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A New Approach of Achieving the Safety of Railways Using Fiber Optics for Data Transmission and Monitoring

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TITLE

A new approach of achieving the safety of railways using fiber optics for data transmission and monitoring

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Abstract

For many years, the cables we used to transmit data via wired media were the familiar 'copper' cables. In recent years, however, this has changed since the use of optical fibers is becoming more and more widespread, due to their greater durability and functionality compared to copper cables. In this paper we will propose a new approach of security of the railways using fiber optics which could increase the safety in many ways, by automatically checking the infrastructure of the railway network, the condition of the train cars, but also by transmitting data and information about the position of the trains. Overall, the entire operation of a railway network and its safety can be improved to a very significant extent, as well as the experience of passengers using the trains. In the following we will see ways and proposals on how the improvement can be made in the railway stations using optical fibers

Additional Keywords and Phrases: Multimode, ERTMS, GSM-R, ETCS, FRMCS, CCTV, RFID/GPS, WDM, LED, SHM, TPS, DAS, CBTC

Introduction

Data transmission over optical networks is a technology that uses light to carry information with high speed and reliability. This technology is based on the use of optical fibers, which are thin cables made of glass or plastic that can carry light with minimal loss. The light encodes the data into pulses, which can be decoded by receivers at the other end of the optical fiber. This technology has many advantages such as high data transmission speed, large capacity, low data loss and resistance to interference. It also has applications in various fields such as communication, education, health, industry, and many more. In rail networks, fiber optics can have many uses, and make travel for passengers more comfortable, safer, more accurate on their routes. In the following, however, we will see in more detail the uses of optical fiber in railway networks.

ERTMS (European Rail Traffic Management System) in Greece

ERTMS is a European standard for the management and operation of trains in a railway network. Its main features and advantages are the following (figure 1):

- Improvement of the interoperability of the railways which allows the uninterrupted/cross-border operation of trains
- Use of command control system for high-speed trains
- Increased safety and efficiency of high-speed trains due to signaling, but also a train protection system (TPS).
- Creation of a unified radio communication system
- Reduced complexity for the train driver

This standard consists of two main parts, the European Train Control System (ETCS) and the Global System for Mobile Communications for Railways (GSM-R).

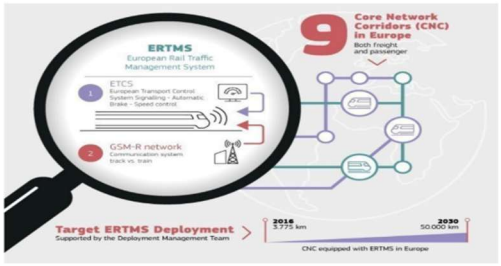

Figure 1: Main features of ERTMS

In particular, the ETCS allows the continuous monitoring of the maximum permitted speed of the trains, the automatic protection against excessive speed, as well as the automatic stopping of the train in case of traffic light violation (Automatic train protection). It also includes the visualization of the traffic lights, which we can represent as traffic lights on the roads, in the driver's cabin with electronic means, in a specific Interface (DMI – Driver Machine Interface) (figure 2). There are 3 levels, all of which provide the signaling display system, but differ in efficiency, cost, and compatibility with legacy signals [1].

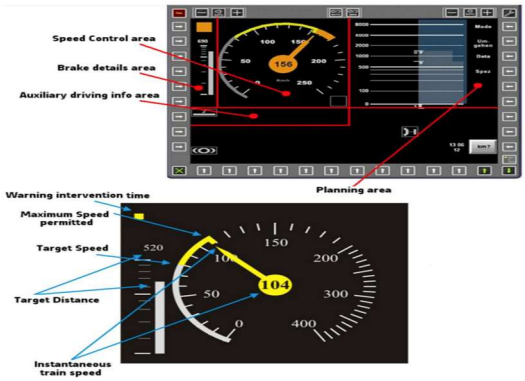

Figure 2: DMI (Driver Machine Interface)

At the moment in many countries of the world, as well as based on ERTMS, wireless communications on railways is done with GSM-R (Global System for Mobile Communications – Railway) which uses GSM technology, which however in 2030 it will be obsolete.

Data Transfer Difficulties

To understand what improvements fiber optics can make to a rail network, it's good to look at where and why there is difficulty in transferring data within any network. There are several challenges associated with data transmission on railway networks, such as:

- Environmental Conditions: Rail networks span long distances and traverse various environments such as tunnels, bridges, open spaces and cities. These conditions may affect signal quality.
- Data Loss: In the event of an error in transmission, all data remaining to be sent may be affected, which may cause performance issues or data loss. Especially in cases where the data to be sent can concern security, there must be no loss of data under any circumstances.
- Noise and Signal Distortion: Noise and signal distortion can affect the quality of data transmission. This can be due to factors such as interference from other signals, signal loss due to distances or obstacles, and signal loss due to environmental absorption.

