Partially autonomous two wheel vehicle for transport of persons at industrial plants – concept of solution

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Abstract: Within the research, the needs and problems occurring in the movement of the workers at industrial plants were specified and characterised. There were developed concepts of systems necessary for the automatic operation of the vehicle in the manner under consideration. The authors carried out the review and preliminary selection of technical means, used in both manually controlled vehicles and the autonomous ones, possible to adapt in order to implement the proposed solution. The paper considers the principles of the development in transport of persons at industrial plants. The results of the analysis performed are observations and assumptions about the possibility of integrating well-known mobile platform, navigation and power supply in an innovative way. It states the fundamentals for the plan of the future work which leads to actualising the device, including designing, constructing and programming of it.

1. Introduction
The movement of workers in industrial plants sometimes involves travelling long distances. In many places, different means of transport are used, either fully mechanical (muscle-based) or with independent propulsion. Due to the specifics of the environment in question, battery electric systems are usually chosen for the latter. Currently, two-wheeled vehicles are among the most popular ones.

Figure 1. High manoeuvring capabilities of two-wheeled vehicle.
They are characterised by high manoeuvrability, mobility, compact design and ease of use. As shown in figure 1, the vehicle rotation $\omega_v$ is achieved by the wheels opposite rotation $\omega_1$ and $\omega_2$. However, the device may not be available whenever it is needed due to the necessity of periodical energy replenishment (e.g., by connecting to the grid or changing batteries) or leaving it in a remote location by the previous user. As a solution to these problems, the research team proposes to develop an electric vehicle with enhanced functionality compared to the currently known. The basic mode of operation is to be the classic manual control by the driver, with all the features of standard operation. However, when the vehicle is not being used to transport a worker, its autonomy is activated. It can then move to a loading zone or go to wherever it is needed at the time. The efficient and safe implementation of such a mode of operation can be achieved using techniques known from AGVs or mobile robots. Implementation of modern means of energy transfer to the vehicle would eliminate the need for human intervention in the whole process.

1.1 Vehicle operating conditions
Autonomous driving modes require complex and sophisticated technical solutions. Depending on the requirements of the customer and the target area of the vehicle, there are different solutions to the problem. By making assumptions about the destination:
- the vehicle will not leave the confined spaces of the workplace,
- the total area of the plant will oscillate around 10 000 m$^2$,
- the vehicle will navigate in a dynamic environment – moving plant workers,
- special transport routes will be set up for vehicles,
the following concept of construction and operation of the device can be proposed.

2. Construction of vehicle
Two-wheeled vehicle of “segway” type keeps balance during the ride thanks to the adjustable torque of the wheels. Keeping constant lean angle $\phi$ is achieved by manipulating torques $M_1$ and $M_2$ which generate balancing force $F$ acting on mass centre, which is presented in figure 2.

![Figure 2. Keeping constant lean angle of vehicle.](image)

The system is a hybrid combination of technical solutions used in industry and other areas of life.

2.1 Sensor equipment
The two-wheelers will be equipped with a variety of sensors (shown in figure 3) to help determine current position and distance from obstacles.
When operating in autonomous mode, it is necessary for the vehicle to know its exact location in relation to individual workstations on the shop floor, base stations and other two-wheelers. Operation in closed facilities does not allow the use of GPS, for which reason localization will take place via Wi-Fi networks and tags in the form of QR codes, infrared emitters or RFID receivers [1].

It is necessary to specify video cameras placed one on each side of the vehicle, especially the front one, of high resolution, which will read the unique QR codes distributed in the workplace, allowing the position of the vehicle to be identified unambiguously. The QR signs will be placed on poles or walls at vehicle steering wheel height. They will not significantly interfere with the appearance of the hall but will ensure the proper level of localization of two-wheelers. In addition, this type of solution does not generate high operating costs, as the signs are printed and do not require illumination for correct reading.

2.2 Energy sources
A set of supercapacitors and batteries will constitute the power supply system, which elements are presented in figure 4.

