Original scientific paper

UDC: 656.2:004.8

Received: July 16, 2024.
Revised: August 02, 2024.
Accepted: August 10, 2024.

10.23947/2334-8496-2024-12-2-467-476

Check for updates

Educational Application of Artificial Intelligence for Diagnosing the State of Railway Tracks

Dobrivoje Dubljanin[1*], *Filip Marković*[2], *Gabriela Dimić*[3], *Dragan Vučković*[4], *Martina Petković*[5], *Lazar Mosurović*[6]

[1] Tehcnical Faculty in Bor, University of Belgrade, Republic of Serbia, e-mail: ddubljanin@tfbor.bg.ac.rs
[2] Faculty of Technical Sciences, University of Priština in Kosovska Mitrovica, Republic of Serbia, e-mail: filip.markovic@pr.ac.rs
[3] Academy of Technical and Art Applied Studies, Belgrade, Serbia, e-mail: gabrijela.dimic@viser.edu.rs
[4] Alfa BK University, Faculty of information technologies, Belgrade, Republic of Serbia, e-mail: dragan.vuckovic@alfa.edu.rs
[5] Academy of Applied Studies of Kosovo and Metohija, Department Zvečan, Republic of Serbia, e-mail: martina.petkovic@akademijakm.edu.rs
[6] Director of the Serbian Railways Directorate, Belgrade, Republic of Serbia, e-mail: lazar.mosurovic@raildir.gov.rs

Abstract: The aim of the work is to present an innovative solution based on artificial intelligence for examining the condition of railway tracks in real time. The system, based on fuzzy logic and metaheuristics such as Fuzzy Logic, Neural Networks and Bee Behavior Optimization, combines hardware and software to provide reliable data on the technical characteristics of the railway. Installed in rail vehicles, hardware collects this data, while software uses artificial intelligence to improve operational reliability and safety. The aforementioned technology is not only useful for infrastructure diagnostics, but also for urban railways such as trams and metros, ensuring a high level of passenger safety. The introduction of artificial intelligence in the railway sector is a key step towards modernisation, improving efficiency, resource optimization and safety. Although still in its infancy, artificial intelligence already shows great potential in transforming the railway sector towards a more efficient, reliable and sustainable future.

Keywords: *hardware, artificial intelligence, intelligent measurement system, MMC/SD cards, educational processes, sensors, security*

Introduction

The introduction of artificial intelligence (AI) in the railway sector represents a key step towards modernization and improvement of efficiency. With the increasing application of AI in various sectors, it is becoming clear that AI has a huge potential to revolutionize the way maintenance and management are done. AI is becoming an indispensable part of everyday life, and its influence on the railway sector is ubiquitous. Its ability to optimize complex rail systems, improve safety and efficiency, as well as improve user experience, makes it a key tool for modernizing and improving the efficiency of the rail sector. (Bešinović, et. al., 2021).

In order to better understand the potential of AI in the rail sector, it is important to look at the current infrastructure and the specific needs of different regions. For example, the application of AI can significantly improve performance and maintenance in areas with a large rail network and traffic frequency, such as Europe and the Balkans. The use of advanced data analysis algorithms can help identify critical network points that require regular maintenance, thereby preventing failures and improving security. Also, AI can optimize the use of resources and energy, which is of particular importance for the sustainability of rail traffic (Tang, et. al., 2022).

Currently, the total length of the railway network in Europe is about 208,000 km. Balkan countries contribute to the network as follows: Bulgaria with 4,030 km, Bosnia and Herzegovina with 1,018 km,

*Corresponding author: ddubljanin@tfbor.bg.ac.rs

Croatia with 2,617 km, Hungary with 7,588 km, Montenegro with 249 km, North Macedonia with 683 km, and Romania with 10,759 km. In addition, there are around 9,000 high-speed lines in Europe where trains can exceed a speed of 250 km/h (Bauranov, 2016). In the Republic of Serbia, the length of normal gauge railways is 3,735.8 km, of which 3,441.1 km are single-track and 294.7 km are double-track. A total of 1,278.4 km of railways were electrified, of which 984.0 km are single-track and 294.4 km are double-track. This network of railways provides vital infrastructure for the transport of passengers and goods across the region. The railway network in the Republic of Serbia is shown in Figure 1 (Ministry of Construction, Transport and Infrastructure).

