THE MECHANICAL DESIGN AND REALIZATION OF THE OMNIDIRECTIONAL MOBILE ROBOT ODIN

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This article describes the process of mechanical designing for an omnidirectional mobile robot Odin. It provides an explanation of the relation between a mobile robotic stair climbing system with shaped wheels and omnidirectional wheels, which are used together in a combined locomotive system. Only a conception study of the whole system is presented. Testing of mechanical parameters and driving abilities of the omnidirectional wheels was performed on a constructed simplified chassis. There was created an experimental calculation for a flange with a clamp connection linking a 3D model. This simplified chassis was the basis of a mobile robot named Odin, which was further improved by mounting a modular manipulator Schunk on its top. The article concludes with an evaluation of the achieved progress and indicates ways of further possible development for the omnidirectional mobile robot Odin.

KEYWORDS
mobile, omnidirectional, robot, wheel, trajectory, testing, Odin

1. INTRODUCTION

Wheels are statistically most commonly used in chassis design of mobile robots as a means that provides ground surface contact and implements energy transfer required for the movement. The difference in wheeled mobile robots chassis primarily lies in the requirement on their function and type of the environment where they are used. A special type is an omnidirectional wheel. Their use brings other possibilities of chassis movement, where the tyre gave way to rolling elements freely rotatable along their axis. The elements are evenly placed along the whole wheel perimeter. Currently, there are two wheel constructions according to the position of the rolling elements axis – either perpendicular to the disk axis (type Stanford), or diagonal (type Mecanum). When using wheel mobile robots chassis for indoor movement, the ability to overcome obstacles (mainly staircase) is limited by construction requirements. The radius must be bigger than the height of one stair. The research at the Department of Robotics analysed special shaped wheels for use in indoor environments. Finding a suitable shape was done by synthesising the reference curve in the form of a logarithmic (exponential) spiral. When overcoming stairs, the resulting movements significantly eliminate centre of gravity oscillations compared with other wheel chassis. The logarithmic wheels cannot be used for movement on flat surfaces, because the non-circular shape causes extreme unwanted oscillation. Combining the characteristics of omnidirectional and logarithmic wheels resulted in creation of a concept of a combined system [Krys 2014, Eich 2008].

2. CONCEPT OF A COMBINED LOCOMOTIVE SYSTEM

Based on this fact, concepts that can combine advantages of using logarithmic wheels to climb stairs and omnidirectional wheels to drive on flat surfaces were suggested. Omnidirectional (Mecanum-type) wheels were chosen due to limited space in the chassis. Based on a raw 3D concept made in Creo Parametric 2.0 and preliminary calculations of drives, a solution was proposed, using low-velocity rotary hydraulic drives for actuation of the logarithmic wheels. These drives are able to develop high torques at low speeds and are economically more profitable than electric drives. The required speed for this application is about 30 rpm, which is a critically low value for the control of these drives. Laboratory tests to determine characteristic behaviour in low revolutions on a test stand confirmed the concerns. The complexity of the solution of the combined system resulted in its division into two separate research areas. The first area deals with the development of omnidirectional chassis for testing mechanical parameters and drive accuracy depending on the load and the position of the center of gravity. The second area covers research of rotary hydraulic drives on a laboratory stand, primarily for independent control of several drives in low revolutions.

The functioning of the combine system is divided into two drive modes. Omnidirectional wheels are ejected for movement on a flat surface (Fig. 1). Having approached stairs, all omnidirectional wheels are retracted and only logarithmic wheels are used (Fig. 2) [Krys2014, Herbert 2008].

