Self-propelled inspection vehicle on omni wheels

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Abstract: In the article design of a self-propelled vehicle for inspecting ventilation ducts and ceiling structures in buildings equipped with omni wheels was presented. Such vehicles are used in places that are hard to reach for people. The vehicle was designed using the vehicle control system – ARDUINO. For this system dedicated program was written, which is used to operate it. The vehicle is remotely controlled by radio waves. Its range is about 100 meters and the power supply is a 12 V battery. The vehicle operator has joysticks (controllers) modelled on those used in game controllers that are used for precise vehicle control. The vehicle is equipped with cameras that allow to view the image in real time. The omni wheels have also been tested for strength by the finite element method (FEM). Carried out FEM analysis as part of the work allowed to determine the strength of omni wheels on the acting forces during vehicle movement.

Keywords: omni-wheels, inspection vehicle, self-propelled vehicle

1 Introduction

Designing modern vehicles requires checking basic elements in terms of strength and stiffness of the structure. In the case of passenger vehicles, simulations of the behaviour of the structure are carried out at the design stage of the individual components, and then polygon tests in extreme weather conditions and crash tests are carried out. In addition, simulations of the behaviour of individual systems are performed, such as simulation of vehicle wheels and suspension when overcoming various obstacles that may actually appear on the road or computer tests of displacements of individual body parts during a traffic accident and operation (carried out at their design phase) [1-4].

In the case of other vehicles or machines, the FEM analysis is used to control the stiffness of the structure [5-6].

The main purpose of the work presented in this paper is to design an inspection vehicle that operates on omni-directional wheels, which can be used when controlling hard-to-reach places such as ventilation ducts. In addition to the selection of all vehicle components in

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terms of their functionality and preparation of model in Autodesk Inventor software, a strength analysis of designed omni-directional wheels was also carried out, with particular emphasis on their strength. Designed inspection vehicle with omni-directional wheels enables forward, backward, sideways and rotation movement around its own axis, which is undoubtedly useful when controlling hard-to-reach places. In addition, the vehicle is capable of remote control, has a power supply in the form of a removable battery, is equipped with sensors that collect data during inspection, as well as has a camera that during the inspection transmits the image on-line. The design of the vehicle itself should allow avoiding or overcoming various obstacles that the vehicle may encounter during its operation. Materials used for construction are characterised by lightness and resistance to falls or hitting obstacles. It is important to have access to a battery that ensures easy and efficient replacement or recharging. The clearance between the chassis and the ground will have a positive effect on the range of application. Optimal placement and selection of appropriate components will significantly affect the dimensions of the device. Inspection vehicles on omni-directional wheels are not able to climb stairs. They are mainly used on flat ground where all four vehicle wheels can have contact with the ground.

2 Construction of self-propelled inspection vehicle

2.1 Omni wheel

The omni-directional wheels constitute the movable elements in the construction of the inspection vehicle. Such wheels were also used in the designs described in papers [7-8]. They rotate around their own axis, which makes the vehicle move, at the same time enabling manoeuvring the vehicle (Fig.1).

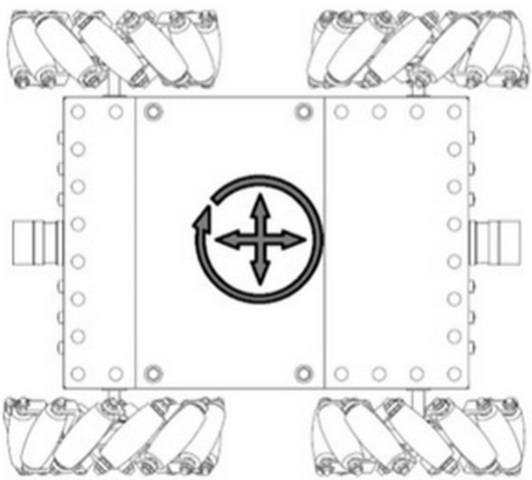

Fig. 1. Inspection vehicle movement pattern on omni wheels [9]

The vehicle can move forward, backward, sideways and rotate around its own axis. This movement is possible thanks to the installation of 12 rubber rollers on the circumference of the wheel, offset by 45° in relation to the wheel drive axle (Fig.2). These elements rotate around their axis at the same time. They were made of vulcanised rubber, which provides very good adhesion to the ground.

