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INTERACTION ASSETS HEALTH STATUS MONITORING

SIA

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Deliverable D2.2

SIA Architecture and Verification Plan

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1 Executive Summary

The present document constitutes the first issue of Deliverable D2.2 “SIA Architecture and Verification Plan” in the framework of the Project titled “System for vehicle-infrastructure Interaction Assets health status monitoring” (Project Acronym: SIA; Grant Agreement No 776402).

Background to this Deliverable

Based on previous project work, primary research and reviews of the current strategies for the management of railway maintenance, Deliverable D2.1 defines user needs and system requirements as input to the SIA system architecture definition (D2.2) and technical development (WP3 onwards).

Conclusion Summary of D2.1

Aim of the Deliverable

The overarching aim of this deliverable is to define the architecture of the SIA system. This will include the identification and consolidation of SIA modules based on the requirements identified in Deliverable D2.1: End User Requirements of SIA and Validation Plan. As part of the architecture definition, we aim to detail the various interfaces between the different modules of the system, along with high level module functionality and a preliminary selection of the hardware that will be used.

Summary of the Technical Modules & Conclusions of the Deliverable

2 Table of Contents

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3 Abbreviations and Acronyms

Abbreviation / Acronyms	Description
NoS	Network of Sensors
ABA	Axel Box Acceleration
VP	Visualisation Platform
DH	Data Hub
CDM	Component Degradation Models
POS	Positioning

4 Introduction

4.1 SIA Overview

The SIA project has the objective of developing 4 ready-to-use new services (iWheelMon, iRailMon, iPantMon and iCatMon) to provide prognostic information about the health status of the railway's most demanding assets in terms of maintenance costs (wheel, rail, pantograph and catenary).

4.2 Purpose and Scope of this Document

This document is deliverable D2.2, SIA's Architecture and Validation Plan. The purpose of this document is to provide the architecture of the SIA system with a corresponding verification plan to ensure and outline how the architecture meets the requirements outlined in deliverable D2.1 (End User Requirements and Validation Plan). This deliverable is submitted as part of Work Package 2.2 SIA Architecture, which is a sub Work Package of Work Package 2, End-user Functionality and SIA Architecture Definition. This deliverable has been led by NSL with contributions from DLR, Ingecontrol and CEIT.

4.3 Intended Audience and Distribution

This deliverable has a public dissemination level.

4.4 Structure of the Document

Following the reference and background information presented in Sections 1 to 4, the content and structure of this document is as follows:

Section 5: User Requirements Summary

This section provides a summary of deliverable D2.1 as part of Work Package 2.1. This section defines high level Functionalities, actors, interfaces and non-functional requirements.

Section 6: SIA Subsystems

This section defines the 6 different blocks/sub-systems which form the overall SIA architecture. These sub-systems are called SIA_Pant, SIA_ABA, SIA_DH, SIA_POS, SIA_CDM and SIA_VP and are defined in a way which corresponds to the different physical entities of the system. For each block a set of functionalities, a preliminary selection of hardware components and the internal interfaces are defined. This section also includes a trade-off between the various options for the approach for the positioning module based on the user requirements defined in Work Package 2.1.

Section 7: SIA Overall Structure

Section 7 brings together the subsystems defined in Section 6 to show the overall architecture of SIA. The interfaces between the subsystems and external interfaces are also defined.

Section 8: Architecture Modelling and Representative Scenarios

To support technical decisions made during the architecture definition, the environment and the essential blocks of SIA will be modelled, and representative scenarios will be simulated.

Section 9: Architecture Verification

Section 9 provides verification for the architecture provided in previous sections of this document. With this purpose, an independent analysis will be completed to ensure that the architecture meets the needs of the use cases, functional and non-functional requirements as detailed in D2.1.