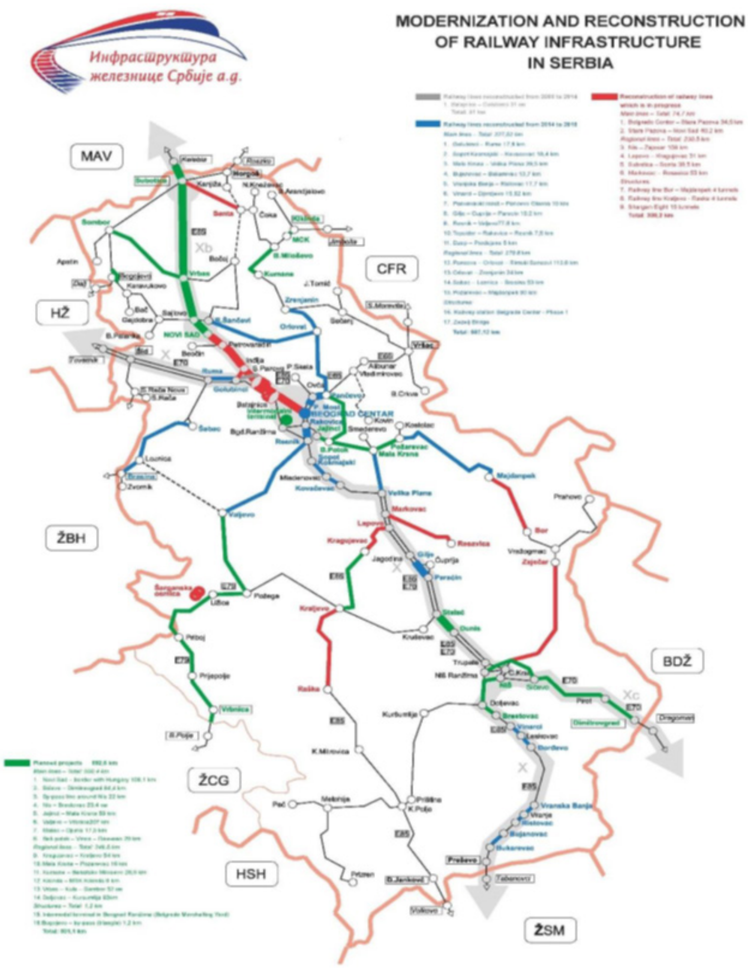

Figure 1. Railway network in the Republic of Serbia (Ministry of Construction, Transport and Infrastructure)

The Republic of Serbia is facing ambitious plans to modernize its railway infrastructure in order to meet the increasingly demanding needs of the transport sector. The completion of the Belgrade-Novi Sad high-speed railway, which covers 76 km, is the first step in this process. It is planned to complete the Novi Sad-Subotica-border with Hungary high-speed rail line by 2024, which will cover 136 km, as well as the Belgrade-Nis high-speed rail line, which will stretch for 204 km, by 2030. In parallel, the construction of metro lines in Belgrade is planned, which will cover a total of 60 km, also by 2030 (Compass Lexecon and Karanović and Partners, 2020).

However, this ambitious development plan faces numerous challenges. The current state of railway infrastructure in the Republic of Serbia is not satisfactory. As much as 55% of the rails date from the 19th century (Ministry of Construction, Transport and Infrastructure), which indicates long-term neglect of maintenance and modernization. The average age of the railway network in the Republic of Serbia exceeds 91 years, with main lines being on average around 85 years old, regional lines slightly more than 98 years old, while local lines are older than a century, Figure 2. This long-term neglect of the infrastructure resulted is due to the relatively poor condition of the tracks and the limited speed of the trains (Compass

Lexecon and Karanović and Partners, 2020).

Progress towards set goals, such as achieving the status of part of the Trans-European Transport Network by 2030, will require serious investment and change. It is necessary to improve the quality of rail transport services, implement much more efficient maintenance of the infrastructure of railway tracks and harmonize with European standards for environmental protection. This will require not only financial investments, but also profound structural changes in order to achieve the goal of modernizing and improving the efficiency of the railway sector in the Republic of Serbia.

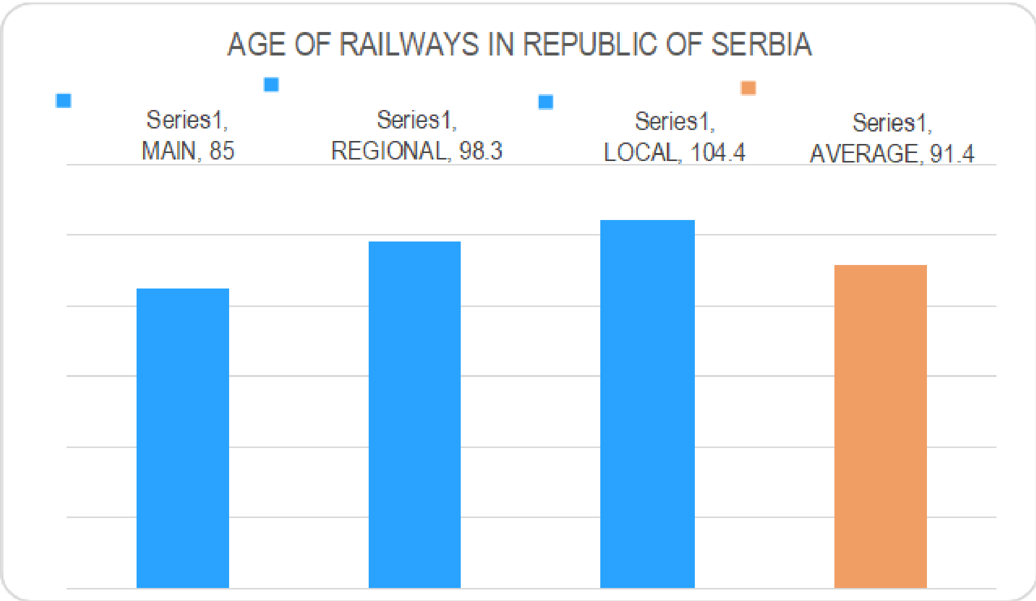

Figure 2. Age of railways in the Republic of Serbia

Artificial Intelligence in the railway sector: optimization, safety and innovation

