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Safer railways with the first fully autonomous rail vehicle

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FBK research powers innovation behind Italy's high-speed rail

One of the primary objectives of the **URV (Unmanned Railway Vehicle)**—an autonomous rail vehicle developed by Rete Ferroviaria Italiana (**RFI**) for Italy's high-speed rail lines, in **the TINO Train for INspection Of railway project** —is the real-time identification and management of operational criticalities. This goal is being pursued with support from Fondazione Bruno Kessler's **Center for Digital Industry**.

This vehicle is capable of **autonomously inspecting railway lines** and is suitable for use in **critical areas** where human intervention is difficult or hazardous. he URV is designed to achieve **Grade of Automation 4** (GoA4), the highest level of rail automation, featuring a fully autonomous system with no onboard personnel—a major milestone in rail technology.

The URV can operate in **two modes**: fully ***autonomously***, thanks to the *Automatic Train Operation (**ATO**)* system, or ***via remote control***. The ATO adheres to the highest **standards, including the ERTMS/ETCS** framework, to ensure operational safety by continuously monitoring the train's speed and position through a vital computer (EVC). The vehicle can reach a top speed of 200 km/h, enabling it to cover extensive railway lines in a short time. Powered by a battery, it has an operating range of approximately four hours. This allows for continuous inspections without the need for frequent charging interruptions, thereby minimizing environmental impact and improving operational efficiency.

Credits: RFI

FBK’s contribution

The **Center for Digital Industry** has been actively involved in this innovative and complex project, which began in 2017 and continues to evolve. The team contributed to **the development of on-board control logic and the creation of the ATO (Automatic Train Operation) software**, which manages the URV’s autonomous and remote driving system. They also developed the tablet interfaces for remote interaction and **conducted system tests** at various stages of the project—from initial laboratory experiments to recent field trials.

Stefano Tonetta, **Marco Bozzano**, and **Gianni** Zampedri—respectively the head and researchers of the Formal Methods for System and Software Design (FM) unit—along with **Angelo Susi** and **Roberto Tiella**, the head and a researcher of the Software Engineering (SE) unit, were all involved in the project, together with **Alessandro Cimatti**, Director of the Center for Digital Industry.

The FBK team managed each project phase, from the detailed analysis of requirements to a series of comprehensive tests, ensuring that every step was accompanied by rigorous verification. This process allowed each designed element to be precisely validated against the defined requirements.

In the project’s initial stages, FBK collaborated on defining both the system’s overall requirements and those of individual components. The team employed a **model-based design** approach, which enables the development of complex systems through graphical models that represent component behavior and facilitate preliminary validation. Based on these models, the team proceeded to implement and generate the software necessary for the system’s operation.

The focus then shifted to the **testing phase, which** was structured into several stages. First, an automatic testing environment was created in the lab using a replica of the train’s equipment, leveraging a Hardware-in-the-Loop (HIL) setup to simulate the real system. Next, bench tests were

performed at RFI's Florence Osmannoro facility, verifying URV subsystems under controlled conditions. Finally, in August 2024, the URV underwent real-world testing at the Bologna San Donato circuit, marking the first fully autonomous rail vehicle trial in Italy.

"This project is a prime example of how collaboration with a major industrial partner can generate tangible, real-world impact—demonstrating how scientific research can be transformed into practical innovation applicable across diverse technological domains. *The synergy between RFI, FBK teams, and academic partners has enabled the development of advanced technological solutions, combining expertise in software engineering and formal methods. We are very optimistic about the future and plan to expand our design work and integrate new features, strengthening this valuable collaboration with a highly strategic partner," says* **Alessandro Cimatti**, *Director of FBK's Center for* Digital Industry.

Working with RFI

The project is part of a collaboration between RFI and FBK, governed by a series of framework agreements— the first signed in 2017, followed by a second in 2021. With the recent signing of a third framework agreement, new features will be developed, and project activities will be expanded. These agreements are signed by RFI with each involved partner, particularly Fondazione Bruno Kessler and Politecnico di Milano. Thanks to the multidisciplinary research teams, the complexity of interfaces and system integration can be effectively addressed, ensuring compliance with safety standards and the adoption of best design practices.

Engineer Ernesto Garrubba, an expert in on-board systems at RFI, explains: "*The URV project will enhance the safety of high speed lines by utilizing the autonomous vehicle to open the lines after night-time maintenance. The integration of vision systems and AI algorithms for image analysis will also enable the monitoring of critical issues and improve line diagnostics. Collaboration with various academic and research partners, including FBK, has empowered RFI's Research and Development department to create a highly innovative system, and for the first time in Italy, it has facilitated in-line tests with a fully autonomous vehicle*."

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