Pilot Project of Autonomization of the Control System for a Newag 126N “Nevelo” Tram

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Abstract. Automation and autonomization are indispensable features of the modern economy, including transport. The use of artificial intelligence contributes significantly to increasing the quality of services provided. The use of autonomous control allows to reduce the impact of the risk connected with human factor, ensures reliability, continuity of supply and the possibility of fast, safe and timely movement of goods and people, and even has a positive effect on the environment. The topic of railway autonomy is constantly deepened, and more and more solutions related to it appear in the world. Semi-autonomous and fully autonomous vehicles are operated in Asian, American and European countries and even in Australia. In Europe, there are examples such as the Paris metro or AirRail Link in Great Britain, but also in Poland work has started on a project on autonomous tram control. The research was conducted in 2020 in Krakow, and the test results are presented in the article.

1. Introduction
In recent years, the world has experienced a significant development of the economy, and thus an increasing demand for high quality services and products. Therefore, many industries began to replace human work with artificial intelligence [1]. The implementation of such a solution significantly contributed to the increase in productivity and the reduction or complete elimination of the risk related to human error. Automation, however, appeared not only in the field of industrial production technology, but also in road and rail transport. The first autonomous car was presented at the Futurama exhibition in New York in 1939, and already in 1958 the vehicle was constructed by General Motors. Subsequently, in 1977, Japan's Tsukuba Mechanical Engineering Laboratory created a semi-automatic car. It used a camera system that allowed data to be transferred to a computer in order to process the road image [2]. Due to the nature of road traffic, a large number of variables that could affect the movement of a vehicle, nowadays very advanced control systems are used in cars. Solutions of this type, appearing, for example, in Tesla or Google Cars [3], have significantly increased not only the level of safety, but also reliability.
The development of autonomy in road transport has also contributed to the reduction of the emission of harmful toxins in exhaust gases [4]. It has been tested that the introduction of electric autonomous vehicles will reduce exhaust emissions by up to 30% [5]. The positive impact of autonomization on the environment and the quality of transport services provided meant that artificial intelligence was
also started to be implemented in rail transport. As early as 1981, the world's first driverless railway was put into operation in the Japanese city of Kobe [6]

Autonomous rail vehicles began to appear in many countries of the world. One of the most advanced countries in this respect was China, where the world's first autonomous rail transport - ART (Autonomous Rail Rapid Transit) was launched. This vehicle, equipped with sensors that enable it to track the track virtually, drives on the road in an urban environment. It is also interesting that it runs on rubber tires [7]. A European example of the autonomy of transport is the Paris metro. The train that travels around the French city is unmanned. The introduction of such a solution increased the capacity of the metro system by about 10% and decreased energy consumption by about 15% [8]. It is also worth mentioning the Australian AutoHaul project, which assumed the introduction of an autonomous railway vehicle into operation in order to improve the quality of freight transport services. Rio Tinto, together with partners from the USA (New York AirBrake) and Japan (Hitachi Rail STS), have developed an integrated train management system. Already in 2018, in Pilbara, Western Australia, this fully autonomous vehicle completed its first delivery of 28,000 tonnes of iron ore, covering a route of 280 km. Currently, this train is known as the largest robot in the world [9].

2. Project of autonomous tram control

The need of automation and autonomization of rail transport has also appeared in Poland. In 2019, the Institute of Rail Vehicles of the Krakow University of Technology in cooperation with such companies as Newag S.A., Cybid Sp. z o.o., Medcom Sp. z o.o. and MPK in Krakow started work on the design of the first in Poland autonomous tram control system. Already at the beginning of 2020, a driverless tram named "Nevelo" (Fig. 1), along with passengers inside, covered a distance of 3 km.

![Figure 1. Low-floor tram type 126N "Nevelo"](image)

2.1. Purpose and genesis of the project

The tram autonomous control system was designed and then made as part of the project "Autonomization of tram driving as a tool supporting the work of tram drivers". This project was primarily aimed at increasing the level of safety and driving comfort by implementing an "assistant" that would support the driver's work and control individual driving parameters.

2.2. The principle of operation of the autonomous control

The operation of the positioning system is based on the cooperation of two independent navigation systems. These systems are:
- Global Navigation Satellite Systems - its principle of operation is based on positioning by receiving radio waves of artificial satellites,
- Inertial Measurement Unit - a system based on the positioning of an object using a navigation unit with a gyroscope that determines the position in three axes and an accelerometer that allows you to measure accelerations in the axes of the gyroscope.