Today, AI has become one of the most important research areas in almost all fields of academia and industry. While in many other sectors mature applications of AI are flourishing, it is noted that AI is still in its infancy in the railway sector (Tang, et. al., 2022).

AI's potential to optimize complex rail systems, improve safety and efficiency, as well as improve user experience, makes it a key tool for modernizing and improving performance in the rail industry (Bešinović, et. al., 2021; International Railway Yournal, 2019).

Guibert et al predict that AI will soon become a standard tool in the rail industry. This holistic perspective suggests that AI will be integrated into all aspects of rail operations, including operations management and customer interaction, resulting in overall improvements in efficiency, safety and customer satisfaction (Gibert, et. al., 2015).

Recent developments in the application of AI for the rail sector have already shown significant results. For example, an AI system implemented to improve train schedules for certain rail operators has shown effectiveness in optimizing schedules and improving customer experience. These examples illustrate the possibilities of applying AI for diagnosing the condition of the railway sector and indicate the potential for further development (Fragnelli and Sanguineti, 2014).

In order to understand the complexity and variety of AI applications in the railway sector, it is important to establish a clear definition and structure. This includes identifying key techniques, research areas, applications and disciplines that rely on AI. Consideration of these aspects allows a better understanding of AI in the context of the application of diagnostics of the state of the railway sector and the identification of key points for further research and development (Bešinović, et. al., 2021).

The development of AI in the railway sector opens the door to new innovations and improvements on many levels. The application of AI in train scheduling optimization has already shown significant results in system efficiency and improved user experience. However, the potential of AI does not stop only in this field. Its application can be extended to diagnostics of the condition of the railway sector, identification of critical points for maintenance and improvement of safety, as well as prediction and prevention of breakdowns and incidents. The further development of AI technologies will enable the creation of increasingly intelligent systems that will be key to the transformation of the railway sector towards a more efficient, reliable and sustainable future (Fragnelli and Sanguineti, 2014).

The influence of the condition of the railway infrastructure on safety

The state of the main and regional lines of the public railway network in the Republic of Serbia indicates long-standing insufficient investment in maintaining the reliability of infrastructure elements. This contributed to a significant decrease in reliability, and therefore to a decrease in speeds on the most important railways. A decrease in the reliability of the infrastructure results in a decrease in the competitiveness of railway traffic in relation to other types of traffic. Observing the complete railway network of the Republic of Serbia, it can be concluded that the situation is far from optimal, because a very small part of the network is in a satisfactory condition (Compass Lexecon and Karanović and Partners, 2020). The manager, due to the lack of other solutions, most often when diagnosing the poor condition of the infrastructure, applies the introduction of slow driving - reducing the speed of traffic, as a risk control measure. Due to the above, the average speeds are similar and even lower than what was the case 20 years ago, despite significant investments in the rehabilitation and reconstruction of certain sections in the previous period.

It was established that the poor condition of the railway infrastructure is the most common cause of accidents and incidents that occur on the public railway network in the Republic of Serbia. Based on the final accident investigation reports and annual reports published by the Traffic Accident Research Center, a large number of significant accidents occurred on the territory of the public railway network in the Republic of Serbia in 2017 alone (Traffic Accident Research Center, 2018). The most common causes of accidents are skids, i.e. poor condition of the elements of the upper machine - sleepers and fastening accessories, as well as deformations in the track geometry (Directorate for Railways, 2023). There is a high probability that a large number of accidents would have been avoided if the diagnostics of the condition of the track geometry had been carried out in a timely manner, significant deviations from the exploitation limit values had been determined and the necessary mechanized maintenance had been carried out.

Methodology for diagnosing the condition of railway tracks

In accordance with the heritage of joint railways from the era of the Socialist Federal Republic of Yugoslavia, the characteristics of the tracks that are measured are defined by the Instruction on unique criteria for controlling the condition of the tracks on the JŽ network ("Sl. glasnik", br. 6/01). These instructions are adapted to the technical characteristics of measuring circuits, such as EM-80L, which were used at that time, and which are currently available to the manager of the public railway infrastructure in the Republic of Serbia. The parameters measured by the measuring circuits include track width, windage, track direction, overhang of the outer rail in a curve and track stability.