5 User Requirements Summary

Document D2.1 defined two sets of SIA requirements. According to the document SIA must have next high-level functionalities:

- F1. Configuration and Installation
- F2. Introduction of inspection data
- F3. Introduction of auscultation data
- F4. Inform about the historic health status of assets
- F5. Inform about the current health status of assets
- F6. Inform about early detection of failures
- F7. Propose maintenance recommendations

In addition, a set of actors have been defied who will interact with SIA and perform the required functionalities:

- A1. Installator / Configurator
- A2. Auscultation systems
- A3. EGNSS systems
- A4. Maintenance manager
- A5. Maintenance operator
- A6. Ambient
- A7. Operations management IT systems
- A8. Maintenance management IT systems
- A9. Asset management IT systems

The above actors will interact with SIA via next input and output interfaces groups:

Input:

- IF0. Configuration
- IF1. Operations data
- IF2. Maintenance procedures
- IF3. Auscultation data
- IF4. Inspection data
- IF5. Ambient
- IF6. EGNSS system

Output:

- IF7. Asset status
- IF8. Early detection of component failure
- IF9. Maintenance recommendations

- IF10. External interfaces

The above interface groups are the external interfaces which are used for communication between the actors and the system. Internal interfaces will be defined in line with subsystem definition in the current document.

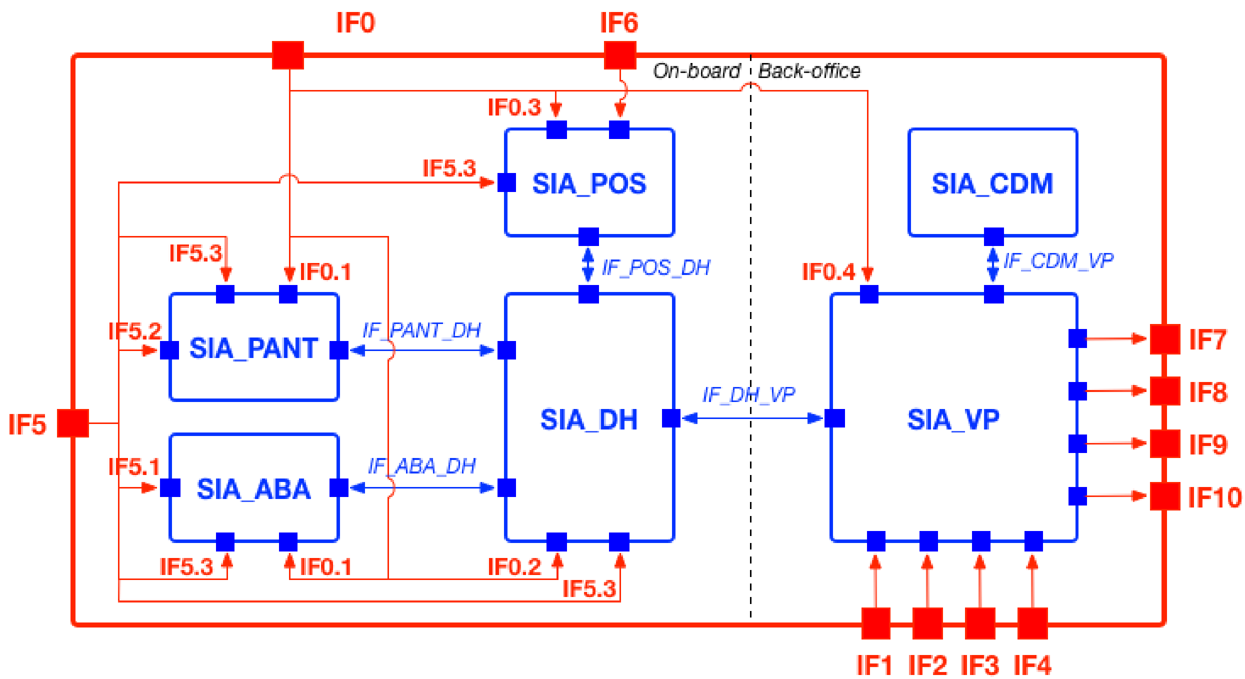
In addition to the functional requirements, D2.1 also defined a set of non-functional requirements which will be verified according to the plane discussed in the current document.