The elements of the positioning system are shown in Fig. 2 and Fig. 3.

![Figure 2. Inertial navigation module](image)

![Figure 3. Satellite navigation antenna](image)

Positioning takes place in the 2D system, and the additional measurement of the azimuth determined by the counting method allows to obtain the third positioning coordinate. The applied solution enables not only precise control of the place where the object is to be stopped, but also allows for taking into account traffic restrictions, such as e.g. reducing the vehicle speed to 10 km/h at turnouts.

![Figure 4. Diagram of an autonomous tram control system](image)

The main element of the system is the Central Processing Unit, which reads and transmits information via CAN buses and controls the vehicle's actuators, thus replacing the actions performed by the driver in normal driving. In the test facility, the functions performed automatically by the CPU include: controlling the vehicle's door at stops, starting the site, stopping at a designated place and using a warning signal in the form of a bell when starting the vehicle. In order to enable the tram to be controlled by the Central Processing Unit, it was necessary to modify the control program, which is the responsibility of MODECOM Sp. Z o.o. This modification enabled bi-directional communication over the CAN bus. The control generated by the CPU is based on previously performed test drives that allow the driver to digitally transmit signals generated during normal driving by the driver, which include: acceleration parameters forced by the driver, braking decelerations and deceleration when starting, and the position of the controller. The elements of the tram control system are shown in Fig. 5.
For the safety of the tests, the possibility of preferential manual control of the vehicle was retained and the emergency braking forced operation was not disturbed by acting on the safety levers located in the tram passenger compartment.

2.3. Test drive of the tram
For safety reasons, the tests were carried out on the track section isolated from traffic of other vehicles (separated track - no car traffic). The tests were carried out at night in order to minimize the number of pedestrians remaining in the immediate vicinity of the track and to avoid disturbance of tram traffic on a given line. An additional parameter examined during the tests was the comparison of the readings from the positioning system and the vehicle wheel speed sensors. Due to the grassy surroundings of the track and the high level of humidity, the presence of wheel slip was checked on the basis of the difference in the readings of these systems.

Eventually, the tests were conducted on the line: Muzeum Narodowe (the National Museum tram stop) - Cichy Kącik (tram terminal) - Muzeum Narodowe (the National Museum tram stop) (Fig. 6). The total length of the covered route is about 3.2 km. There are 6 intermediate stops on the route, the starting stop of the National Museum, the stop at the Cichy Kącik terminus and the final stop of the National Museum. There were also two turnouts on the route, where the vehicle speed was automatically reduced to 10 km / h.

2.4. Development possibilities of the implemented project
Positive tests results are the basis for further project development. Work is already at the planning stage consisting in the implementation of a system for detecting and recognizing streaks, integrated with the Central Processing Unit, based on measurements read with the use of thermovision. Additionally, preliminary work is underway to introduce the vehicle to the unassigned track. This will enable the identification of further necessary elements with which the autonomous vehicle control system must be expanded, taking into account dynamically changing road situations and maintaining the highest possible level of safety. The conducted tests confirm the high probability level of introducing into traffic initially autonomous rail vehicles, initially supervised by a man, and in the next stage of development of the project, fully autonomous rail vehicles used for passenger transport. The solution initially implemented in Krakow, with efficient implementation, can be used throughout the country and abroad.

3. Summary
The examples presented at the beginning and the design of the autonomous tram itself illustrates the advancement of work on the autonomization of the rail transport. The solutions currently used allow using the autonomous trains only on selected routes, but there are still many possibilities, and the progressing work towards the use of vehicles with artificial intelligence may soon lead to the implementation of complete transport autonomy. However, in order for there to be a possibility of a wider application of solutions regarding autonomy, apart from the purely technological aspect, changes in the legal conditions in the field of personnel or train traffic specifications are also necessary. While the movement of metro trains is dependent on a small number of external factors, the tram is in constant contact not only with other vehicles but also with pedestrians, which directly increases system requirements and the complexity of the algorithms. Further work on the software and the appropriate implementation of individual devices will allow for the creation of an autonomous tram transport, which will be more reliable, precise and safe for all road users.

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