These parameters, in combination with the size of the deviation and the length of the section on which the deviations were noted, are used to determine the groups of errors: A, B and C. Group A indicates values according to the parameters up to which it is not necessary to plan and carry out work, while errors in groups B and C require planning and execution of works, whereas errors in group C require immediate elimination or reduction of speed.

The evaluation of the condition of the track is done on the basis of the total length of defects in groups B and C over a length of one kilometer. Track condition can be classified as very good, good, satisfactory or unsatisfactory, depending on the total length of defects in meters (Hronik, 1970).

This described procedure is still applied today on the entire public railway network, as well as on all industrial railways and industrial tracks.

With the introduction of technical specifications for interoperability (TSI) in order to implement European regulations, the track parameters that are measured, as well as the entire track condition diagnosis procedure, are defined by the group of standards SRPS EN 13848. Specifically, the parameters for measuring track geometry are defined by the standard SRPS EN 13848-1 (Institute for Standardization of Serbia, 2019; Institute for Standardization of Serbia, 2017):

- track width - is the distance between the inner sides of two opposite rails in the track, measured 14 mm below the running surface of the rail,
- vertical profile – represents the profile of the rail head, the relative height of the rail is measured along the lengths 35-70 m,
- horizontal profile – measures the deviation of the middle line of the track in the longitudinal vertical plane from the projected direction of the track,
- height difference between rails (cantilever) - difference in height between two running rails at any point of measurement (can also be called cantilever, although it is a term characteristic of the difference in rail height in horizontal curves),
- track steepness - the algebraic difference between two normal sections of the track at a defined distance, usually expressed as a slope (in percent or mm/m) between two measurement points.

Each parameter has a defined measurement method, measurement wavelength range, measurement resolution, allowable measurement uncertainty, measurement range, analytical method, output data requirements, and other characteristics.

Tolerances for each parameter are given in three groups of track quality levels: Alert limit (AL), Intervention limit (IL) and Immediate action limit (IAL). AL refers to the value that requires an analysis of the condition of the track geometry when planning regular maintenance, IL refers to the value that requires corrective maintenance to prevent reaching the IAL before the next inspection, while IAL refers to the value that requires measures to be taken to reduce the risk of derailment derailed to an acceptable level. These tolerances are prescribed by the standard based on experience and theoretical considerations of wheel-rail interaction (Hodas, et. al., 2022; Yazawa, 2003).

An intelligent measuring system for examining the condition of railway tracks in real time

The motivation that initiated the development of this solution stemmed from worrying data on railway safety in the Republic of Serbia. During 2017 and 2018, over 140 risky incidents were recorded, while in 2019 alone, their number reached 95. More than 90% of these incidents happened on railway tracks. In order to solve this problem, an innovative system was developed for measuring and analyzing the geometric condition of the tracks. The track is tested in both directions of travel. In this way, without the presence of personnel for control and supervision, the operational reliability of railway tracks is increased and improved, and maximum safety is achieved in the railway sector (Tararychkin, 2020).

The innovative system for measuring and analyzing the geometric condition of the track consists of a device that contains a number of sensors and assemblies for measuring the condition of the railway track, as well as computer applications for graphical display and diagnostics of the obtained results. The data is recorded (saved) on an MMC/SD card, and then can be transferred to a computer, laptop, tablet or permanently stored in the monitoring center's computer base. The data can also be delivered to the central monitoring computer center through an ONLINE connection (Internet), so that there is an overview of the state of the track in real time. The geometric condition of the track on the screen can be displayed in the form of diagrams, graphs or numerically on different surfaces.

Track data is collected during train movement. The device is placed on the train, and the software is written on the basis of AI (Fuzzy Logic, Neural Networks and Bee Colony Optimization). Based on the received data from the sensors, the software analyzes track errors, defines priority among errors and makes suggestions for eliminating all identified track defects by priority (Yaman, et. al., 2017; Shafieenejad, et. al. 2021).

Functionality has been implemented in the software that enables the display of the total number of errors (deformations) on a specific section or on the entire track, for all parameters defined by the group standard SRPS EN 13848. These errors are classified into three groups - A, B and C, in accordance with standard SRPS EN 13848-1, as described earlier.

Each railway infrastructure manager can set limit values of track parameters in accordance with their track maintenance policy. The software package that was developed on the basis of AI analyzes the data from the sensors and makes decisions about the condition of the tracks and about the priorities for removing any identified track defects (breaks, cracks, damage...).

For the analysis of the obtained results, selected longitudinal dimensions are used that are harmonized with GPS, on the basis of which, in addition to the display of individual elements of the geometric condition of the tracks, other necessary data about the condition of the tracks can be seen (Espinosa, et. al., 2018). In perspective, the possibility of installing special HD cameras, which would show the image of tracks, objects and terrain, is foreseen. Those images would be stored on the MMC/SD card and then permanently stored in the computer database. The cameras would be synchronized with certain transmitters so that recording would not be done continuously, but only when necessary, i.e. when detecting critical conditions, which were initially set.

