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PROTOTYPE OF 3D PRINTED MECANUM WHEEL

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Abstract

This article presents the results of work related to design, analysis and selection of the 3D printed mecanum wheels. Initial CAD model does not include material type of the rollers. Rollers were printed in 4 types of filament: PLA, ABS, PETG, FLEX. Analysis, tests and target destination of use allowed to choose the best material for rollers which will meet the usage requirements. Next step after choose material for roller were assembly of the wheels. Wheels were tested on the simple platform. Assembled 4 wheels (two left and two right) allowed to carry out tests to verify the mobility of the mobile robot and check the adhesion between rollers and ground.

Introduction

Mobile robotics is an increasingly important. They are used in a home use as autonomous vacuum cleaners, lawnmower, in industry as AGVs (Automated Guided Vehicle) (WILSON 2015), urban search and rescue robots (MATEJA, PANFIL 2021). Mobile robotics is moving towards electromobility and greater maneuverability. This second element is connected with use different types of wheel and joints, e.g. omnidirectional wheel, mecanum wheel, complex joint

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mechanisms used in modular mobility. Different construction of wheel allow for avoid additional elements like differential, steering system.

Mecanum wheels have rollers placed at an angle of 45 degrees (GFRERRER 2008). This kind of assembly allow for different movement of robot (straight, sideways, rotate) by starting different motor and direction of rotation (TAHERI et al. 2015). Robots which are equipped with mecanum wheels need at least 2 pieces of wheels – right and left. However, not all combinations of Mecanum wheels can implement omnidirectional motion, and the arrangement of Mecanum wheels also influences the mobility performance of the robot (HE et al. 2019, LI et al. 2019). Configuration of the mecanum robot can be centripetal or symmetrical rectangular. Figure 1 presents the typical four-Mecanum-wheel configuration on mobile robot.

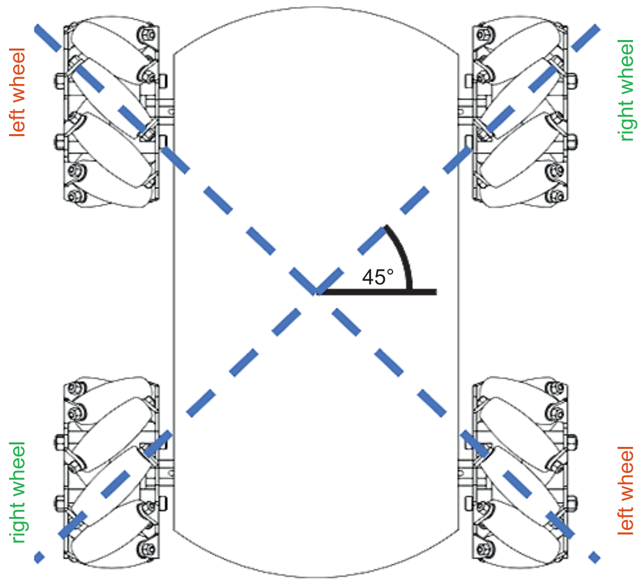


Fig. 1. Structure of the vehicle based on the four mecanum wheels

The tire and the rim are the elements of the drive system that have direct contact with the road surface. It cause that tires all time are improved particularly when considering safety. Technical condition identification of the mechanical objects can be realized with material structure non-invasive diagnostic methods, including forced vibration excitation, data collection, and artificial neural network (BORECKI 2021).

In currently produced cars during the ride, in-vehicle equipment is able to data control from sensor nodes which are located inside the tires. They are responsible for data acquisition, processing, and transmission data which, if necessary, notify the driver of, e.g., low tire pressure (ERGEN et al. 2009). More sensor allow for the more precisely and reliability data acquisition.

Sensors and non-destructive testing allow for continuous improvement of tires and rims, but in order to develop the target product, it turns out to be necessary to make prototypes. One of the methods that allows additive manufacturing is 3D printing. This method is not perfect for industry, but it works great in new concepts.

Depending on the purpose of the mobile robot, the mecanum wheels can be made of various materials. 3D print allow for fast manufacturing of elements, mechanisms, and connections (What are the Advantages and Disadvantages of 3D Printing?). Fast prototyping enable quick corrections, change of dimensions and fits. All changes are low-cost what is a big advantage. Depending on the purpose of the element, we can choose the type of material, pattern and percentage of filling (FERNANDES et al. 2018). All these features affect the mechanical strength of the element.

The goal of the work is design and manufacturing of the 3D printed mecanum wheel and next verification of this wheel on the mobile platform. During the work a few types of filament were taken into account as a roller of mecanum wheel. Printed mecanum wheels were tested on the mobile platform which allowed for research of the drive by change of movements, precision of movements, and repeatability of movement.