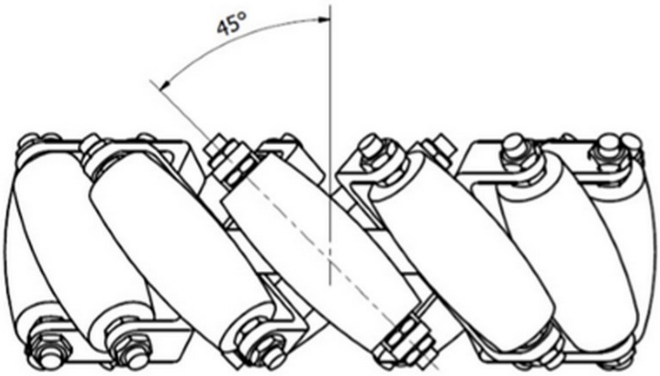

Fig. 2. Omni wheel with marked angle between the rollers and the wheel axis [9]

The rollers have a through hole with a diameter of ø5.2 mm, allowing them to be mounted in a U-type holder made of 3 mm thick stainless steel. The connection of these components was made through a screw with metric thread M5, secured with self-locking nuts (Fig.3). The handle has a centrally made hole with a diameter of ø5 mm, through which the whole element is screwed to the wheel hub.

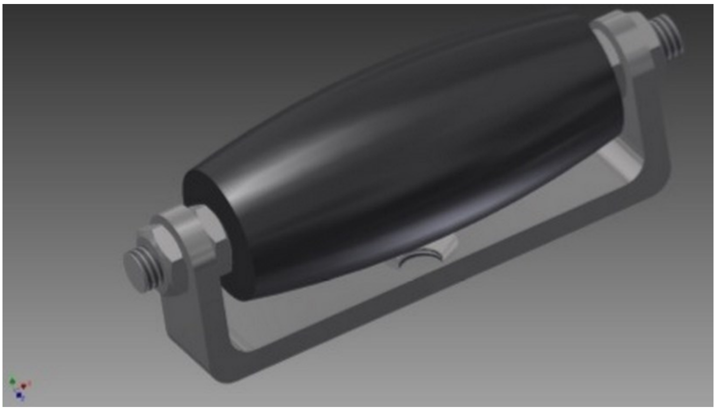

Fig. 3. CAD model of the roller mounted in the holder [9]

Another element of the designed wheel is its hub. It was made of a very durable material that is HPL laminate. On the circumference of the wheel, grooves have been milled, thanks to which it is possible to correctly orient the rollers to the wheel axis. The hub has mounting holes for connection to the drive axle. Omni-directional wheels are divided into right and left. In both types, the rolls are offset from the main axis by the same angle, but in the opposite direction. In the case of an inspection vehicle, they were mounted diagonally. The vehicle is symmetrical, which means that its front and rear look the same. From this perspective, it can be seen that the rollers are shifted in opposite directions. The inside of the hub was milled in the shape of a six-pointed star, which reduced its mass. The complete omni-directional wheel was mounted to the designed axis through three M4×16 Allen screws. The view of the designed omni-directional wheel is shown in Fig. 4.