During the movement of the train, the device examines and measures the geometrical parameters of the track, such as: longitudinal level of the left and right rails, alignment of the left and right rails, transverse level of the track, torsion, curvature, slope radius and the slope itself.

Compared to similar devices such as measuring circuits, the device is many times more economical and practical to use. In practice, measuring circuits are most often used to test track geometry. However, they are very expensive, in the order of several million euros, and require regular maintenance, training of a certain number of workers for their use, their speeds are lower, they take up the track during measurement, and thus affect regular services on the railway network. Less than a year ago, Infrastructura Železnice Srbije a.d. they bought one such measuring car whose price was 2.2 million euros.

There are similar devices on the market that are installed in the railway vehicle itself and serve to diagnose the track condition during regular driving, but they are not based on AI. Some of these devices are: ENSCO (USA), ASC German Sensor Engineering (Germany), Aarsleff Rail A/S (Denmark), etc. (Railway Gazette International).

The device consists of 9 optical/ultrasonic sensors, GPS receivers and circuits for measuring the track condition, as well as computer applications for graphic display and diagnostics of the obtained results:

- sensors for measuring the horizontal and vertical distance between the rails,
- sensors for measuring the slope of the railway embankment,
- sensors for detecting acceleration and deceleration,
- laser track temperature gauge,
- for noise measurement,
- sensors for detecting unnatural depressions or elevations on the track,
- sensors for the longitudinal level of the left and right rails,
- left and right rail alignment sensors,
- sensors for measuring the curvature of the rails,
- GPS receiver.

The visual appearance of the device is shown in Figure 3.

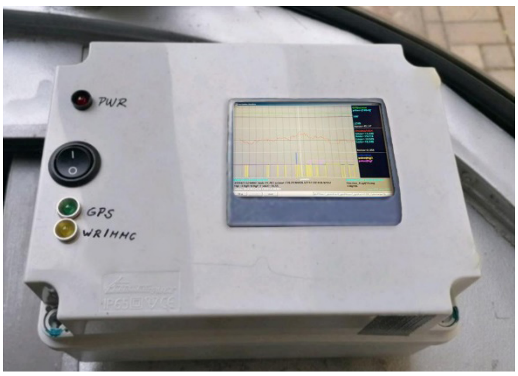

Figure 3. Visual appearance of the device

One of the components of the device is the gyroscopic module NEO-6. Figure 4 shows the physical appearance of the NEO-6 gyro module together with the patch antenna (Betke, 2000).

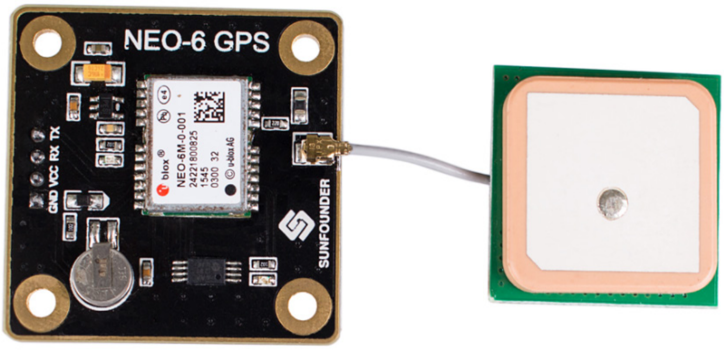

Figure 4. Gyro module NEO-6 (*Sreenivvas, et. al., 2023*)

The module also contains a rechargeable battery that enables long-term storage of configuration settings. The module works with DC voltage in the range of 3.3-5 V. An algorithm for data protection was also developed and implemented in the microcontroller (Saleh, 2016; Zohari and Nazri, 2021).

An AI-based software application was developed for data processing, which stores and processes data obtained from sensors. On the screen, it is possible to display the number of errors (deformations) on a certain segment of the section, as well as on the entire track for all parameters determined by the standard SRPS EN 13848. Display of errors is possible in different colors, through different images, graphs, numerical or geographical maps.

The layout of the graph obtained by testing the device in Bosnia and Herzegovina on the Doboj-Živinice section is shown in Figure 5.