6 SIA Structure

To fulfil the requirements defined in D2.1, next sub-systems are defined for SIA:

- Pantograph (Pant)
- Axel Box Acceleration (ABA)
- Positioning system (POS)
- Data Hub (DH)
- Component Degradation Model (CDM)
- Visualisation Platform (VP)

Next diagram defines SIA overall structure and the associated interfaces.



SIA will provide 4 services with characteristics defined below:

- *iWheelMon*, which is intended for TOCs and integrated operators, will provide real time information about wheel status (e.g. presence of wheel flats) and prognostic health status information within a certain time frame such as predicted wear, RCF and poligonization, and maintenance recommendations for meeting ISO 1005-8 and TOC specific requirements.

- *iPantMon*, which is intended for TOCs and integrated operators, will provide real time information about the pantograph status (e.g. incorrect vertical damping forces of upper arm) and prognostic health status information in a certain time frame such as wearing of contact stripes, and maintenance recommendations for meeting EN 50405 and TOC specific requirements.

- *iRailMon*, which is intended for IMs and maintenance subcontractors, will provide real time information about the rail status (e.g. broken rail) and prognostic health status information in a certain time frame such as squats, corrugation, wear and RCF, and maintenance recommendations according to ISO 5003:2016 and IM specific maintenance requirements.

- *iCatMon* which is intended for IMs and maintenance subcontractors, will provide real time information about the catenary status (e.g. wearing of cable) and prognostic health status information in a certain time frame such as inclination of the mooring balance with respect to the rail, break of the automatic regulation pulley, wear of cables, and maintenance recommendations for meeting EN50119.

These services will be delivered by different modules/sub-systems of the SIA system according to the next table.

SIA subsystems	SIA services			
	iWheelMon	*iPantMon*	*iRailMon*	*iCatMon*
SIA_Pant		√		√
SIA_ABA	√		√	
SIA_DH	√	√	√	√
SIA_Pos			√	√
SIA_VP	√	√	√	√
SIA_CDM	√	√	√	√

Table 7-1: Table: SIA services mapped to subsystems

In the coming sub-sections each of SIA sub-systems will be discussed in terms of their functionalities, hardware components and interfaces.

6.1 Pantograph (Pant) [CEIT]

6.1.1 Functionality

The Pant sub-system provides data acquisition of pantograph-to-catenary dynamic interaction, which will be used for condition monitoring of the catenary (i.e. Overhead Contact Wire) and the pantograph. Specifically, on the one hand, Pant data can be linked to OCW irregularities, such as wear, height and stagger. One the other hand, failure mechanisms associated to the pantograph, such as the wearing of the contact strips. The characteristics of these different failures are analysed in the time, space and the respective Fourier domains, namely frequency and wavenumber domain.

In a tentative manner, by using sensors with different orientations (longitudinal, lateral and vertical) in combination with repeated measurements through passing the same track segment several times, will help to separate and classify the different failures of the OCW and pantograph. By means of the POS sub-system identified OCW irregularities can be accurately localised.

The Data gathered with the Pant sub-system will serve as an input for condition-based and predictive maintenance tasks.

6.1.2 Hardware Components

The core of the Pant sub-system will be a set of sensors to assess the dynamic interaction of the catenary-pantograph system. The data need to undergo certain pre-processing, such as band-pass filtering, feature extraction etc. before they are sent to the back office. It must be noticed that, considering the challenging environment in which the sensors will operate (from an Electro Magnetic Compatibility standpoint), mixed electrical-optical interfaces might be needed. Depending on the use case it might be desired to store large amounts of raw data on an on-board storage medium. Therefore, on-board processing and storage units are necessary. These units can either be integrated within the Pant sub-system or centralised in the data hub subsystem.

6.1.3 Interfaces

External:

IF0.1: It is used for configuration of Pant sub-system.

IF5.2: Physical signals to be obtained by Pant sub-system from the dynamic interaction of the pantograph-catenary system

IF5.3: Electrical power supply.

Internal:

IF_PANT_DH: It is used for transmitting, depending on the use case, condition relevant features and/or raw data as well as status information on sensor performance from the Pant sub-system to SIA_DH.