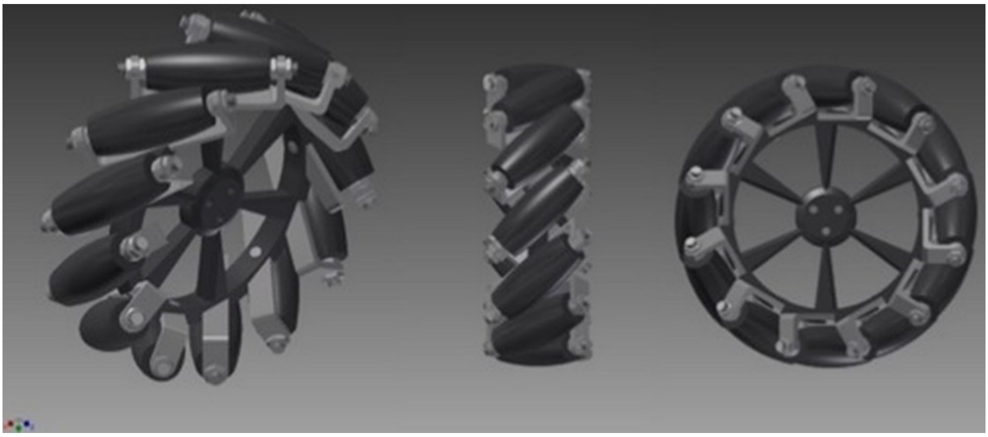

Fig. 4. CAD model of the omni wheel [9]

2.2 Model of self-propelled inspection vehicle

The basis of the vehicle structure is a plate (Fig. 5a) designed from 3 mm metal sheet made of structural steel S235JR. It contains all the mounting holes necessary to attach individual elements of the vehicle.

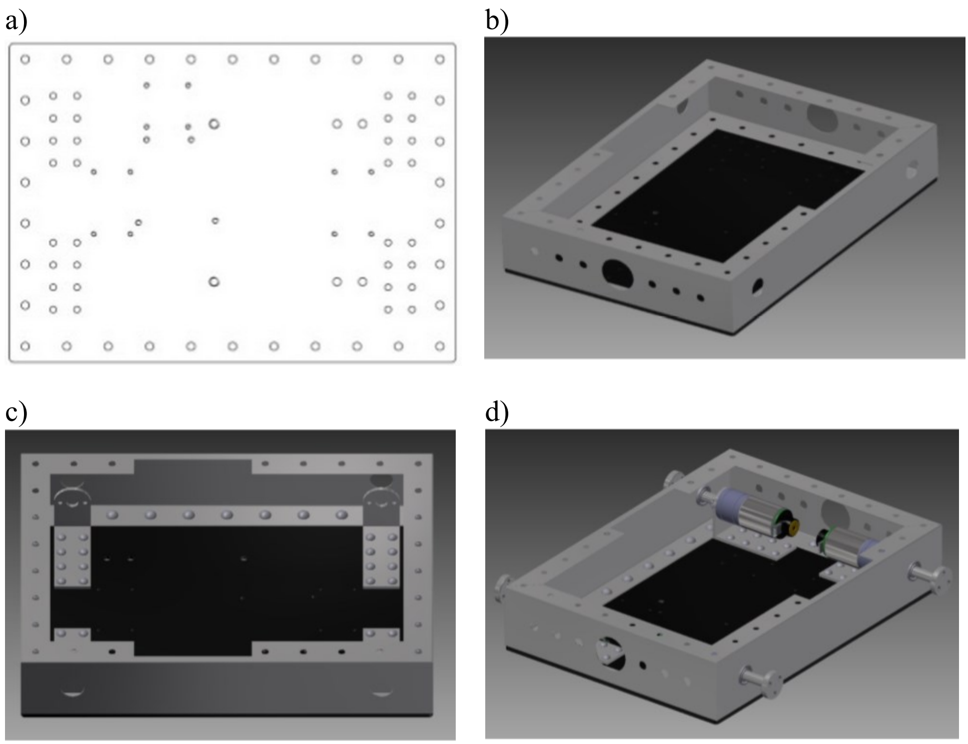

Fig. 5. Designed parts of vehicle: a) The undercarriage of the inspection vehicle, b) Body of the inspection vehicle, c) Body of inspection vehicle with engine mounts, d) CAD model of the vehicle body together with engines and drive axles [9]