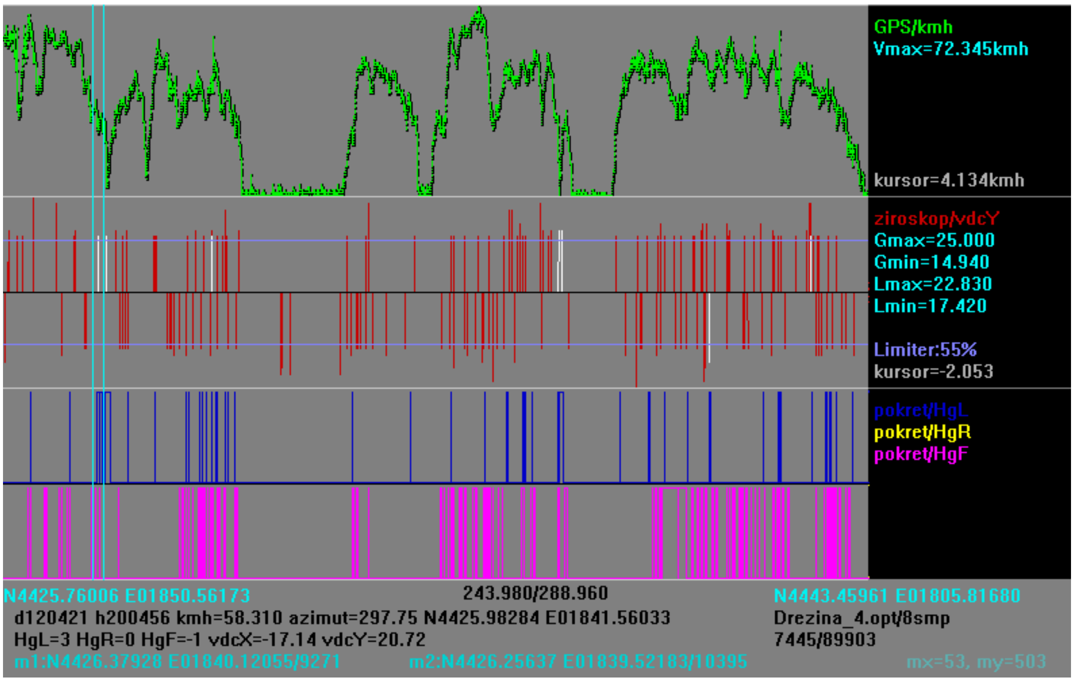

Figure 5. Graphs-values from transmitters and sensors

Figure 5 shows four horizontal graphs in different colors.

The first graph (green) shows the function of changing the movement azimuth and the speed of the locomotive.

The second graph (red) shows the changes in the Y-axis value of the gyroscope. The response threshold is flexible and can be set to different disturbance values. The currently selected value is 55% of the maximum recorded deformation on the route.

The third and fourth graphs (blue and purple) show the mercury's FORWARD/BACKWARD and

LEFT/RIGHT motion sensors.

From the diagram, two vertical light blue lines can be seen, which represent the place of deformation on the route. The software independently places these two vertical lines as the place of potential deformation of the rails on the route. In order to see the details of the deformation of the rails on the route, it is necessary to zoom in on these two vertical lines and the software will display the details of the information.

Showing the deformation of tracks on different surfaces

The display of the location on the topographic map on the Doboj-Živinica section based on the GPS position is shown in Figure 6. The top segment of the topographic map shows the exact and precise GPS position where the deformation of the rails occurred. The position is marked with blue pointers p21 and p22.

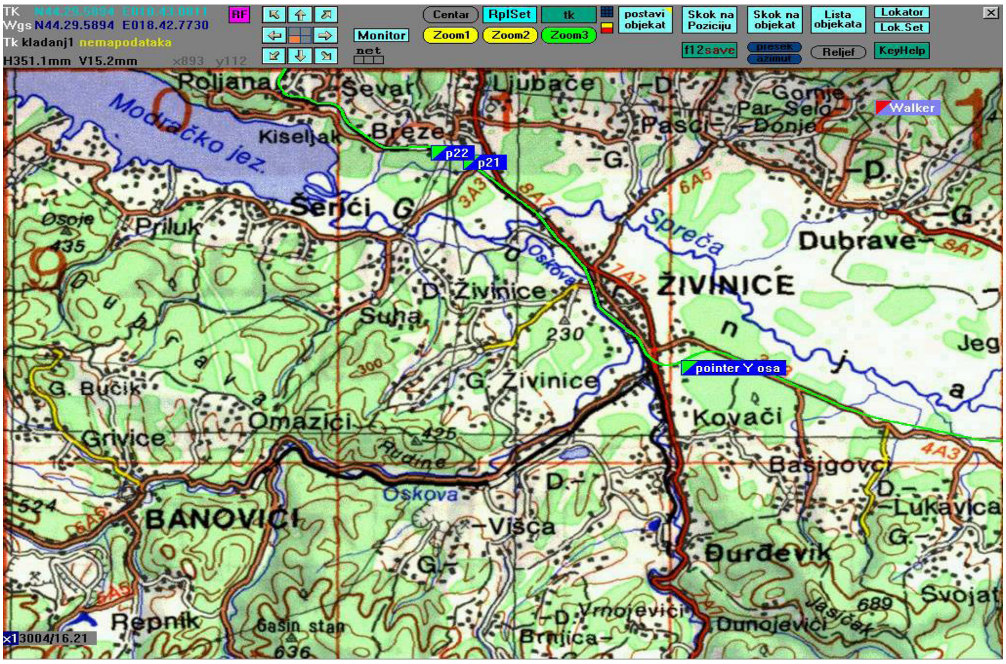

Figure 6. Display of rail deformations on the topographic map

Figure 7 shows the deformation of the tracks on the Google earth surface. The yellow marker represents the position of the track deformation.

