Development of the Preliminary Stages for ATO lab prototype in sight of a future inspection vehicle.

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Introduction

CEIT is currently involved in diverse Work Packages (WPs) of the R2DATO Project [1] under the European Rail Joint Undertaking (ERJU) [2], a European partnership dedicated to rail research and innovation within the Horizon Europe program (2020-2027) and the successor to the Shift2Rail Joint Undertaking (S2RJU) [3]. Specifically, CEIT is an active partner in Work Package 10 (WP10), aiming to develop a lab prototype solution based on an automatic driving system for an inspection vehicle. This automatic driving system is being designed based on the reference architecture for GoA3/4 system from the System Requirement Specification (SRS) of the X2Rail-4 project (baseline 1.0.0) [4] and relevant standards such as the Technical Specification for Interoperability – Control Command and Signalling (TSI – CCS) [5]. Of note, the current SRS with its associated reference architecture from the X2Rail-4 project was transmitted to EU-RAIL for future evolutions of the SRS ATO up to GoA4 system.

The current work focuses on detailing the progress of the lab prototype solution that is under development at CEIT, through the collaborative efforts of diverse research groups. These research groups include Railway, Intelligent Systems for Industry 4.0 (ISI 4.0), Data Analysis and Information Management (DAIM), Electronic Systems and Communications (ESC), and Sustainable Transportation and Mobility (STM). These collaborative efforts are not only aimed at advancing the development of automatic driving systems but also at ensuring compliance with railway industry standards and facilitating future integration into existing rail infrastructure.

Novel reference architecture for GoA 3/4 systems

The reference architecture for GoA3/4 system proposed in the X2Rail-4 project is depicted in Figure 1, which includes a diverse range of components for a complete railway system. This reference architecture encompasses both trackside and onboard systems. The upper part of the architecture is focused on the trackside components, which includes the Traffic Management, Train Management, Train Control, Route Control, Incident Solving Manager, Digital Map (DM), Operational Execution (OE), Mission Data (MD), and Train Data (TD). On the other hand, the lower part of the framework is dedicated to the onboard components, which includes the Train Protection, Signal Converter, Signal Detection, Onboard Recording Device, Localization (LOC), and four novel GoA 3/4 components, namely Automatic Driving Module (ADM), Automatic Processing Module (APM), Repository (REP), and Perception (PER). Finally, the railway system actors are representing externally to logical system.

The reference architecture guarantees seamless interaction and integration between trackside and onboard components via communication networks and data exchange via relevant standards. Trackside systems supply real-time data and instructions to the onboard systems, while the onboard systems deliver status and operational data back to the trackside components. This reciprocal communication is essential for maintaining synchronized operations, ensuring safety, and maximizing performance.