6.2 Axel Box Acceleration (ABA) [DLR]

6.2.1 Functionality

The ABA sub-system provides data acquisition of axle-box acceleration data. These data give valuable insights on the vehicle track interaction and can hence be used for condition monitoring of the track and wheels. Specifically, on the one hand, ABA data can be linked to track irregularities, such as corrugation, squats, defective joints or hollow sleepers. One the other hand, wheel shape errors, such as flat, polygonal wear and tread spalling have an impact on the ABA. The characteristics of these different failures are analysed in the time, space and the respective Fourier domains, namely frequency and wavenumber domain.

Using sensors with different orientations (longitudinal, lateral and vertical) in combination with repeated measurements through passing the same track segment several times, will help to separate and classify the different failures of the track and the wheel. By means of the POS sub-system identified track irregularities can be accurately localised.

The Data gathered with the ABA sub-system will serve as an input for condition-based and predictive maintenance tasks.

6.2.2 Hardware Components

The core of the ABA sub-system is a three component broadband ABA sensor that senses the vibration caused by the wheel-rail interaction. The data need to undergo certain pre-processing, such as band-pass filtering, feature extraction etc. before they are sent to the back office. Depending on the use case it might be desired to store large amounts of raw data on an on-board storage medium. Therefore on-board processing and storage units are necessary. These units can either be integrated within the ABA sub-system or centralised in the data hub subsystem.

6.2.3 Interfaces

External:

IF0.1: It is used for configuration of ABA sub-system.

IF5.1: Vibrations generated at the wheel-rail contact reaching to the ABA sensors in the ABA sub-system.

IF5.3: Electrical power supply.

Internal:

IF_ABA_DH: It is used for transmitting, depending on the use case, condition relevant features and/or raw data as well as status information on sensor performance from the ABA sub-system to SIA_DH.

IF_POS_ABA: Used for synchronisation of ABA sensors with other sensing nodes within the vehicle.

6.3 Positioning system (POS) [NSL]

6.3.1 Functionality

In order to identify the evolution of failures in the infrastructure, accurate positioning and time stamping that synchronize measurements from sensing nodes within the vehicle is essential. These functionalities are provided by the POS sub-system (SIA_POS). Such system must provide high accuracy positioning (centimetre or decimetre levels) in railway environment. Global Navigation Satellite Systems (GNSS) are capable of delivering centimetre-level positioning accuracy. GNSS positioning can be achieved based on code or phase measurements. The phase measurement is an order of magnitude more accurate than code and can be used in techniques such as Real Time Kinematic (RTK) and Precise Point Positioning (PPP) to deliver high accuracy positioning. PPP is the preferred option here as it involves only one GNSS receiver as opposed to the RTK technique which requires at least one extra receiver in a known location. In the railway environment, satellite masking is one of the main challenges which limits GNSS availability. Using a multi-constellation approach will improve the availability. In addition, using inertial measurements will overcome short GNSS signal blockages in the railway environment and will help to detect and exclude faulty GNSS measurements.

Whether the precise positioning takes place onboard the train or at the server side is to be determined based on the user requirements. As such, the main functionality of the POS sub-system will be one of the following:

- To prepare and output multi-constellation GNSS and inertial measurements to the data hub, which will then deliver them to the server for post-processing purposes.
- To compute high accuracy train positions and output these to the data hub.

6.3.2 Hardware Components

The main components of the POS sub-system are:

- Multi-frequency GNSS antenna: Different GNSS systems occupy different frequency spectrum. In addition, high accuracy positioning requires measurement for at least two frequencies from one satellite to eliminate the ionospheric impact. The antenna will provide radio frequency signals to the receiver.
- Multi-frequency multi-constellation GNSS receiver: In order to achieve high accuracy positioning the receiver must at least receive GPS and GALILEO signals. It will output raw measurements for each signal tracked (pseudoranges, carrier phase, Doppler offset, signal-to-noise-ratios)
- IMU, outputting raw sensor measurements.
- Positioning engine (onboard or server-side). It will process the raw GNSS measurements and IMU sensor measurements, integrating them with other data e.g. digital maps, to output high accuracy train positions.