Figure 7. View of the route and pointer on the Google Earth surface

Figure 8 shows the deformation of the tracks on the Google Maps surface. The blue marker represents the position of the track deformation.

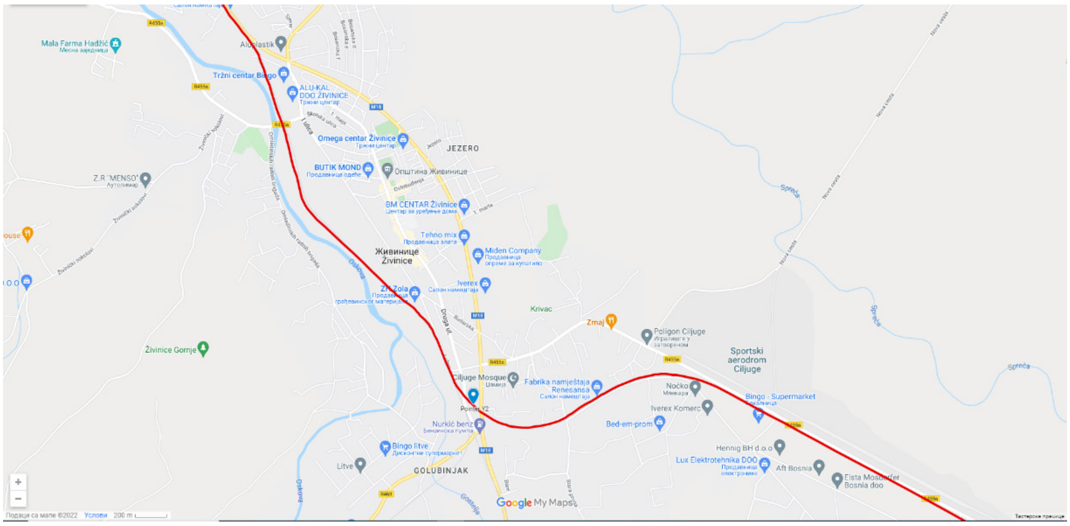

Figure 8. Pointer displays on Google Maps

The locations of track deformations along the Doboj-Živinice section are identified in detail by showing them on the topographic map. Precise GPS positions marked with markers enabled the exact location of the problem. This analysis provides a basis for effective intervention and damage repair, ensuring the safety and stability of rail traffic on a given section.

Conclusions

The proposed solution is an intelligent measuring device that can be used to diagnose the state of the railway tracks, thereby improving the operational reliability and safety of the railway infrastructure. It is implemented in digital technology and uses artificial intelligence. It can be used to diagnose the deformation of rails on which fast/slow trains, trams, subway vehicles, freight trains and trains for the transportation of dangerous goods travel. The device is reliable, economical and easy to use. Compared to similar devices (measuring circuits), its price is several times lower.

Data from the device is recorded (saved) on an MMC/SD card or via an ONLINE connection (Internet). They can be delivered to the central monitoring computer center where there is a current overview of the condition on the track. With it, railway maintenance operations are more easily managed, there is no need for a physical inspection of the rails, and in the event of an accident or incident, all data on the actual condition of the railway tracks are available. It can be used in all climatic conditions and does not pollute the environment.

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization: D.D. and F.M., Formal Analysis: D.V. and M.P., Investigation: F.M. and P.S., Methodology: D.D., F.M. and P.S., Writing – original draft: D.D. and D.V., Writing – review & editing: D.V. and M.P. All authors have read and agreed to the published version of the manuscript.

References

Bauranov, A. (2016). *The Port of Piraeus – Opportunity for Railways in South East Europe*. Retrieved from https://www.globalrailwayreview.com/article/29672/port-piraeus-railways-south-east-europe/

Betke, K. (2000). *The NMEA-0183 Protocol*. Retrieved from https://www.tronico.fi/OH6NT/docs/NMEA0183.pdf

Bešinović, N., Tang, R., Lin, Z., Liu, R., Tang, T., Donato, L.D., Vittorini, V., Wang, Z., Flammini, F., Pappaterra, M.J., Goverde, R.M.P. (2021). Deliverable D1.2: Summary of existing relevant projects and state-of-the-art of AI application in railways. *RAILS Project*. https://doi.org/10.13140/RG.2.2.11353.03686

Centar za istraživanje nesreća u saobraćaju (2018). Sektor za istraživanje nesreća u železničkom saobraćaju i međunarodnu saradnju, *Godišnji izveštaj za 2017. godinu*, br. 340-00-4/2018-2-40-1. Retrieved from https://www.cins.gov.rs/doc/zeleznicki-saobracaj/Godisnji-Izvestaj-za-2017godinu.pdf

Compass Lexecon and Karanović & Partners (2020). Tržište prevoza robe u železničkom saobraćaju u Republici Srbiji. Izveštaj. https://www.kzk.gov.rs/kzk/wp-content/uploads/2020/08/Tr%C5%BEi%C5%A1te-prevoza-robe-u-%C5%BEelezni%C4%8Dkom-saobra%C4%87aju-u-Republici-Srbiji.pdf