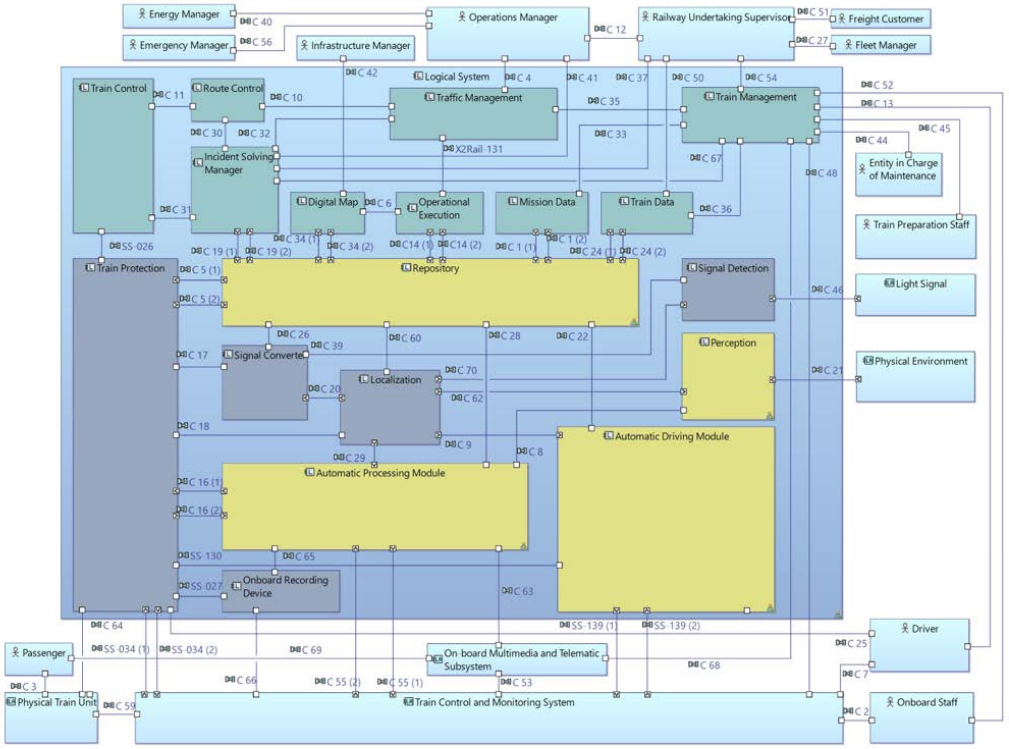

Figure 1: ATO up to GoA4 - Logical reference architecture *[4]*.

Preliminary architecture for ATO lab prototype.

CEIT is currently developing some components for the ATO laboratory prototype that have been specifically designed to meet the requirements of an inspection vehicle following the SRS described in the X2Rail-4 Project. These components are being specifically tailored to meet the requirements of an inspection vehicle, ensuring that each component can perform its functions effectively and efficiently. To bring these components to fruition, CEIT has organized several research groups, each dedicated to developing a specific component. Table 1 showcases the research groups that are currently working on these components, highlighting the collaborative effort and expertise being applied to the ATO laboratory prototype project.

On the other hand, Figure 2 illustrates the preliminary architecture of the ATO lab prototype. This architecture reveals the components and standard interfaces that are in the process of development and will be integrated in subsequent stages of the project. Among the components to be developed are Trackside system, Localization (LOC), Train Control and Monitoring System (TCMS), Repository (REP), Perception (PER), Automatic Processing Module (APM), and Automatic Driving Module (ADM). It is important to note that the SS-126 [6] and SS-139 [7] interfaces are currently undergoing lab testing, while the remaining standard interfaces are still being defined.

Table 1: Research groups involve in the ATO lab prototype for an inspection vehicle.

Research group	Component
Railway	Trackside system
DAIM	REP
ESC	TCMS
SIS 4.0	PER
STM	ADM
	LOC
	APM