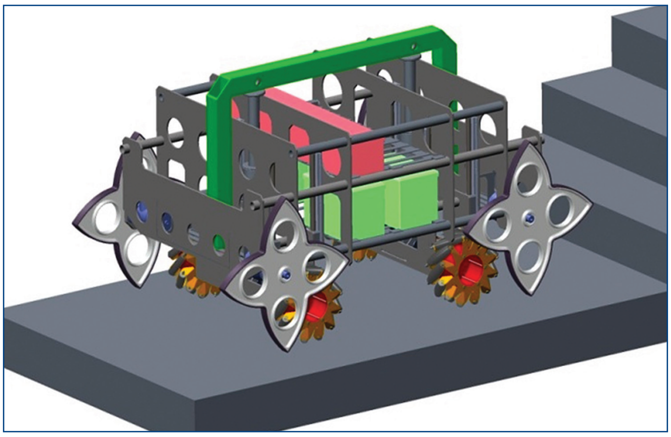


Figure 1. Drive mode on a flat surface

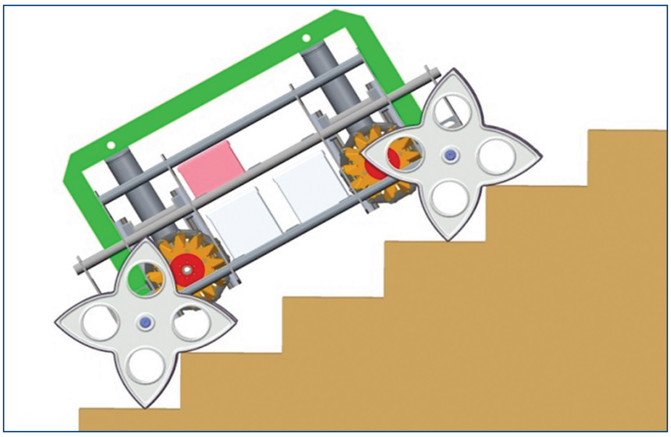


Figure 2. Drive mode on a staircase

3. SIMPLIFIED CHASSIS WITH OMNIDIRECTIONAL WHEELS

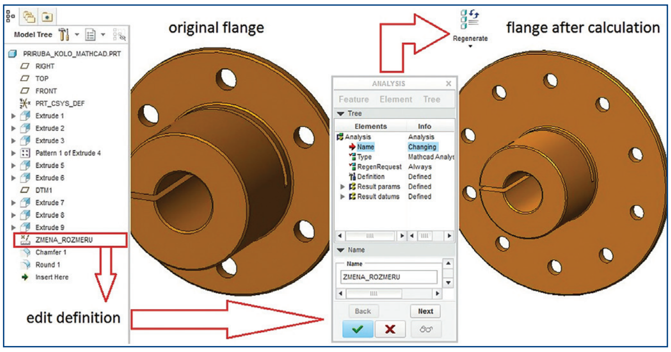
A simplified chassis with omnidirectional wheels has been designed based on the requirements and specifications of its use [Doroftei 2007]. The basic requirement is its easy and assemblable frame construction, use of off-the-shelf omnidirectional wheels, and indoor application. Specifically, it concerns Mecanum wheels sized 10" produced by Andy Mark. Other mechanical chassis components, such as bearing housings, shafts and drive holders, were designed and produced in a school workshop. Based on the determined limit chassis weight and speed requirement, 4 different drive modes were used to perform a drive design calculation.

DC brushless motors Maxon RE 35 90 W with planetary gear GP 42 with speed reduction in the ratio of 36:1 were selected as sufficient according to the calculation.

3.1 Wheel flange design

When designing the drive, a methodology of a general flange design with clamp connection was developed. It was supported by a calculation in MathCad, which is parametrically linked with the model of the clamp in Creo 2.0. This link enables to automatically generate a basic 3D model of the clamp or to change it based on the design calculation. The calculation is verified in the torque range 1 – 25 *Nm*. In addition, it checks and calculates the clamping force, length of the hub and screws. Continuous check of user input by "OK" and "FALSE" if the limits have been exceeded. The screw torque is based on the axis force in the screw and the preload value acquired in an experimental comparison with the torque values of connections with a similar construction. The calculation being done, it is adjusted by a correction coefficient.

At the end of the calculation, the user is familiarised with the main force parameters, which are exported to Creo 2.0. Generating a basic 3D model in Creo 2.0 is controlled by several relations. The screw preload force and the transferred torque from the MathCad calculation are the input definition of the strength analysis of the flange. A simple change of the 3D model in Creo 2.0 is possible by refreshing the source of the MathCad calculation (Fig. 3.)



Elements	Info
Analysis	Analysis
Name	Changing
Type	Mathcad Analys
RegenRequest	Always
Definition	Defined
Result params	Defined
Result datums	Defined

Name: ZMENA_ROZMERU

Figure 3. Change of the 3D model

3.2 Electronic control system

A proposed electronic control system consists of four speed control units Escon 50/5 for each of the Maxon drive. The unit can process only analogue values, which required adding a programmable module i7024 with an A/D converter working under voltage of –10 V to +10 V.