- Speed of Data Production: The speed at which data is produced can be very high, especially in the case of big data. This can create challenges in storing and processing data in real time.
- Data Complexity: Data can include various types, such as GPS data, data from mobile applications, data from health records, etc. This complexity can make data processing and analysis difficult [2].

It is important to note that choosing the appropriate solution to address these challenges depends on the specific situation and needs of the data transmission system.

Solutions to Data Transfer Difficulties

But there are several solutions to avoid data transmission problems:

- Signal Boosting: Using signal boosters can help prevent signal loss due to long distances.
- Noise Protection: Using shielded cables (optical fibers) and noise reduction technologies can help prevent signal interference and distortion.
- Vulnerability Management: Vulnerability management is a risk-based approach to identifying, prioritizing and remediating vulnerabilities and misconfigurations.
- Upgrading Infrastructure: Upgrading existing infrastructure using the latest technologies can help avoid issues related to obsolescence or incompatibility.
- Data Security: The use of encryption technologies and secure transmission protocol can help protect data from breaches.
- Data Recovery: In case of data loss, using data recovery software can help recover lost files.
- Use of combined technologies, so that in places where there is a difficulty in data transmission with one technology, another technology can help so that there is no problem.

It is important to note that the choice of the appropriate solution depends on the specific situation and the needs of the data transmission system [3].

Optical Fibers in Railway Stations

The first way that fiber optics can be used in a rail network is by looking at the network as a whole, and thinking about the key network functions that we want to improve. This mainly includes the communication that railway stations need to have with each other, and the transfer of data to and from them. So, data transmission over optical networks in railway stations/network can have applications in various areas such as:

- Communication and Coordination: Optical networks can enable fast and reliable transmission of data between different stations, trains and control centers, improving communication and coordination between them, making train movements safer, and keeping their routes more correct.
- Security and Monitoring: Optical networks can support high-resolution monitoring systems to monitor the security conditions and operation of railway stations (figure 3).
- Automated Train Control: Optical networks can support automated train control systems, providing real-time, reliable information about the location and status of trains. So, before a train starts for a journey, having it checked to see if it meets the conditions to travel increases the security provided to passengers (figure 4).

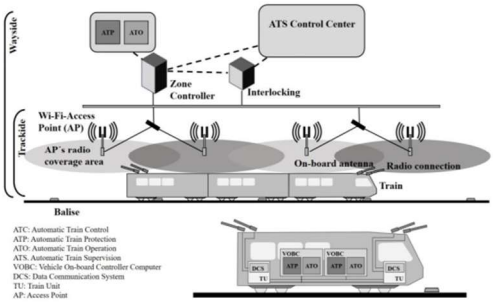

Figure 3: CBTC (Communication Based Train Control) equipment

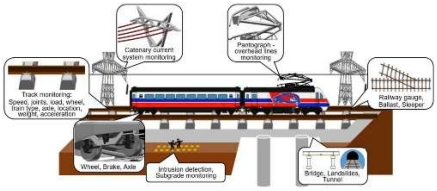

Figure 4: Possible Controls in a Railway Network

Optical Fibers in Wagons

Optical fiber can be used to send data from sensors that monitor temperature, humidity, pressure and air composition in the wires. This can be achieved by installing sensors at critical points on the train, which collect data in real time. At one end of the optical fiber, there is the transmitter and at the other, the receiver. At their destination, the receiver converts the light waves back into digital data. This allows two-way and real-time exchange information, allowing direct monitoring and evaluation of the operation and status of the systems [4]. Optical fiber can support many applications on trains, including Wi-Fi, VoIP, CCTV, RFID, GPS, and IoT. The following applications can improve the passenger experience, manage expenses and optimize the use of resources.

- Wi-Fi: Optical fiber can provide high-speed internet connection for passengers.
- VoIP: Fiber can support voice over IP services, allowing communication between passengers or between passengers and staff.
- CCTV: Optical fiber can carry video from CCTV cameras, enabling security monitoring on trains.
- RFID/GPS: Optical fiber can support train location and status tracking via RFID and GPS.
- IoT: Optical fiber can connect various IoT devices, such as sensors and control devices, enabling automation and remote management of train systems.

However, the implementation of this system requires significant technical knowledge and investment. Also, the effectiveness of the system depends on the accuracy and timeliness of the data it receives.

