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Innovative Urban Transport System – Autonomous and Locally Low-Emission

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Abstract. In recent years, intensive research on urban transport has been observed. The search is about finding such solutions that will enable, among others: increasing the importance of public transport, matching transport for the needs of people with reduced mobility, increasing capacity, reducing emissions, energy efficiency (technical and organizational dimension through the organization of transport on demand), increasing the vulnerability to recycling and remanufacturing. The paper presents the main concept and technical solutions of the innovative transport system – HMASSUT Prometheus (Hybrid Modular Autonomous System for Sustainable Urban Transport), which combines the concepts of personal rapid transport and an electric vehicle at the L4 autonomy level (according to the Society of Automotive Engineers classification). An assessment of the effectiveness of an innovative transport system using indicators used in road engineering is given in the paper. The concept of simulation and optimization of the transport network is presented together with the theory of cellular automata.

Keywords: urban transport, autonomous vehicle, electromobility, simulation, theory of cellular automata

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Инновационная автономная система городского транспорта с низким уровнем локального загрязнения окружающей среды

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Реферат. В настоящее время появилось множество исследований в области совершенствования городского общественного транспорта. Осуществляется поиск таких решений, которые позволят сделать данный транспорт более значимым и доступным для людей с ограниченными физическими возможностями, увеличить его пропускную способность, сократить выбросы загрязняющих веществ, повысить энергоэффективность путем внедрения перевозок по требованию, усовершенствовать рециклинг материалов и вторичное производство. В статье представлены основная концепция и технические решения новаторской транспортной системы HMASSUT Prometheus (гибридная модульная автономная система устойчивого городского транспорта «Прометей»), сочетающей концепции персонального скоростного транспорта и электромобиля на уровне автономии L4 (в соответствии с классификацией SAE (Общества автомобильных инженеров)). Дана оценка эффективности инновационной транспортной системы с использованием применяемых в дорожной инженерии показателей. Приведена концепция моделирования и оптимизации транспортной сети совместно с теорией клеточных автоматов.

Ключевые слова: городской транспорт, автономные транспортные средства, электромобильность, компьютерное моделирование, теория клеточных автоматов

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Introduction

The basic tasks for modern transport are:

• limiting the number of accidents, in other words increasing road safety;

• reduction of pollution generated by motor vehicles;

• adaptation of transport to people with reduced mobility (especially older people);

• striving to use, especially in urban traffic, public transport and limiting personal transport;

• increasing transport capacity, especially in cities.

It seems that the above-mentioned objectives can be achieved through the technologies of autonomous electric vehicles. Typical solutions based on existing ITS (Intelligent Transport System) technologies seem to have already reached the peak of their capabilities. Currently, one can observe a very dynamic development of vehicles and autonomous transport systems in the world. New solutions are based on various IT and measurement technologies, vehicle positioning module and decision modules (decisions on maneuvers). The levels of vehicle autonomy are also different (a five-level classification defined by Society of Automotive Engineers, SAE) can be used as a reference. To date, standards, certification methods, safety measures, etc., for autonomous vehicles have not yet been developed. The IT side of the vehicle is based on artificial intelligence (the so-called deep neural networks).

This article aims to present a certain concept developed and constantly developed in Poland. This concept dates back to the beginning of the current century. At that time, the first Polish PRT (Personal Rapid Transit [1]) system and a powered car were developed.

The basic system was developed in Poland at the Faculty of Transport. The system was developed as part of the ECO Mobility project financed by the European Union (project manager – Prof. W. Choromański). As part of the project, a prototype of an electric car was also made, with special utility functionality – it can be managed by non-disabled people and those with mobility disorders. The designs have been described in detail in [1, 2].

Currently, works are being carried out to add an electric module enabling autonomous driving and modification of the PRT system to move not only on the track infrastructure (located above the ground) but also to move on the road in autonomous mode and share this road with other vehicles.

Elements of the future system – car and Personal Rapid Transit

Fig. 1 shows the car preprototype made as part of the ECO Mobility project, and Fig. 2 – a model for presenting the functionality of a PRT vehicle. Here we will discuss the most important features of these vehicles.

Fig. 1. ECO car (Warsaw University of Technology – ECO Mobility)

Fig. 2. Model cabin of a Personal Rapid Transit (Warsaw University of Technology – ECO Mobility)

The designed vehicles are equipped with innovative control systems. The car uses a new type of Human Mashine Interfase (HMI) steering wheel using the steer by wire system (Fig. 3) [3]. This HMI is adapted for sharing by fit and disabled people.

PRT vehicles moving in a track system are guided by a roller system and a turnout referred to in the Anglo-Saxon literature by the term "passive switch". The model of this system is shown in Fig. 4, 5 and a detailed description is contained in [4]. A non-contact dynamic power supply system was used in the vehicle track motion.