An unquestionable advantage of using supercapacitors is the possibility to recharge them instantly. They have high efficiency (about 90%), wide operating temperature range (-40°C ÷ 60°C), are maintenance free, resistant to deep discharge and their operating cost is very low, because repeated charging and discharging does not significantly affect their capacity. The disadvantage of this solution is low current capacity, which makes it necessary to use a separate energy storage, in this case a battery pack [2].

The biggest advantage of using batteries is their high capacity and current efficiency. They are able to power a vehicle much longer than supercapacitors, so they will serve as the main energy storage. However, they have a number of disadvantages such as long charging times, reduced efficiency during repeated charging and discharging, the need for periodic replacement and therefore higher operating costs. The combination of these two types of power supply and their synergic action, results in the mutual elimination of the disadvantages of each solution.

The power supply system will be equipped with an inverter maintaining voltage at a constant level, a charging module protecting batteries and supercapacitors against excessive discharge and a module allowing inductive charging. Together with the two-wheeler, the set will form a docking station or a network of stations equipped with a wireless inductive charging system.

![Figure 3. Location of sensor, communication and control equipment in vehicle.](image-url)
3. Vehicle operation
The vehicle will be suitable for driving indoors, on level pavement and outdoors, provided that the terrain does not have irregularities in excess of 3 cm.

The minimum range of the vehicle on one full charge is 10km. The vehicle will be travelling in the vicinity of other people, so the driving speed with the driver will be limited to 20km/h, and in autonomous mode to 8km/h. This will allow for safety and at the same time efficient movement around large-scale sites.

3.1 Autonomy in driving and vehicle navigation
The minimum range of the vehicle on one full charge is 10 km. The vehicle will be travelling in the vicinity of other people, so the driving speed with the driver will be limited to 20 km/h, and in autonomous mode to 8 km/h. This will allow for safety and at the same time efficient movement around large-scale sites [3].

In addition, by connecting the vehicles to a server that monitors their operation and manages their movement, it is possible to generally locate the vehicle based on the strength of the signal to individual routers located on the premises.

In order to develop autonomous systems, a suitable solution is to implement artificial intelligence, which, on the basis of data on the movement of vehicles and the environment, will make it possible, for example, to avoid collisions with pedestrians or to plan the optimal route to the charging station.

The vehicle will recognise its surroundings using a laser scanner. In a short period of time it will send out laser beams which will determine the location, shape, size and distance of possible obstacles. An additional environmental recognition and safety system will be a thermal imaging camera. If a person appears on the route, the system will distinguish him/her from the rest of the environment by detecting body temperature. The vehicle will stop and then slowly avoid the obstacle. The process of gathering the surroundings data is presented in figure 5.

The application of the above proposed solutions for vehicle navigation and obstacle detection and appropriate response, meets the requirements set for the design of an autonomous vehicle to navigate within the work premises. If it is necessary to travel outside the hall, the autonomous mode will be unavailable until the vehicle is located again at a point that is the limit of the autonomous operation area.

![Figure 4. Location of power equipment in vehicle.](image-url)
Table 1. Summary of major problems and their solutions related to autonomous operation of unoccupied vehicle [1, 4-6].

| No.  | Problem                                                                 | Identified classes of useable equipment to be adapted from mobile robotics                                                                 | Description of solution                                                                 |
|------|-------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| 1.   | Finding unoccupied vehicles and checking their battery levels by a person | Human-machine mobile interfaces, local positioning systems, wireless communication                                                   | The person receives the localisation of vehicles and their battery levels on a mobile device. |
| 2.   | Getting a mean of transport by a person who is far from the vehicle      | Human-machine mobile interfaces, wireless communication                                                                               | The person calls the vehicle using a mobile device which transmits their localisation to the vehicle controller via a wireless network. |
| 3.   | Automated verifying if the unoccupied vehicle range meets the requirements for executing a task | Area mapping, energy consumption modelling, local positioning systems                                                                    | The person specifies the destination while their localisation is read automatically. |
| 4.   | Automated positioning, way finding and self-navigating of an unoccupied vehicle | Area mapping, area scanners, distance sensors, local positioning systems                                                                | The vehicle scans the surrounding, creates a map of it and locates itself as well as routes and other objects on the map. |
| 5.   | Automated position verifying – assuring that the unoccupied vehicle is next to the particular object | Distance sensors, tag readers                                                                                                         | The vehicle scans the RFID or QR tag placed on the reference object and measures the distance from obstacles. |
| 6.   | Automated reacting to people around by an unoccupied vehicle which moves | Artificial intelligence, machine vision, thermography                                                                               | The vehicle recognises specific motions as well as the temperature distribution of people and modify the velocity or change the position in the case of collision anticipation. |
| 7.   | Automated reacting to fixed obstacles as well as objects which move by an unoccupied vehicle | Area scanners, distance sensors, tag readers, wireless communication                                                                       | The vehicle identifies the object by shape scanning, tag scanning or wireless communication and adapt the motion parameters to moving around it. |