Model of the wheel

Concept model

The works began with develop a concept of mecanum wheel. Designed model of wheel is presented in the Figure 2. Mecanum wheel consist of two main elements. First is a rim which is composed of inner plate, outer plate, and hub for mounting the motor shaft. Second are rollers which are in contact with the ground. These parts are connected by a bearing-mounted shaft of rollers.

Wheel parameters which was developed are presented below:
- wheel outer Diameter – 100 mm;
- wheel width – 50 mm;
- number of rollers – 9 pcs;
- roller maximum diameter – 19.5 mm;
- roller minimum diameter – 14 mm;
- roller height – 47 mm;
- bearing type – ball bearing 684 ZZ.

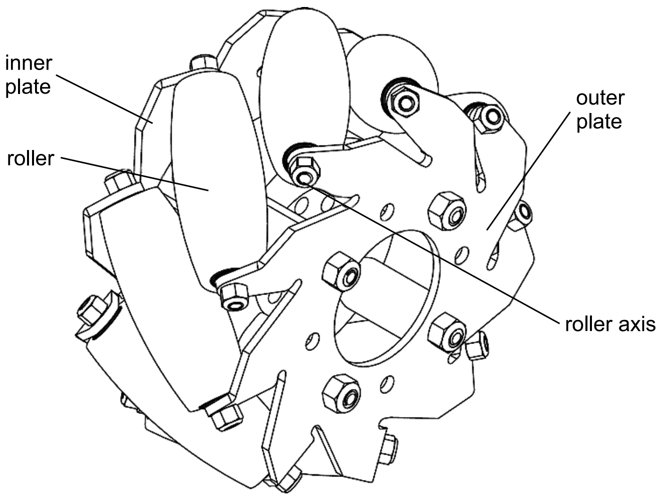


Fig. 2. Design of mecanum wheel

Material

Rims have to ensure enough stiffness of the wheel. Material for this part should be mechanically strong. As material for plates and hub I decided to use ABS (Acrylonitrile Butadiene Styrene). The main advantage of this material is high strength, but the disadvantage is high shrinkage during the print.

Rollers should provide good coefficient of friction with the ground. As the material for the roller I took into account ABS, PLA (Polylactic acid), PETG (Polyethylene Terephthalate Glycol), TPU (Thermoplastic Polyurethane). In the Table 1 data of advantages and disadvantages of 4 types of filament are placed.

To select the final material for the rollers, the best solution seemed to be to print the rollers in all 4 types of material (Fig. 3) to check properties of samples. During analysis it was decided that PLA, ABS, and PETG has good impact resistance. However, the coefficient of friction was a big drawback. The rollers slipped over most of the surfaces, which could at a later stage result in a incorrect working of the mecanum wheel.

Despite the lower resistance to damage and the effects of certain factors, the flexible filament presented its best. I decided to print all the roller from TPU. Flex filament was resilient and able to change the shape, which made it adhere much better to the surface. Higher coefficient of friction between rollers and surfaces should provide appropriate work of the wheel.

Table 1

Filament properties

Advantages	Disadvantages
	PLA
Low material shrinkage	possibility of deformation under the influence of high temperatures
Durable	limited flexibility
Insoluble	
	ABS
High strength	soluble in acetone
Better temperature resistance than PLA	high material shrinkage
	PETG
Good strength properties	moderately difficult to use
Insoluble	
	TPU
Resistance to low temperatures	not resistant to: acids, hot water, alcohols
Good flexibility and elasticity	less resistant to damage than PLA, ABS and PETG
Chemical resistance - greases, oils	

Fig. 3. Rollers printed in 4 filaments: PLA, ABS, PETG, TPU

Printed mecanum wheel

All printed parts was assembled (Fig. 4). In order to test the proper operation of the mecanum wheels, four wheels were assembled - two right and two left - and then adjust to the mobile platform. Hub of the mecanum wheel were mounted to the shaft of the electric motor to verify correct operation.

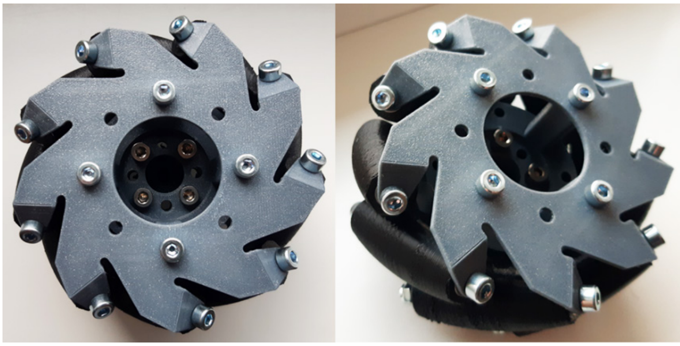


Fig. 4. Assembled mecanum wheel

Verification

Mobile platform

The mobile platform for tests should enable checking the correct operation of the printed mecanum wheels. Model of the platform is presented in the Figure 5. Length of the platform is 220 mm, width 150 mm (260 mm with the wheels), distance between axis 110 mm, total weight with all equipment 2.45 kg. The mobile platform was also manufactured using the additive manufacturing. I used a ABS to print the construction of the platform.