Another element constituting a part of the vehicle body are the side walls (Fig. 5b), which were made of C-profiles (cold bent stainless steel) and have dimensions 20×50×20×0.8 mm. The C-profiles were attached to the base plate with rivets. In these elements, holes for wheel axle bearings as well as inspection cameras and LED diodes have been prepared. Next, the mounting brackets for the motors were attached to the base plate (Fig. 5c). The motors were bolted to these elements, and in the side profiles bearings for the wheel axles were placed. They were connected to the motor shaft and secured with an AS 1421 type screw (Fig.5d). The previously designed omni-directional wheels were mounted to the axle. In addition, electronic elements and the battery bottom bracket that prevents any battery movement were mounted in the base plate. Cameras that will transmit the image to the vehicle operator on an ongoing basis were installed in the side profiles. Right next to them LED diodes were installed as additional lighting for operating in a darkened environment (Fig. 6).

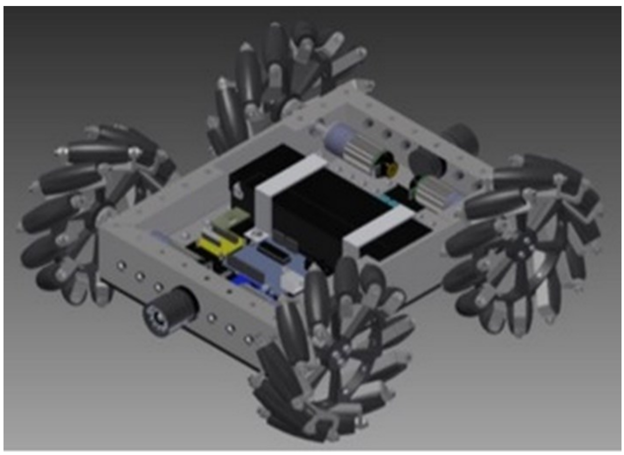

Fig. 6. Designed model of vehicle with all components [9]

The vehicle body was closed by two plates fixed to the side profiles with rivets, and the area under which the battery was located was covered with a flap bolted by 4 M5×8 screws, which allow easy access to this component as well as its free replacement or charging. The final vehicle design is shown in Figure 7.

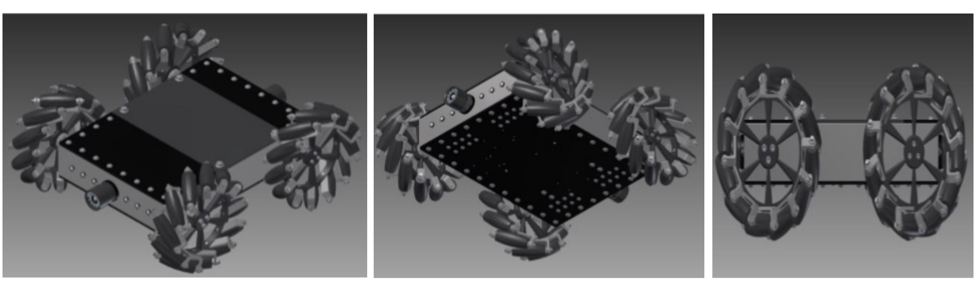

Fig. 7. Designed model of vehicle [9]

2.3 Electric connection and control program of vehicle

For controlling DC motors, a system based on two Waveshare 9208 motor controllers has been designed that use the L293D integrated circuit to control the two motors. These modules have been connected to the Arduino UNO rev.3.0 controller based on the ATmega328P micro controller. Control of the inspection vehicle takes place remotely. A radio module nRF2401L operating on 2.4 GHz radio waves was installed in both the transmitter and receiver system.

The system will be powered from a 12 V battery. Together with the radio module, it provides the ability to easily operate the vehicle. In the transmitter a joystick has been placed, through which it is possible to send a control signal responsible for driving forwards, backwards and to the sides. In addition, a 10 kΩ potentiometer was mounted, which will provide a smooth rotation around its axis. Additionally, two microSwitch switches were installed. They are responsible for switching on additional lighting and for activating the inspection cameras. All modules have been equipped with USB connectors that provide communication with a PC-class computer. Thanks to this, it is possible to easily send control programs and to modify them if necessary. All modules are equipped with additional inputs/outputs, which can be used to expand the control system with new modules, or to collect information from additional sensors.

