytics** will focus on complementing the on-board computation functionality of the drone with the ground-segment ODM platform, covering all data related aspects including cybersecurity, privacy, data management and analytic for predictive asset maintenance through a direct interface with the standard IAMS.
- **Tests and validation**: The individual components will be tested in-lab and in-field, and the whole system will be tested and validated in a relevant railway environment on a selected redesigned signalling asset.

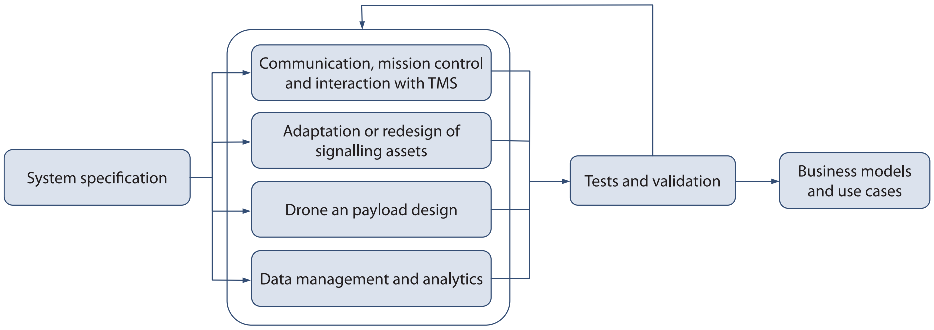

Fig. 1. RADIUS Methodology.

4. Discussion and project results

The RADIUS project is still at a very early stage of its work, and it would be premature to present actual results. However, some preliminary and the expected results of the project are presented below.

4.1. System architecture

The main outcome of the project will be a UAS based TRL 6 prototype with monitoring and maintenance capabilities of railway signalling assets that will be further developed (see section 4.3) as a commercial grade solution that integrates several components that are susceptible of independent exploitation. The system architecture of the RADIUS system is shown in Figure 2.

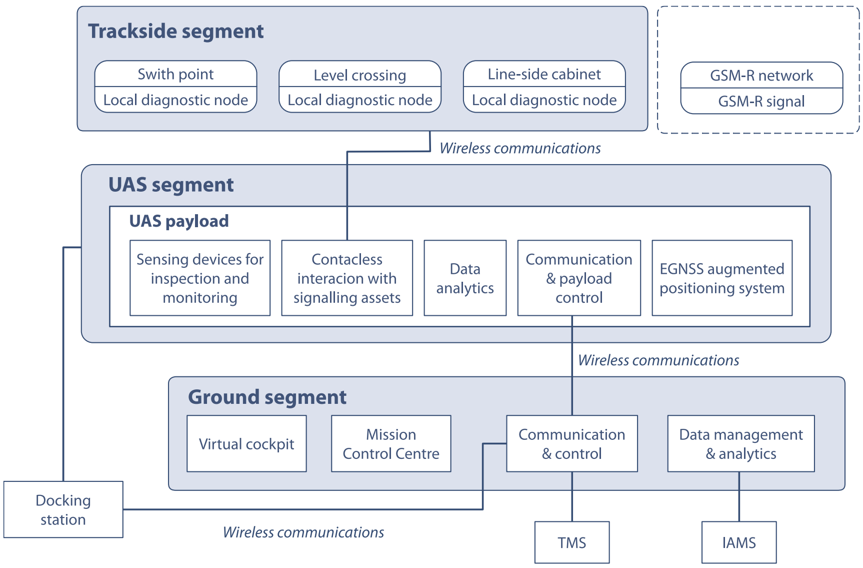

Fig. 2. RADIUS system architecture.

4.2. RADIUS solution highlights

The only significant incident involving UAS and their interactions with the railway is the event happened in Stoke Gifford (UK), described in AAIB (2020). An UAS suffered a complete loss of control because of magnetic deviations of up to 140° observed over localised regions that were caused by the overhead high-voltage wires. For that reason, RADIUS should investigate the possibility of either shield the drone against EMI or use EMI-immune on-board equipment.

Besides common operational limitations that affect UAS operations, a particular operational constraint with an impact on the system design has been identified; train induced winds and vortexes. The magnitude of aerodynamic forces caused by a train in movement increases in proportion to the square of the train speed, Yang et al. (2014) and depends on the horizontal and vertical distance to the train. Preliminary results have been estimated using the method described by Sebesan (2015), extrapolating the results to the expected height of the flights, to establish a safe distance and height of the UAS for different train speeds.

A key component of the solution is an augmented positioning system based on EGNOS and GALILEO, capable of providing accurate and safe positioning, as described by GSA (2019b). The accuracy of conventional positioning systems may not guarantee the required accuracy to avoid unwanted interactions between the UAS and its surroundings. Therefore, an SBAS, such as EGNOS, is necessary for applications where accuracy, integrity, continuity, and availability of positioning information are critical.

The UAS payload includes visual sensing devices (RGB, hyperspectral, or thermal cameras) for inspection and monitoring of signalling devices using open-source image processing techniques to recognise, categorise and monitor the changes of objects (signalling components, rails, etc.) The image processing algorithms address three main issues:

- Identify the linear and non-linear assets using the filtering processes described in Duncan (1984). A bidirectional action-perception model approach, such as Palomino et al. (2016), followed by semantic segmentation, Li et al. (2009), and object recognition techniques, Girshick at al. (2014) will analyse the scene and detect the objects contained inside it.
- Detect and report defects using a catalogue of common rail defects, such as UIC (2018) for each kind of asset monitored. Defects will be detected using techniques similar to those of Yamaguchi et al. (2010).
- Identify and remove any personal identifiable data at the source, preventing its storage and transmission, following the recommendations of DroneRules (2018).