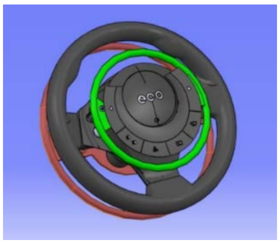

Fig. 3. The model of universal steering wheel [3]

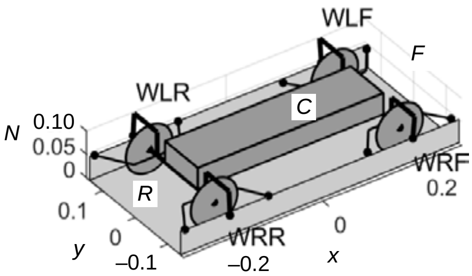

Fig. 4. Overview of model's arrangement of solid bodies: WLF, WRF, WLR, WRR – left front, right front, left rear, right rear; *F*, *R* – front and rear wheel set [4]

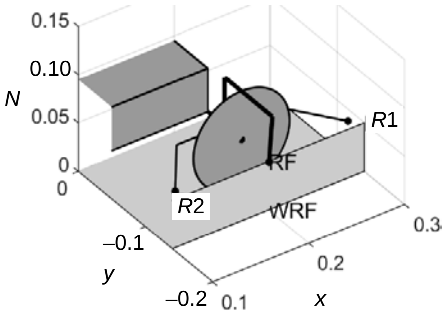

Fig. 5. Right wheel's set of passive switch rollers: *R*1, *R*2 – inner rollers; RF – outer roller [4]

The view of the completed PRT system on the laboratory scale is presented (Fig. 6) [5].

Fig. 6. Scaled physical model of a Personal Rapid Transit vehicle at a laboratory testing station [5]

The applied construction solutions required a special design approach – the virtual pre prototyping procedure was used here. The tests performed primarily concerned parametric sensitivity analyzes.

They provided many valuable data on the driving properties of the vehicles being built. The results of theoretical studies on vehicle traffic stability with the Steer by Wire system are contained in [6]. The following works [7, 8] show the results of experimental research on the HMI system made using a dynamic simulator. Particularly interesting turned out to be works in the field of contactless power supply design for PRT vehicles, the results of which are presented in [5], as well as the results of torsional vibration analyzes of wheel axles in track motion. The reason for these vibrations is the lack of a centering mechanism for track motion with the use of car tires. The results of the analysis are presented in [4].

In the scope of simulation tests regarding PRT transport, simulators operating on the basis of incident analysis [9] and operating on the principle of cellular automata using parallel calculations and the CUDA platform [10] were made.

Polish future proposal of autonomous vehicles and transport systems

The autonomous transport system developed at Warsaw University of Technology combines three technologies (Fig. 7). PRT technologies (a prototype solution developed at the Faculty of Transport of the Warsaw University of Technology), technologies of an electric car suited to driving a vehicle by disabled people [1] and Report NTC [11], technologies of autonomous cars (L2 autonomy levels or L4/B). The system can be configured in various ways depending on your needs.

In the case of extension of the classical PRT system, the Polish system consists of small, four-person electric vehicles moving autonomously on a light aboveground infrastructure (in autonomous and track mode). Vehicles perform "point to point" transport, i. e. from the initial stop to the final stop, there are no intermediate stops, in addition they choose the optimal travel route. Vehicles in the same mode can travel on roads that they share with other vehicles. In this case, the autonomous mode (at L4/B/level) is also preserved – it is a driving mode without a driver.

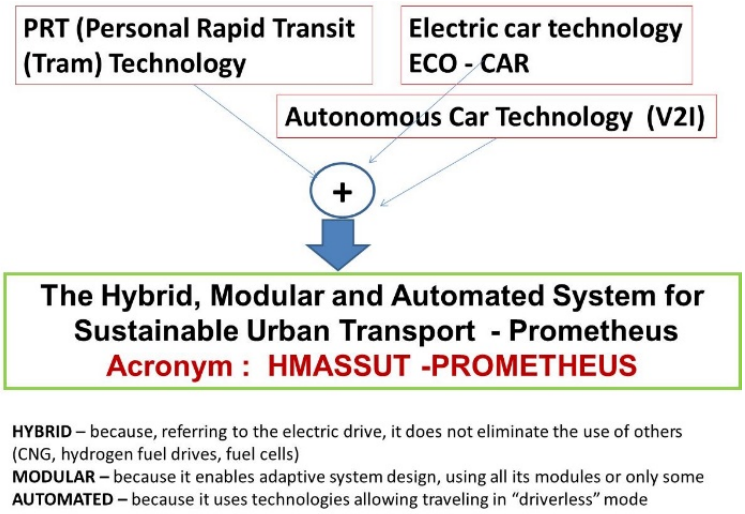

Fig. 7. Polish autonomous transport system [12]

The vehicle uses an electronic track (electromagnetic signals generated from the road installation) or (at a later stage of the system development) a track designated by a measuring car using radar, lidar and camera measurements. In the case of a (electric) vehicle, this vehicle can only move on the road in two modes:

- as an electric vehicle at the level of L2 autonomy. This vehicle is adapted to the disabled with the possibility of positioning wheelchairs of the disabled and adjusting the interface (multifunction steering wheel);
- as a vehicle at the level of L4/B autonomy, then they share the road with PRT vehicles.