3.2 Recharging

The power system monitors the battery charge level in real time. In the event of the charge level dropping below the specified threshold, the vehicle will signal and suggest that the user replace the vehicle with another - charged - vehicle or park the vehicle. When the charge level drops below the critical threshold, further driving will not be possible in order to protect the cells from accelerated wear (one can see the process in figure 6).

The supercapacitors will be responsible for quickly recharging the vehicle when there is a need to quickly recharge the batteries. This will take about two minutes, after which it will be possible to drive about a kilometre to get to work and to the nearest charging station. The main energy storage facility will be a set of batteries that will take around 15 minutes to fully charge [2].

The charging system will work in such a way that the supercapacitors will be charged first, from which the batteries will then be charged. This system will allow the vehicle to be recharged unattended. Thanks to the autonomous mode, when the two-wheeler is close to being discharged, it will drive itself from its parking place to the charging station.
3.3 Proposed modes of operation

The vehicle is capable of operating in different states of activity as required. The standard state of the power system is moving with a person on board. During this operating mode, the batteries are gradually discharged due to the current drawn by the motors and the lack of charging. This is due to the assumption that the vehicle can not only move along strictly defined routes (where induction loops for charging the batteries are installed).

The next operating condition is the return of the vehicle to the parking point. The vehicle moves completely autonomously, taking the most optimal route to its destination. The vehicle moves along predefined paths equipped with an integrated inductive charging system under the ground surface. As it moves, the two-wheeler is charged via the aforementioned induction loop using supercapacitor fast-charging technology, which enables it to return to the base even when the batteries are deeply discharged.

The next mode of operation of the power system is charging in the docking station. The vehicle is located in the docking station, which is primarily responsible for charging the two-wheeler to the appropriate level and maintaining it. The vehicle does not consume any significant amount of energy, due to the advanced software of the power supply system enabling the power consumption to be reduced to a minimum.

The last mode of operation of the power supply system is the so-called "standby mode". The vehicle enters this mode while in the docking station or "waiting" for the driver to return. In this state, the system does not consume much power due to the intelligent power saving mode. When in the docking station, the battery charge is maintained at 80-100%.

Figure 5. Sources of data in automated vehicle positioning system.

Figure 6. Autonomous power management in vehicle.
4. Conclusions
The work led to the formulation and consideration of innovative concepts for the technical means of transport under consideration in the area of in-plant transport, but which can also be transferred to non-industrial applications. The analyses carried out concerned an innovative solution, namely a partially autonomised means of transport. A two-wheeled vehicle without a user is supposed to arrive safely at various places in the industrial hall independently on demand. This leads to easier and faster passenger transport. The respective mobile unit is supposed to be connected to other machines in the environment as well, which determines the safety and efficiency of its operation. Autonomy can also manifest itself in manual operation, assisting the user in preventing collisions and maintaining safe movement parameters, or in selecting and optimising routes. Similar solutions are used in highly automated industrial plants with a large number of mobile robots. The research mainly included the identification of needs, accompanying problems and possibilities of their solution. The activities performed form the basis for future work involving the design and construction of an innovative device that meets the requirements identified so far.

5. References
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