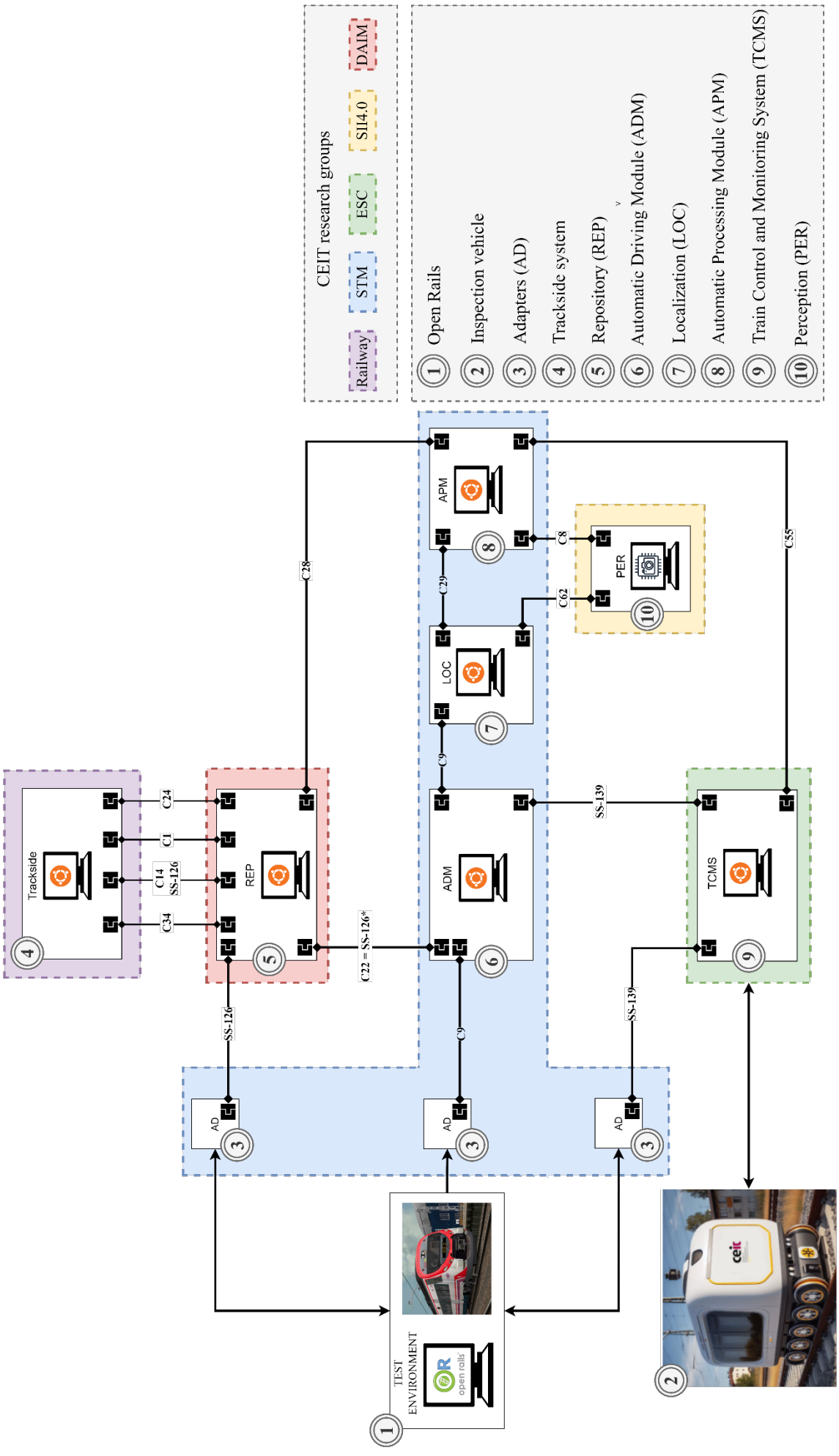

Figure 2: Premilinary reference architecture for ATO lab prototype based on X2Rail-4 project *[4]*.

Test environment and adaptors

The selection of Open Rails (OR) [8] as the test environment for the ATO prototype laboratory was based on its status as a transport simulation platform that operates as an open-source train simulator, compatible with routes, activities, trains, locomotives, and rolling stock designed for Microsoft Train Simulator (MSTS). To facilitate interaction with OR, adapters (AD) will be developed that will interpret the packages defined in the standard interfaces specified in the SRS of the X2Rail-4 project. This will enable the use of OR as a test environment until the inspection vehicle is available for field testing.

Components

- **Trackside system:** The Railway research group is currently developing a project known as "RailVOS," which is a simulator intended to evaluate the capacity of track lines, as well as the robustness of timetables and energy consumption. It is anticipated that this simulator will provide valuable information, including the Journey Profile (JP), Segment Profile (SP), Mission Profile (MP), and Train Data (TD), which will be transmitted via standard interfaces to the on-board system of the vehicle.

- **Perception:** The ISI 4.0 research group is currently working in the PER module, which is considered as the “eyes” of the driver in GoA3/4 systems, comprising a group of onboard sensors with the aim to evaluate the Physical Railway Environment and enhance the perception of the driver, encompassing not only visual sensing but also other factors that contribute to safety and dependability in operations.

- **Train Control and Monitoring System:** The ESC research group is currently working in the TCMS module, which operates similarly to the central nervous system in humans as it oversees and connects all subsystems of rail vehicles and trains. A crucial function of this module is the control of train propulsion and braking, in accordance with the information provided to the ADM module.

- **Repository:** The DAIM research group is currently developing an onboard module named REP, which is designed to collect, validate, and filter data received from the trackside system in accordance with the requirements of the onboard components. This module will subsequently transmit the data via the relevant interfaces.