Data Transmission

Data transmission over optical networks in a railway company can be accomplished using technologies such as WDM (Wavelength Division Multiplexing), which transmits multiple optical wavelength signals over different optical channels on the same fiber. In optical data

transmission, data is converted into light signals using lasers or light-emitting diodes (LEDs) and then transmitted over optical fiber. These fibers are made of glass or plastic and are designed to carry light signals with minimal loss or distortion.

Optical fiber is a data transmission medium that uses the reflection of light to carry signals with high speed and accuracy. It can be used to synchronize train departure and arrival times with stations and passengers, enabling a more efficient and safer operation of the transport system (figure 6). To achieve this, optical fiber can connect the trains to a central control system, which will receive information on the position, speed and condition of the trains, and send commands to adjust lights, gates and announcements. In addition, the system can receive information from stations about operating conditions, such as any delays or schedule changes. This information can also be included in updates sent to passengers (figure 5). However, the implementation of this system requires significant technical knowledge and investment. Also, the effectiveness of the system depends on the accuracy and speed of the information it receives [5].

Optical Fibers on Train Tracks

Regarding GPS train location, in hard to reach areas such as tunnels, using fiber optic alone is not enough to locate a train. Using combined technologies such as Distributed Acoustic Sensing (DAS), the problem can be solved. Therefore, the location of trains within a tunnel can be detected, and through the connection with the optical fiber, the location of a train can be sent without the use of GPS technology (figure 7). It is very useful to apply optical fibers on train tracks. Their quality can be altered without this alteration being apparent. Earthquakes, landslides, ice, floods, can cause enormous damage. Rails can also wear out over time due to natural wear and tear from time, from changes in their temperature, and can deviate. This can be called SHM (Structural Health Monitoring), where through sensors/technological means the condition of rails can be monitored (figure 8). It is also noteworthy that the use of AI in SHM has attracted the attention of engineers in recent times. In other words, it is considered possible that by collecting data and using special algorithms, predictions can be made about the condition of the rails, and in some cases, problems can be prevented [6].

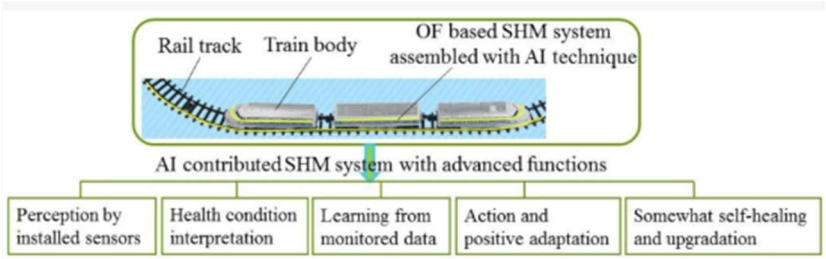

Figure 5: Possible Controls in a Railway Network

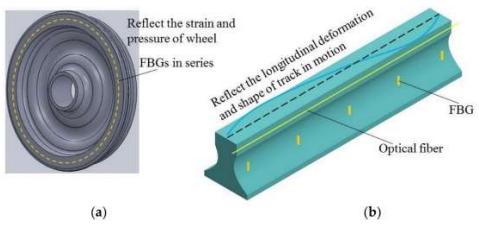

Figure 6: Optical fibers and FBGs (Fiber Bragg Grading) on train rails and wheels

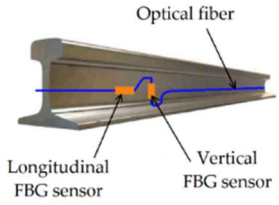

Figure 7: FBG (Fiber Bragg Grading) reflector on rails (speed control/rail status)

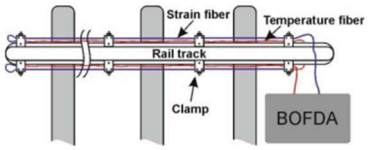

Figure 8: Temperature and track tension/pressure control

Conclusion

In this paper, an attempt was made to present a study about the security of the railways. Fiber optics is something so innovative that it can literally change our lives in all areas. Massive data transmission speeds, even in combination with other technologies/sensors, can improve every area of our lives. Likewise, in the railway networks, we saw how we can have improvements as passengers in the quality of journeys, in our information about them, but also in our safety. The carriages themselves can be provided with entertainment services that require an internet connection, but tracking the carriages is also a security measure. It is also possible to monitor the condition of the tracks, or to locate the trains by installing optical fibers on the tracks. Having such a powerful tool in our day and age, it would be wise to use it as much as possible

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