6.3.3 Interfaces

External:

IF0.3: It is used for configuration of POS sub-system.

IF6.1: GNSS signals reaching to the GNSS antenna in the POS sub-system.

IF6.2: Inertial signals reaching to IMU unit.

IF6.3: Digital map database

IF5.3: Electrical supply.

Internal:

IF_POS_DH: It is used for outputting positioning related measurements or final positions to SIA_DH, depending on the approach taken as discussed above. It also is used to pass on configuration information to the GNSS receiver and/or positioning engine if applicable

6.4 Data Hub (DH) [NSL]

6.4.1 Functionality

The data hub will manage the interface between the on-board system and the back-office, via wireless communications. It will interface with SIA_PANT and SIA_ABA in order to retrieve sensor measurements. It will interface with SIA_POS in order to retrieve positioning data.

6.4.2 Hardware Components

The data hub will include a ruggedized computer, a communications module (e.g. 4G/5G modem, WiFi access point) and the necessary communications antennas.

6.4.3 Interfaces

Input:

IF0.2: It is used for configurating SIA_DH.

IF5.3: Electrical supply.

Internal:

IF_POS_DH: It receivers positioning related measurements from POS sub-system.

IF_PANT_DH: It receives Catenary-pantograph related sensor observations.

IF_ABA_DH: It receives Wheel-Rail related sensor observations.

6.5 Component Degradation Model (CDM) [DLR, CEIT]

6.5.1 Functionality

The Component Degradation Models are implemented algorithms to provide estimations about the expected future asset degradation development based on the historic sensor data and additional information provided by the Visualisation Platform (VP) via interface IF_CDM_VP.

6.5.2 Hardware Components

The CDM are represented by algorithms implemented in Python running at the back-office backend system utilizing the architecture of the Visualisation Platform (see section 6.6).

6.5.3 Interfaces

The CDM are interfacing the VP (IF_CDM_VP) to obtain the necessary input data and to provide the modelling results (output) back to the VP for further expert analysis, reporting and visualization.

6.6 Visualisation Platform (VP) [ING]

6.6.1 Functionality

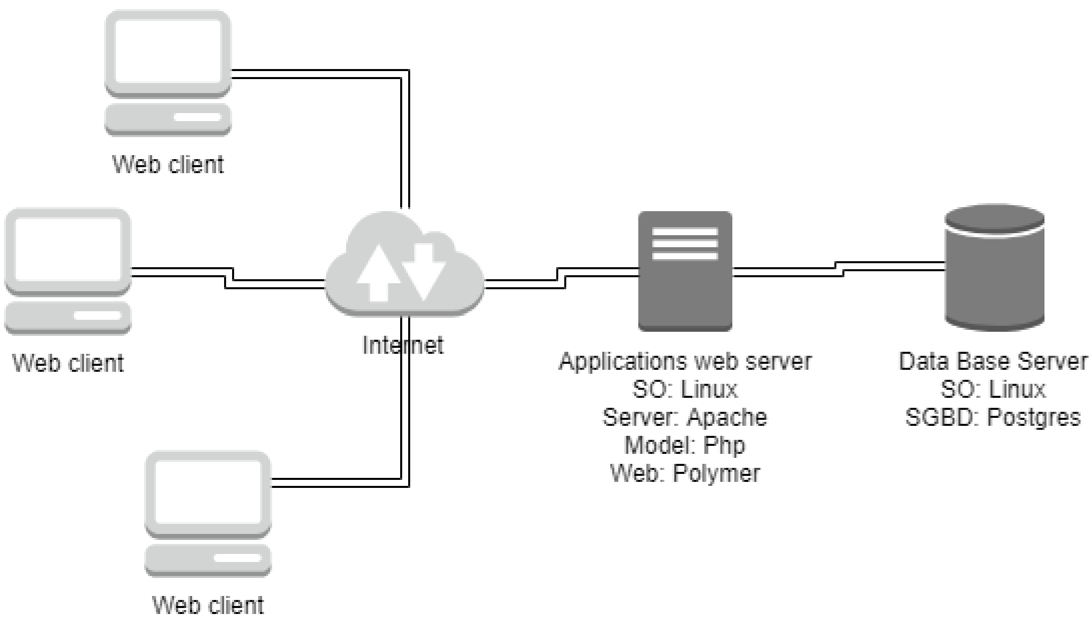
The Visualization Platform (VP) is the SIA subsystem that will display to the users the relevant information generated by the rest of SIA modules. It will also provide an input interface for the configuration of the different subsystems requiring an interaction with the users.