The STM research group is currently developing in the following modules:

- **Localization:** This onboard module provides tachymetry and location information for all train subsystems.
- **Automatic Processing Module:** This module is regarded as the “brain” of the driver in GoA3/4 systems, as it is responsible for emulating the responsibilities of the driver and train attendant in responding to incidents. This onboard module oversees the execution of missions, safe reflexive actions, evaluated reactions, and safety procedures that occur during the mission, including both train and track incidents.
- **Automatic Driving Module:** This module is concerned as the “hearth” of the train operation since GoA2 and is responsible for execute the driving functions which allow to driving the train automatically.

Relevant Interfaces

The mandatory specifications, including TSI – CCS, establish a set of relevant interfaces, such as SS-126 [6], SS-139 [7], and others, that aim to facilitate communication among the various components of the reference architecture from X2Rail-4 Project. These mandatory interfaces are currently being developed by CEIT, while the remaining interfaces, such as C9, C22, and others, as depicted in Figures 1 and Figure 2 are subject to ongoing updates.

Future works

The subsequent phase of this project entails the development and integration of adapters (AD) into the Open Rails simulator. This integration will facilitate the bidirectional exchange of data between the track and the vehicle within a simulated environment, ensuring seamless communication via standard interfaces to modules such as the Automatic Driving Module (ADM), Train Control and Monitoring System (TCMS), and Repository (REP). Concurrently, efforts will be dedicated to testing the SS-126, SS-139, C9, and C22 interfaces to achieve comprehensive integration into the OR simulator. This process is essential for accumulating experience in the development of these interfaces, which will be instrumental in defining the remaining interfaces.

Furthermore, each research group involved in this project will persist in enhancing the functionalities of their respective modules. This continuous development will gradually increase the complexity of the system requirements, which are based on the System Requirements Specification (SRS) of the X2Rail-4 and R2DATO projects. Through this iterative process, the project aims to elevate the overall performance and functionality of the system, ensuring that the Automated Train Operation (ATO) laboratory prototype meets the stringent standards required for advanced rail automation and inspection.

Conclusions

CEIT's engagement in the R2DATO Project under the European Rail Joint Undertaking (ERJU) exemplifies a notable dedication to progressing railway research and innovation within the Horizon Europe program. Particularly, CEIT's proactive involvement in Work Package 10 (WP10) endeavors to create a laboratory prototype solution for an automatic driving system customized for an inspection vehicle. This system has been designed in accordance with the reference architecture for GoA3/4 systems specified in the X2Rail-4 project's System Requirement Specification (SRS) and relevant standards, such as the Technical Specification for Interoperability – Control Command and Signaling (TSI – CCS).

CEIT's collaborative efforts across multiple research groups such as Railway, Intelligent Systems for Industry 4.0 (ISI 4.0), Data Analysis and Information Management (DAIM), Electronic Systems and Communications (ESC), and Sustainable Transportation and Mobility (STM) are pivotal in developing the necessary components for the Automated Train Operation (ATO) laboratory prototype. This collaboration ensures that the components are designed to meet the rigorous requirements of an inspection vehicle while adhering to railway industry standards.

In the preliminary architecture for the ATO lab prototype, CEIT has outlined the development of essential components such as the Trackside system, Localization (LOC), Train Control and Monitoring System (TCMS), Repository (REP), Perception (PER), Automatic Processing Module (APM), and Automatic Driving Module (ADM). These components are undergoing rigorous development and testing, particularly the SS-126 and SS-139 interfaces, to ensure their effective integration into the Open Rails simulator. The selection of Open Rails (OR) as the test environment underscores the project's commitment to leveraging open-source platforms for simulation and testing. The development of adapters to facilitate interaction with OR will enable comprehensive testing and validation of the ATO prototype until the inspection vehicle is ready for field deployment.

Looking forward, the project will focus on the development and integration of adapters into the OR simulator to enable bidirectional data exchange between the track and the vehicle. Concurrently, the testing of the SS-126, SS-139, C9, and C22 interfaces will continue, providing valuable experience for the definition and development of the remaining interfaces. Each research group will persist in enhancing their respective modules' functionalities, gradually increasing the system requirements' complexity. This iterative development process aims to enhance the overall performance and functionality of the ATO laboratory prototype, ensuring it meets the stringent standards required for advanced rail automation and inspection.

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