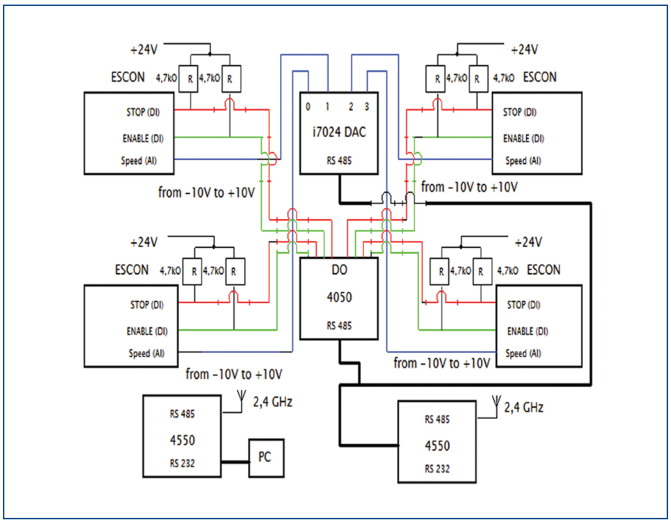


Figure 4. Operating principle of electronics

Additional programmable units ADAM 4050 and 4550 were installed for Wi-Fi communication with a PC and to provide "Enable" and "Stop" modes of the drives. The Enable mode enables the drives to rotate by changing the voltage. When it reaches 0V, the drives are stopped, but the analogue signal does not allow reaching exactly 0V. Connection and operating principles of the components are depicted in Fig. 4. The whole chassis design in Fig. 5.

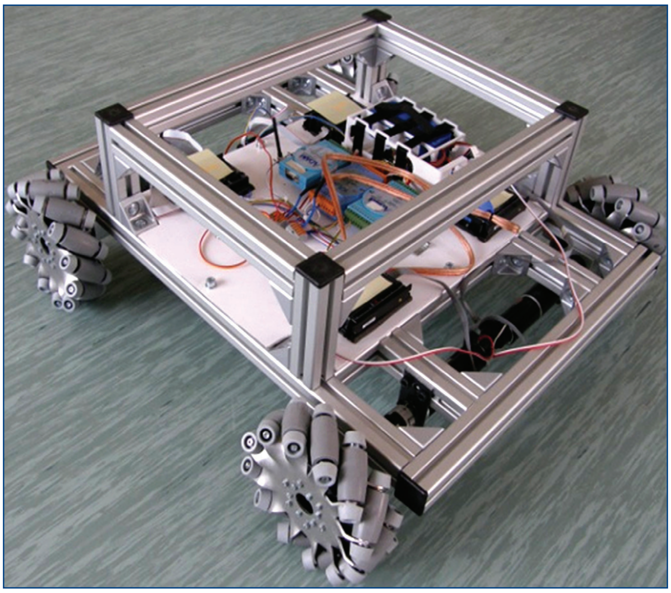


Figure 5. Simplified chassis

Based on the prepared electrical wiring on a simplified chassis, a control application was developed in Microsoft Visual Studio in the programming language C#. The chassis is controlled by using standard mathematical relations [Tlale 2008] and kinematic equations for omnidirectional movements. It is derived from the angular velocity of each drives ($\omega_1 - \omega_4$), radius of wheel ***R***, width (***W***) and length (***L***), speed of movements in x direction ($\boldsymbol{v}_x$) and y direction($\boldsymbol{v}_y$) and angular velocity perpendicular in a relation to the chassis (θ).

$$\begin{pmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{pmatrix} = \frac{1}{R}\begin{pmatrix}1 & 1 & -(L+W)\\ 1 & -1 & -(L+W)\\ 1 & 1 & (L+W)\\ 1 & -1 & (L+W)\end{pmatrix}\begin{pmatrix}v_x\\ v_y\\ \theta\end{pmatrix} \tag{1}$$

The resulting values of individual drive speeds are sent to the above-mentioned D/A converter. The chassis can be controlled interactively by a gamepad. Special pre-prepared demo modes (trajectory following) can be chosen in the control application.

4. OMNIDIRECTIONAL MOBILE ROBOT ODIN

The experience with the control and designing of a simplified omnidirectional chassis led to changes and improvements of the chassis. The main improvement consisted in installing a modular manipulation arm Schunk with 6 degrees of freedom. The design of deployment of the manipulator in the chassis was performed by a study of its movement range based on a 3D analysis on Creo 2.0. Several positions that represented extreme ranges were selected. The range is determined by the centre of the jaws' grasp point. A movement kinematic analysis provided a model of its working range. The working range under the manipulator base is 250 mm and the maximum working radius is 637 mm.