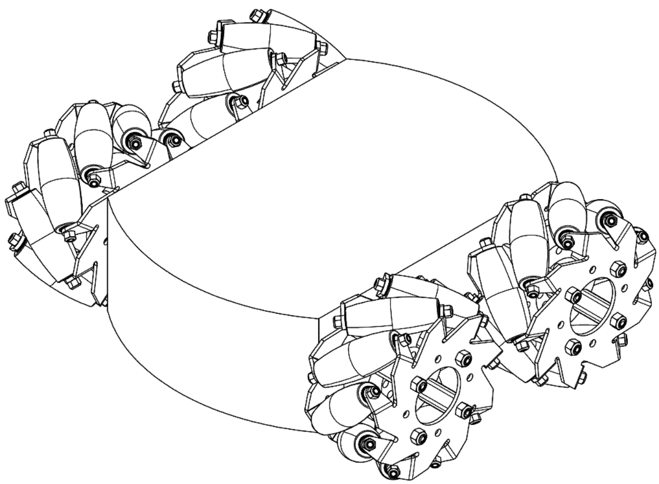


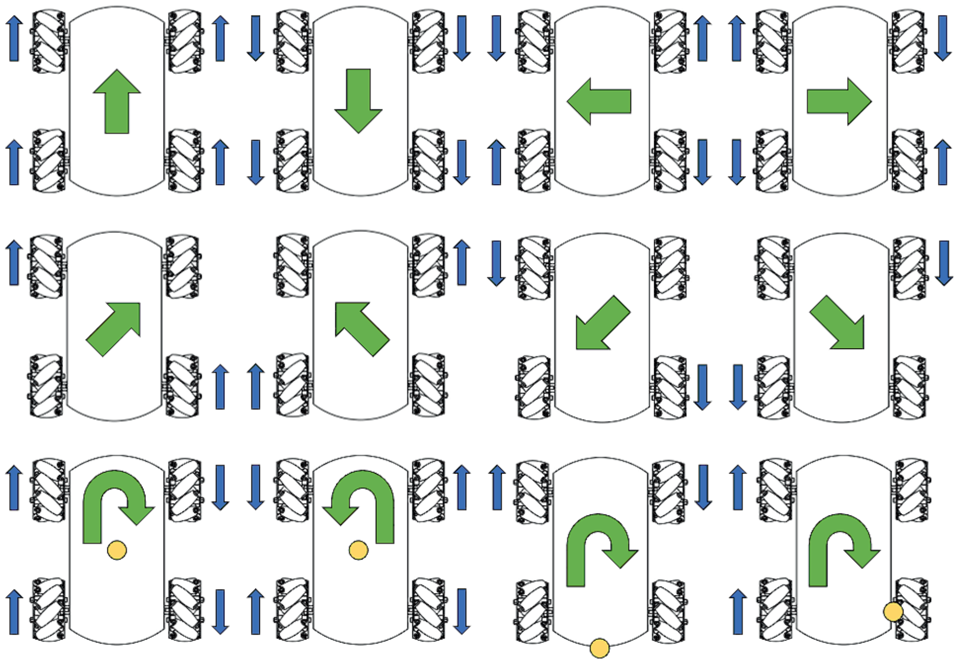
Fig. 5. Designed mobile platform

Stepper motors were used as a drive for a platform. This kind of motors have many advantages e.g.:

- allow for precise positioning and repeatability of movement,
- excellent response to starting/stopping/reversing
- high torque at startup and low speeds

These features made the choice of this type of electric motor. For application I used stepper motor NEMA 17 - HS13-0404S1. Step angle is 1.8 deg, holding torque is 0.26 Nm, weight 230 g. Low mass of the platform allow NEMA 17 put in motion the vehicle.

All moves which platform is able to done are presented in the Figure 6. Mobile robot has three degrees of freedom. It allows movement in a straight line in eight directions and rotate around its own vertical axis in three points of rotation. These moves was tested during conducting the verify tests. All moves were performed on the flat surface.



* blue: wheel drive direction; green: vehicle moving direction; yellow: point of vehicle rotation
Fig. 6. Four Mecanum wheels configurations

Verification – tests of the wheels on the mobile platform

To verify the correct operation of the mobile platform and mecanum wheels the tests were prepared (Fig. 7). Tests were divide such that platform performed each kind of movement on eight types of surfaces. Surfaces which were taken into account during tests could be use as ground for the mobile robot in the intended use. Table 2 presents results of the surface test with remarks on the feasibility of the movements, problems while driving.