The inspection vehicle on omni-directional wheels requires control of each wheel separately. Providing the right speed and direction of rotation of each wheel, it is possible to achieve the assumed manoeuvrability of the vehicle. The operator has a remote control equipped with a joystick and tactile switches for individual functions of the vehicle. The individual modules have been programmed in the Arduino environment. The program has been verified and compiled and then it was sent to the micro controller.

2.4 Vehicle components

For the construction of the inspection vehicle on the omni-directional wheels, the motor of the POLOLU model 25DX52L with a 34:1 gearbox equipped with 48 pulses per revolution was selected. The robot speed is 7 $km \cdot h^{-1}$. Four motors were used, for which two WAH-9208 motor controllers from the WAVESHARE manufacturer were applied. This controller enables simultaneous control of two DC motors, and its construction is based on the L293D micro controller.

In addition, the main control module from Arduino, model Uno Rev3, has been selected. It has been equipped with 14 digital I/O and 6 analogue outputs. The module's construction was based on the popular ATmega328 micro controller in a removable cover. It has been connected with motor controllers and relays for controlling the sensors and switching on the inspection cameras. In addition, the set has been equipped with a radio module nRF24L01, which makes it possible to use it as a transmitter or as a receiver. Radio waves are transmitted in the 2.4 GHz range. Two modules were used, one of which was placed in the vehicle as a receiver and the other in the remote control as a transmitter. The electronic components in the vehicle are powered by a 12 V and 2.3 Ah gel battery manufactured by MOTOMA. The manufacturing technology allows the device to be installed in a horizontal position as well. Such location of the battery in the vehicle allowed to obtain the lowest possible height of the vehicle body. The inspection vehicle was equipped with white-light LED diodes and two cameras.

3 FEM analysis of omni wheel

The designed omni-directional wheel was subjected to an illustrative FEM strength analysis in the Autodesk Inventor software. The boundary conditions have been determined. The appropriate material has been assigned to each of the individual elements, the rollers are set to be made of rubber containing a high content of natural rubber. The elements of the roll holder are set to be made of stainless steel, while for the hub polypropylene was used. The assembly was loaded with the maximum torque of the drive motor, which amounts to 444.9 Nm. Between the individual elements of the wheel, bonded and sliding contact types were used. Selected results of the analysis are presented in Fig. 8.