In order to secure stability, it was necessary to check the centre of gravity position under maximum reach of the arm holding an object of 3 kg. The centre of gravity was located 145 mm behind the front wheel axis without any contra counterweight (Fig. 6).

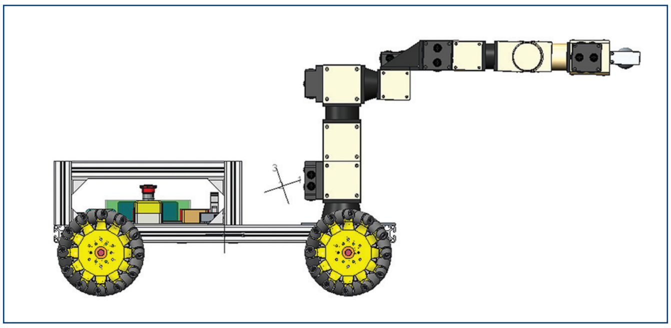


Figure 6. The centre of gravity

While integrating the modular manipulator Schunk, chassis covers were also designed and implemented. The aim was to create covers that meet the safety function from the point of view of waterproofness and mechanical security of individual components. Another requirement was their easy mounting and dismounting in the case of maintenance. Electronic connections and powering up the power source was also carried out.

A concept of a sensory subsystem was also created for the mobile robot Odin (Fig. 7). It consists of two 2D scanners and a sensor Microsoft Kinect. The camera subsystem uses two camcorders Ace acA1300-30uc to connect stereovision.

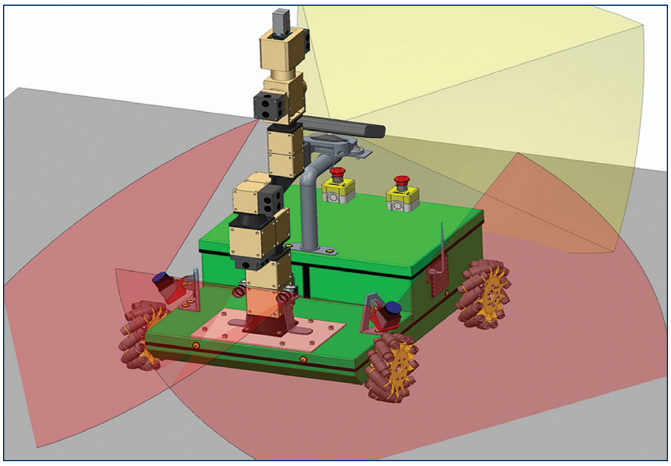


Figure 7. Sensory subsystem

5. TESTS

The simplified omnidirectional chassis and the developer omnidirectional robot Odin underwent the same test of following a predefined trajectory. Driving modes were tested based on changing the loads on individual axles. Using various positions of the arm as well as its removal from the chassis resulted in the change of the centre of gravity and load on individual axles. (Fig. 8).

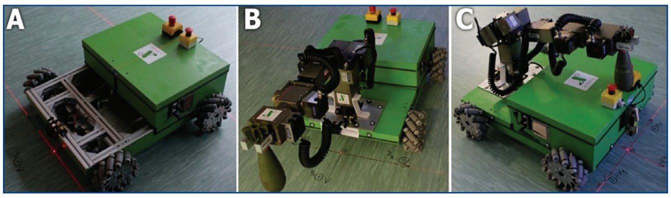


Figure 8. Odin testing configurations
(A –no load, B – load on front, C – load on back)

5.1 Methodology of testing

The goal of chassis tests was to determine the driving accuracy on various types of trajectories. Driving on each of the trajectories was measured in several cycles. The tests began with a single cycle, followed by tests with three cycles and finally there were five cycles. The accuracy of adhering to the required trajectory was measured using the Bosch GLL3-80360-degree 3-plane levelling and alignment line laser in combination with a cross laser.

It was necessary to prepare measurement points on the chassis. The centre of the chassis was determined (290 mm) and two point lasers were placed there (one at the front and one at the back of the chassis). The measurement was always carried out after the required cycle(s) had been completed. The measured values were the *x*-axis and *y*-axis deviation between the measured point on the chassis and the measuring point on the floor in relation to the selected Cartesian coordinate system (Fig. 9.).