In the case of moving in autonomous mode, vehicles are additionally equipped with 4 laser radars (lidars), two video cameras, DGPS and IMU sensors together with the appropriate software.

Optimization problems and software

The development of simulation systems and working in real mode was based on various techniques and methods. The areas which were studied are shown in Fig. 8 [12].

The analysis required (for autonomous vehicles) acceptance of route topology (Fig. 9) [12]. Having identified flows of passenger flows, the location of stops was determined using genetic algorithms. Determining the route was carried out using the equations of the modified Dijkstra's algorithm. During the passage through individual nodes, the modification of the optimal routes takes into account the current traffic conditions. Optimization coefficients (multicriteria) include: minimization of travel time and waiting time for stops, minimization of energy consumption, maintaining the smoothness of driving and the number of vehicles (unfavorable is both too many and too few vehicles).

Control algorithms are deterministic and relatively simple. Vehicles in autonomous mode move on a mechanical or virtual track. So the control problem is significantly simplified. Vehicles in the Polish system do not perform overtaking and bypass maneuvers. The vehicle's location system is implemented through infrastructure, i. e. for example, a magnetic marker system. In autonomous mode, vehicles on the road must be supported by an additional system (laser radars, cameras and additional, redundant positioning systems based on DGPS).

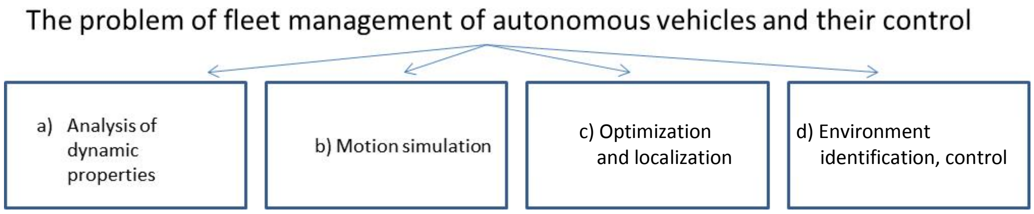

Fig. 8. Areas of numerical analysis [12]

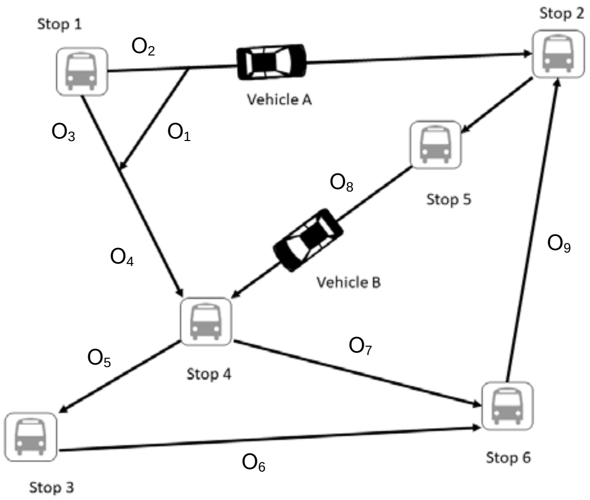

Fig. 9. Scaled physical model of a Personal Rapid Transit vehicle at a laboratory testing station [12]

CONCLUSION

ECO Mobility Poland [2] is planned for implementation in three Polish cities: Rzeszów, Kraków and Łódź. Certain certification procedures and standards will be borrowed from standards and procedures of Automated People Movers. These are track vehicles moving in autonomous mode. It can be noticed that the vehicles in the proposed system are essentially also track vehicles. At the same time we are dealing with a non-mechanical track. In addition to the separated track above the ground surface (where ROW – Rights of Way has level A) [5], when moving on the ROW roadway it is equal to Vuchan R 2007. It is therefore assumed that vehicles share roadways with other vehicles. The proposed system is very flexible and can be configured depending on the needs of cities. It will work partly in the on-demand transport system, partly (especially with regard to the electric car, the possibility of using it in the "car sharing" mode is considered). The described solution was awarded the 2016 prize of the Prime Minister of Poland.

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