Specifically, the VP will be able to:

- Display in a simple GIS (Geographical Information System) map the railway lines in the system
- Manage the list of components
- Manage the list of KPIs associated to components, as well as their limits and thresholds
- Manage the maintenance list associated to each KPI, and the actions to do based on the KPIs status
- Report and visualize the raw auscultation data
- Report and visualize the raw inspection data
- Display the current status of the components based on the KPIs
- Display a prediction of the future status of components base don KPIs
- Generate alerts reporting the early detection of future failures
- Display maintenance recommendations based on the assets status

6.6.2 Hardware/Software Components

The visualization system is going to be a web-based platform with a client-server architecture in three layers, as displayed in the next figure:



Web Client: Any device (i.e.: PC, laptop, Tablet…) with Internet Access and a web browser to load the web app interface.

Applications web server: Linux OS server hosting an Apache Web server with:

- Database connection interface implemented in PHP to retrieve from the Data Base Server the data to be displayed.
- Web app, with the business logic implemented, for example, in Javascript using the Polymer library for web components

Data Base Server: Will store efficiently based on visualization requirements the data to be displayed coming from the rest of SIA subsystems.

The physical infrastructure characteristics will depend on the system load, and is not strictly required as servers can be virtualized and/or deployed in a cloud based provider, providing a higher flexibility to face system load fluctuations.

6.6.3 Interfaces

External

Input:

- IF0.4: Configuration parameters and SIA-VP parametrization.
- IF1.1.1 FIS map of the line(s).
- IF1.1.2. Composition of the infrastructure (e.g. sections, curvature, switches and crossings, tunnels, components, materials, etc.)
- IF2: Maintenance procedures.
- IF3: Auscultation raw data.
- IF4: Inspection raw data.

Output:

- IF7: Asset Status
- IF8: Early detection of component failure
- IF9: Maintenance recommendations.
- IF10: External interfaces.

Internal

- IF_CDM_VP: Sends input data to SIA_CDM and receives the calculated output data from SIA_CDM.
- IF_DH_VP: Receives the data in SIA_DH generated by the different subsystems and sends data introduced in the system through SIA_VP required by the rest of subsystems.

7 Architecture Modelling and Representative Scenarios

In order to make support the technical decisions during the architecture definition, the environment and the constituent blocks of SIA will be modelled, and representative scenarios will be simulated.

8 Architecture Verification

8.1 Technical Requirements [NSL]

Document D2.1 defined a set of non-functional requirements which can be grouped as:

- Hardware
- Software
- Performance
- Supportability
- Maintability
- Operability

In this section a verification plane is defined to verify these requirements.

According to Unai text in the D2.1, the non-functional req needs verification.

8.2 Requirements Sequence [CEIT]

Time line: To be provided by CEIT

8.3 Verification Plan [NSL]

Verify each sub-system individually against sub-system requirements. Or verify the overall system against a set of scenarios?

The verification plan should define a process to ensure that the overall system once developed, meets the system and service requirements. This would typically be carried out in a laboratory environment, and many requirements may be verified through a basic cross-checking process. Some requirements may not be verifiable in this way if they are dependent on operational conditions.

The verification process will be recorded in a table containing:

- System/Service Requirement No.
- Requirement text
- Verification successful?
- Verification notes

9 Conclusions

10 References