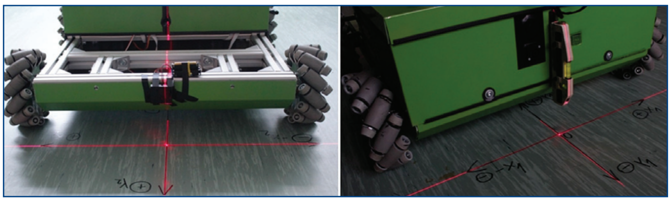


Figure 9. Measuring of the starting position of the chassis

Fig. 10 illustrates the predefined drive trajectories and the position/orientation of the chassis during the movement (depicted in grey).

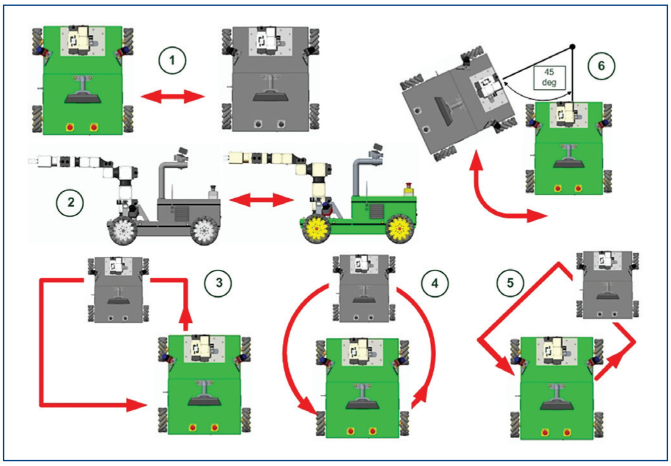


Figure 10. Predefined drive trajectories

5.2 Test results

The following graphs show positions of the reference line on the chassis (created by connecting the two measuring points) at the starting position (continuous line) and its deviation after 1 (dashed line), 3 (doubled line) and 5 (dot-and-dash line) cycles. Due to the large amount of data, only some combinations are presented (Fig. 11.).

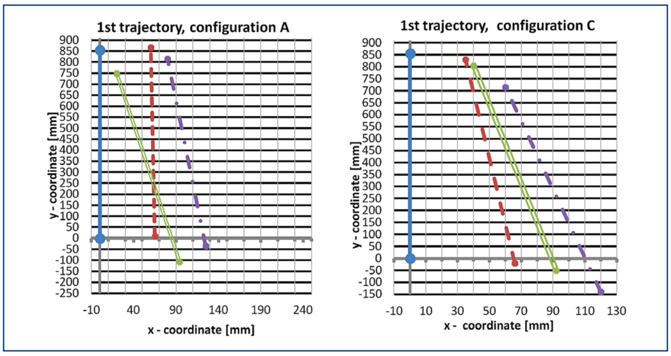


Figure 11. Graphical comparison of the results

6. CONCLUSION

Based on newly acquired findings from the concept study of the combined system, a new solution for an independent omnidirectional chassis was developed in order to test and verify characteristics of omnidirectional wheels. A prototype was designed for such reasons. Along its designing, a general methodology of designing a clamp connection was created, when a design calculation in MathCad is transferred to Creo 2.0 to automatically generate a 3D model, which is finally tested in the strength analysis. Installing a manipulation arm Schunk, covering, and necessary adjustments in electronic wiring resulted in creation of a mobile omnidirectional robot Odin. Testing the trajectory drive accuracy was done for both versions, which were graphically compared.

Graphical illustrations of the positions on trajectory #1 for configuration A and C of the chassis (see Fig. 8). The point [0, 0] always represents the starting position of the back part and the point [0, 856] represents the starting position of the front part of the chassis. Due to an unbalanced load on individual axles, the back part has greater momentum than the front part. Another factor explaining the deviations from the initial position, which are also visible in other tests, is the fact that the size and shape of individual trajectories are specified in the control application by velocity vectors (with a direction and amplitude) and durations (time). The resulting wheel speed, which corresponds to certain values of the control voltage, is inaccurately interpreted during the conversion to an analogue value for the drive control units, thus the wheel does not turn at the desired speed. The return of the chassis to its starting position is also influenced by the current angle of the wheels and the possibility of sliding on individual rolling pins, which cannot be avoided without positional control. A significant role is played by the used speed parameters and the sizes of trajectories in relation to the momentum of the chassis. Therefore, it was decided to replace the current inaccurate analogue speed control done by Escon units with a positional control ensured by Epos2 control units.

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