Wireless interaction with the monitored assets can store the full set of diagnostic data needed for an off-line detailed analysis after the UAS returns to the DCF. Maintenance actions can include setting the internal temperature of a shelter to a new value, switching on/off some diagnostic or measurement equipment installed inside a shelter, enabling the recording of some log files, changing the configuration of some equipment inside the shelter, etc. Diagnostic data for each peripheral post doesn't require cabled communication networks.

The RADIUS data analytics architecture is based on two layers:

- The on-board analytics platform to perform limited real time analysis to detect and monitor the different assets, as described above, using hardware-friendly smart models, as in Oneto (2016).
- A ground control analytics centre that will host the core of the data analytics solution. It will store and process all collected data to perform ‘nowcasting analyses’ to assess the status of each monitored asset and ‘forecasting analyses’ to predict possible failures. State-of-the-art machine learning and data mining such as Deep (Hinton et al., 2016), Multi-Task (Evgeniou et al., 2004), Transfer (Pan et al., 2010) and Semi-supervised (Chapelle et al., 2018) algorithms will be used, together with rigorous statistical inference derived from Oneto (2018).

The ground control analytics will interface with the existing IAMS to update the information about each monitored asset automatically. The interface will comply with the relevant Shift2Rail initiatives on asset maintenance.

4.3. Business model

A preliminary RADIUS business model has been developed following the Business Model Canvas template proposed by Osterwalder et al. (2010). The identified business model is promising, having identified four customers segments (public and private infrastructure managers, railway maintenance service companies, and suppliers of railway maintenance solutions) and the corresponding revenue streams and channels according to the Business Model Canvas approach.

The preliminary business model includes the following main conclusions:

- The RADIUS concept is fully viable and exploitable in the railway domain, confirming the strengths identified at the proposal level.
- Two main modes of operation can be considered for RADIUS: survey and condition-based missions.
- RADIUS cannot be exploited for continuous monitoring.
- The most appealing lines for the RADIUS business are the Regional and Community Lines and the Heavy and Conventional Freight Lines, providing an extremely high potential in the EU railway network.
- The number of docking stations required to cover a railway line has an important impact on the total cost of the RADIUS system. Thus, the design of the system should consider choices to minimise the cost of the docking stations, or to increase the UAS operational range to reduce the number of required docking stations.

4.4. Safety analysis and privacy issues

To support the test and validation campaigns, we have performed a Specific Operations Risk Assessment (SORA), identifying the robustness level for each safety and the mitigations prescribed by SORA. The assessment includes the risk for third parties on the ground (ground risk) and in the air (air risk). A final SORA supporting the proposed use cases for the RADIUS solution will be conducted towards the end of the project.

After an on-site test campaign, after the automatic phase of detection and cancellation of personal information we will conduct a manual check to verify if images related to a person external to the project have been recorded accidentally and these images allow the individual recognition of the person. If this situation occurs, we will apply mask algorithms and record this situation and the application of the masking procedure for overcoming the detected issues. Based on the analysis of these accidental breaches of privacy, the automatic detection algorithms will be refined.

4.5. Future work

To achieve the intended TRL 6, a comprehensive test and validation campaign will be carried out, as shown in figure 3.

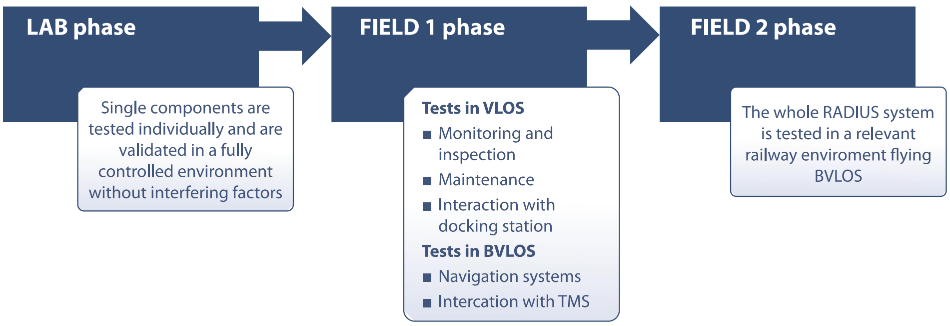

Fig. 3. Test and validation campaign.

The RADIUS consortium has identified two locations where to implement the RADIUS UCs:

- Field 1: The Hitachi Rail industrial plant in Naples (Italy), that has a private rail ring.
- Field 2: The railway station of Casa Branca (Portugal) and a corresponding piece of track on the Alentejo railway line.

These two locations cover the inspection of all the relevant assets identified in an at least TRL6 environment.

The Field 1 site will enable tests and validation of the preliminary RADIUS prototypes and to carry out specific tests on a switch and cabinet assets.

The Field 2 site covers around 12 kms of the Alentejo line from the Casa Branca to the Alcaçovas railway station. This site presents all the characteristics necessary for the RADIUS project and will allow the testing of the BVLOS functionalities of the RADIUS prototype:

- It is a section of a real railway track allowing tests and validation up to TRL7.
- Train traffic is limited to few slots during the day, offering several traffic-free windows.
- The section includes both tracks with and without catenary.
- Key assets of RADIUS interest are present, including a level crossing at the Alcaçovas station.
- The section includes typical obstacles to be avoided by a UAS in a railway domain (a road bridge, a passengers' walkway, light poles, ...
- The area has a very low population density and is free from critical installations (airports, military bases, etc.)

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