Fig. 7. Mobile platform during conducted tests on different surfaces

Table 2

Surface test results

Surface	Mobility and stability of all movements	Remarks
Concrete	good	the rough texture of the concrete damaged the rollers after a few passes. The friction between the rollers and the surface prevented a smooth sideways drive
Ceramic tiles	average	the smooth texture of the tiles resulted in a lack of smooth movement, especially when moving sideways
Rubber	very good	high adhesion between the rollers and the rubber/resin allowed for smooth movement in every direction
Resin floor	very good	
Wood	good	on the wood/OSB mobile platform was able to move smooth in every direction. Test was performed on planed wood. The result may differ on unplaned wood, veneered wood, etc.
OSB	good	
Floor panels	low	the slippery texture of the floor panels resulted in a lack of smooth movement, especially when moving sideways. Test was performed on the laminated floor panels

Table 3 shows on which surfaces the mobile platform will be able to move in which directions. The goal was to obtain knowledge which surfaces allow mobile platform to performance the movement in all directions or what cause the impossibility of perform the movement.

Table 3

Smooth movement test results

Surface	Straight drive	Rotate	45 degree drive	Sideways drive
Concrete	✓	✓	✓	×
Ceramic tiles	✓	✓	✓/×	×
Rubber	✓	✓	✓	✓
Resin floor	✓	✓	✓	✓
Wood	✓	✓	✓	✓/×
OSB	✓	✓	✓	✓/×
Floor panels	✓	✓	✓/×	×

During the smooth movement test there were a few several significant changes have been noticed:

- sideways driving was a minor problem – not always mobile platform move in a straight line. Sometimes this movement was a spline line;
- oblique movement was fine, but sometimes angle was not equal 45 degrees;
- rotation was not always relative to the rotation point.

During the tests I noticed that if roller is load with high force (the gravity of the platform) it can change the shape of cross-section. Rollers infill was 15% in pattern of grid. When the roller was loaded and the point of contact of the roller with the surface was reinforced (infill line is perpendicular to loaded surface) than the deformations were small or even absent (Fig. 8*a*).

Fig. 8. Roller load: *a* – infill line is perpendicular to loaded surface, *b* – infill line is not perpendicular to loaded surface, *c* – infill equal 100%

When the roller was loaded and the point of contact of the roller with the surface was not reinforced (infill line does not exist or occurs at a certain angle – not perpendicular to loaded surface) than the deformations are significant (Fig. 8*b*). It cause that cross-section of roller is not circular but ellipse.

To solve this problem different infill pattern, percent of infill (Fig. 8*c*) or outer perimeters of each layer can be used. It is a significant in case when the force of gravity acting on the vehicle will be able to deform the shape of roller.

Discussion and conclusions

Works which were carried out allow us to perform the tests of the 3D printed mecanum wheel. Stepper motors which transfer torque to wheels allowed for smooth movement, quick change of movement, precise positioning, and repeatability of movement. 3D printed rollers had not got problems with mobility in the environment which provide enough friction between rollers and ground. Rubber and resin was the best from the tested surfaces. All the movements were possible to perform without the problem. Drive on the wood, OSB, and concrete were satisfactory but these kinds of surfaces resulted in less accurate driving. Sideways movement was not always 90 degree to the straight drive. The reason can be rough texture of concrete which caused damage the surface of the rollers. In case of wood and OSB the reason can be lower friction coefficient. Ceramic tiles and floor panels had smooth or even slippery texture. It caused that sideways drive tests could not be done. Oblique drive had some problems with angle of drive. This value not always was equal 45 degree.

It is believed that some problems with drive is connected with the assembly of the mobile platform and the mecanum wheels. All components were made by additive manufacturing. Side walls of mobile platform were printed from ABS. ABS is a material which high shrinkage. It could caused that walls had different dimensions or slight offsets causing the axes are not centered. Also 3D printed mecanum wheels – TPU rollers and wheel rims from ABS – could have similar discrepancies.

Another problem which can cause not enough precisely movement is elliptical shape of rollers when force of gravity acting on them in some parts of the cross section. It were caused because of 15% infill in pattern of grid. In the case of the operation of lower loads, such filling should be sufficient. For other cases there should strive to increase the infill and to change the infill pattern to sufficient results.

The goal of 3D print is fast ability to prototyping. 100% TPU infill is time-consuming and unprofitable. Performed tests allowed to carried out tests of 3D printed mecanum wheel and look out weaknesses of this method for this kind of elements. In the built mobile platform we can refine some elements.

First is change the material of the platform frame and walls. Instead of ABS better will be wood, polymer or aluminium with CNC drilled holes and contours. Second is change the infill percentage and infill pattern. Further works allow to determine whether these changes are sufficient and allow for more precise movements.

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