Direkcija za železnice, Republika Srbija (2023). Izveštaj Direkcije za železnice o stanju bezbednosti u železničkom saobraćaju za 2022. godinu. Retrieved from https://www.raildir.gov.rs/doc/izvestaji/Godisnji_izvestaj_o_bezbednosti_za_2022_godinu.pdf

Espinosa, F., García, J.J., Hernández, A., Mazo, M., Ureña, J., Jiménez, J.A., Fernández, I., Pérez, C., García, J.C. (2018). Advanced monitoring of rail breakage in double-track railway lines by means of PCA techniques. *Applied Soft Computing*, 63, 1-13. https://doi.org/10.1016/j.asoc.2017.11.009

Fragnelli, V., Sanguineti S. (2014). A game theoretic model for re-optimizing a railway timetable. *European Transport Research Review*, 6(2), 113-125. https://doi.org/10.1007/s12544-013-0116-y

Gibert, X., Patel, V.M., Chellappa, R. (2015). Robust Fastener Detection for Autonomous Visual Railway Track Inspection. *IEEE Winter Conference on Applications of Computer Vision*. https://doi.org/10.1109/WACV.2015.98

Hronik, R.H. (1970). Apparatus for high-speed measurement of track geometry, patent. https://patentimages.storage.googleapis.com/ed/20/e4/3b40165f0510e3/US3517307.pdf

Hodas, S., Izvoltova, J., Chromcak, J., Bacova, D. (2022). Monitoring the Geometric Position of Transition Zones to Increase the Quality and Safety of Railway Lines, *Appllied Sciences*, 12, 6038. https://doi.org/10.3390/app12126038

Institut za standardizaciju Srbije (2019). SRPS EN 13848-1:2019. https://iss.rs/sr_Cyrl/project/show/iss:proj:62968

Institut za standardizaciju Srbije (2017). SRPS EN 13848-5:2017. https://iss.rs/sr_Cyrl/project/show/iss:proj:60555

International Railway Yournal (2019). The future of intelligence is artificial. https://www.railjournal.com/in_depth/future-intelligence-artificial/

Ministarstvo građevinarstva, saobraćaja i infrastructure. Retrieved from https://www.mgsi.gov.rs/cir/projekti/term/195

Railway Gazette International. https://www.railwaygazette.com/

Saleh, S. (2016). *Spherebot Design and testing of a robot inside of a sphere*. Examensarbete inom teknik. https://kth.diva-portal.org/smash/get/diva2:957832/FULLTEXT01.pdf

Shafieenejad, I., Rouzi, E.D., Sardari, J., Araghi, M.S., Esmaeili, A., Zahedi, S. (2021). Fuzzy logic, neural-fuzzy network and honey bees algorithm to develop the swarm motion of aerial robots. Evolving Systems, 13, 319-330, https://doi.org/10.1007/s12530-021-09391-4

Sreenivvas, U., Drakshayani, E., Basha, D., Vardhan, M.H., Jhansi, Y.S., Naik, P.B. (2023). Multi-functional blind stick by using solar charging system. *International Research Journal of Engineering and Technology*, 10 (3), 1282-1287, Retrieved from https://www.irjet.net/archives/V10/i3/IRJET-V10I3205.pdf

Tararychkin, I.A. (2020). Selection of network structures of pipeline systems resilient to mixed damage. *Dependability*, 20(2), 12-17. https://doi.org/10.21683/1729-2646-2020-20-2-12-17

Tang, R., Donato, L.D., Bešinović, N., Flammini, F., Goverde, R.M.P., Lin. Z., Liu, R., Tang, T., Vittorini, V., Wang, Z. (2022). A literature review of Artificial Intelligence applications in railway systems. *Transportation Research Part C* 140, 103679, https://doi.org/10.1016/j.trc.2022.103679

Uputstvo o postupku verifikacije proizvoda i proveri podobnosti proizvođača kočne opreme ("Sl. glasnik Zajednice JŽ", br. 6/01). https://www.srbcargo.rs/sr/biblioteka-propisa/?script=lat

Yaman, O., Karakose, M., Akin, E. (2017). A Vision Based Diagnosis Approach for Multi Rail Surface Faults Using Fuzzy Classificiation in Railways. *International Conference on Computer Science and Engineering*. https://doi.org/10.1109/UBMK.2017.8093511

Yazawa, E. (2003). Track inspection technologies, *Railway Technology Avalanche*, 1(1), 3. https://www.rtri.or.jp/eng/publish/newsletter/pdf/01/RTA-01.pdf

Zohari, M.H.B., Nazri M.F.B.M. (2021). GPS Based Vehicle Tracking System. *International Journal of Scientific & Technology Research*, 10(04), 278-282. https://www.researchgate.net/publication/352559892_GPS_Based_Vehicle_Tracking_System