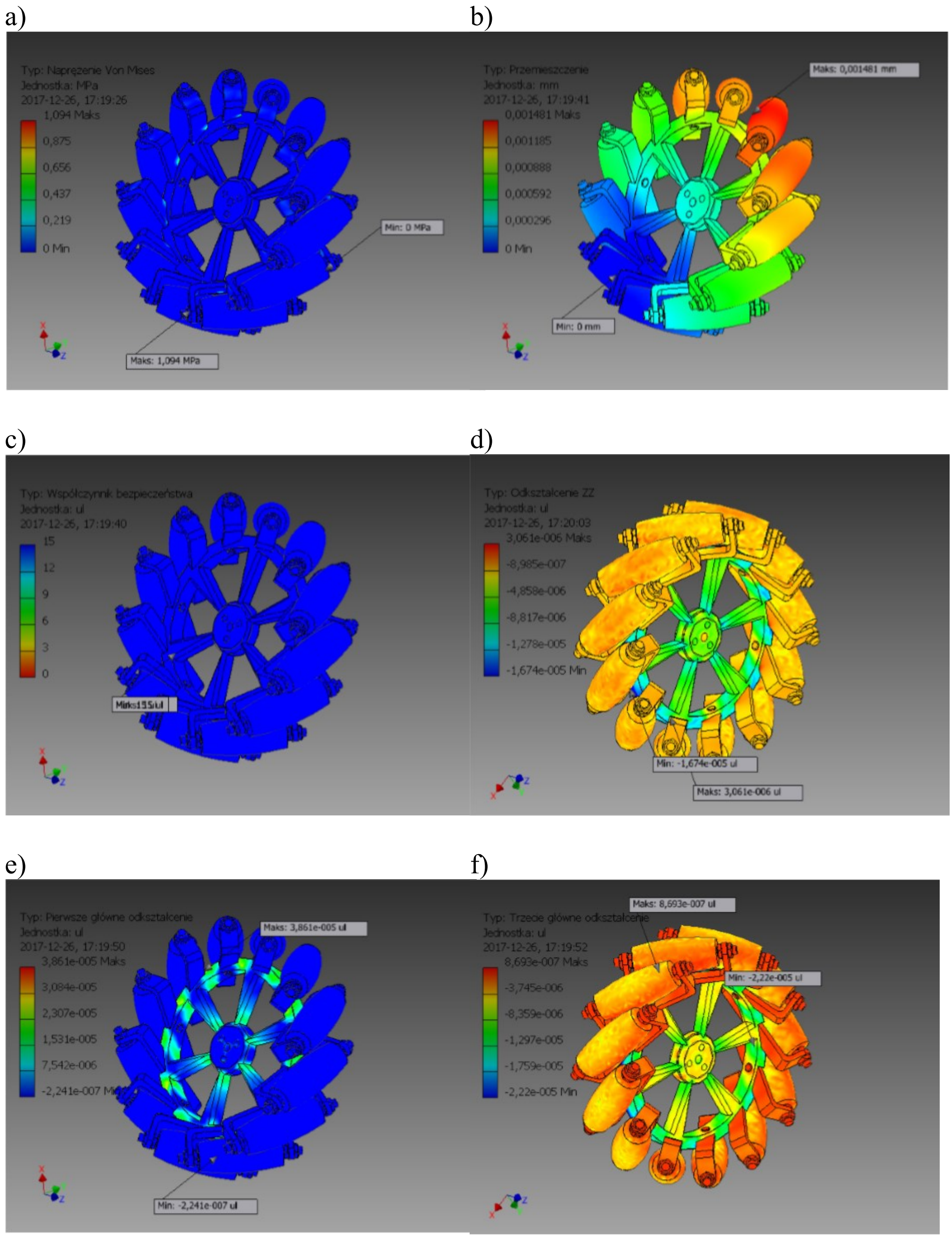

Fig. 8. FEM analysis results [9]; a) Von Mises maximum stresses are located at the positioning edges of the roll, b) Maximum displacement, c) Safety factor, d) Deformation in the ZZ axis, e) The first main deformation, f) The third main deformation

The analysis was carried out in static mode at maximum load. Maximum stresses in all possible directions are well below the strength limit of individual materials. The determined safety factor is 12, which means that the project will meet the assumed requirements. During normal operation, each of the components will work under a safe load, which will ensure durability and failure-free operation of the construction. The maximum displacement was 0.001481 mm, which is a very small value, not affecting the proper operation of the device.

4 Conclusions

The concept of using omni-directional wheels in an inspection vehicle comes from the need to obtain a large manoeuvrability of the vehicle in narrow and winding channels, in which a man is denied to access. The paper presents the construction of an inspection vehicle on omni-directional wheels, which enables inspections of ventilation systems and ceilings in old buildings. Manoeuvrability of the vehicle is ensured by designed omni-directional wheels with a diameter of 147 mm. The construction of the vehicle was designed based on existing inspection vehicles with very similar kinematics. The friction resistance in the roller of omni-directional wheels has not been calculated and in the dynamic analysis the friction between the roller and the ground should be taken into account. Nevertheless, the selected elements have the exact dimensions required, and the strength many times higher than required, as evidenced by the safety factor of 15. Generally available electronic and structural elements have been used, which allows minimising the cost of vehicle construction, while meeting the requirements for functionality and strength of the structure.

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