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# DESIGN AND ANALYSIS OF A NEW TYPE OF MECANUM WHEEL

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**Abstract** - Mobile robots are very complex and they face a lot of challenges. One of the main challenges is the capability to move in tight areas. This capability mainly depends of the design of the wheel. In this project, the main objectives are giving a better maneuverability for wheelchairs, and consequently improve the life of the users. That is the reason why mecanum wheels were chosen for this project. This paper is providing information about the new mechanical design made and how to define the best possible design for a roller with a circular shape.

**Keywords** - Mecanum Wheels; Omnidirectional;Rollers; Wheelchair;

## I. INTRODUCTION

Recently, many researchers are focused on researches related to the use of wheeled omnidirectional running mechanism. Especially, mecanum omnidirectional vehicles have been widely used in military, storage and transportation, social services, and other fields [1]. Compared to conventional vehicles, omnidirectional robotic vehicles possess multiple advantages in terms of their mobility in narrow spaces and crowded environments. They have the ability to easily perform certain tasks in congested environments foreseen with static obstacles, dynamic obstacles or narrow areas [2]. Usually such environments can be found in factories, workshops, warehouses, hospitals, etc. Omnidirectional vehicles have been traditionally designed to operate on smooth/hard/flat surfaces. Very little effort has been dedicated for developing such vehicles to move on complex rough terrains such as rocky surfaces [3],[4]. Omnidirectional vehicles have 3 degrees of freedom (DOF) on the ground. They can achieve longitudinal motion, lateral motion, center-point steering motion, and any composite motion of above three, so they are suitable for highly maneuverable, narrow or accurate positioning occasions [2]. In the omnidirectional wheel, the wheel velocity can be divided into the components in the active direction and in the passive direction. The active component is directed along the axis of the roller in contact with the ground, while the passive one is perpendicular to the roller axis [2]. The design of a simple mecanum wheel is shown in the Figure 1.When a mecanum wheel is rotating, at least one roller, and maximum of two rollers are in contact with the ground.

However, theoretically, just one point of the roller is in contact with the ground. The area of this surface traverses the roller from one side to another, depending on the sense of wheel rotation. This makes the direction of the traction force be done by the traversing sense of the contact of the roller with the surface.

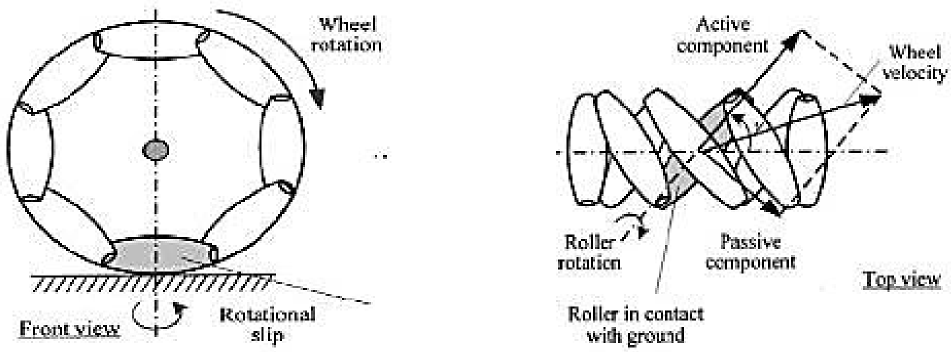


**Figure 1 – DOF's in Mecanum Wheel**

On the tests conducted for several researchers across the world, it had been noticed that the biggest challenge for the Mecanum wheels is the inability to overcome obstacles during the lateral motion and their inability to move laterally in sand, as the sand or dirt piles up on the side of the vehicle preventing the vehicle from moving after the dirt pile reaches a certain height [3],[5]. Based in these problems, one of the main objectives of our research was to design a new type of Mecanum wheel able of overcoming those drawbacks.

## II. CONVENTIONAL MECANUM WHEELS

The mecanum wheel was invented by the Swedish engineer BengtIlon in 1973. It consists of a set of k congruent rolls placed symmetrically around the wheel body. The face of each roll is part of a surface of revolution R whose axis b is skew to the wheel axis a [6]. Many similar designs have been proposed, however these design differ in the number of rollers, the way the rollers are attached to the hub, the relative angle of the rollers with respect to the wheel, materials used, etc [3]. Despite the large number of designs, all designs have used the same principles, and as a result, all current designs perform poorly on rough terrain. Despite much higher maneuverability than common wheeled vehicles, the wheeled omnidirectional vehicles still have significant limitations in engineering applications [1]. Some of the main problems are as follows:

**Large Vibrations –** The Mecanum wheel is almost rigid and its ground contact roller is discontinuously changing.

**Limited Loading Capacity** – The ground contact area of the Mecanum wheel is extremely small, so the ground pressure is extremely large in the case of heavy loads.

Another drawback related to a vehicle using Mecanum wheels it is the slippage, and as a result, with the same amount of wheel rotation, the lateral travelling distance is different from longitudinal traveling distance.

A traditional Mecanum wheel is presented in the figure 2. This design has a good load carrying capacity, however if the vehicle makes contact with some inclined or uneven surface, the rim of the wheel can make contact with the surface instead of the roller, and this way preventing the wheel of operating correctly.

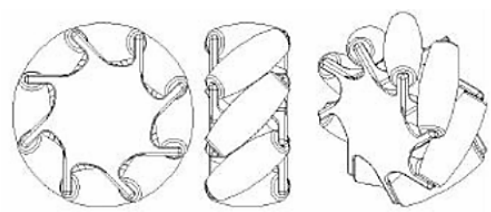

**Figure 2 – Conventional Mecanum Wheel [1]**

## III. ROLLERS DESIGN

When designing a new drive system, one of the main worries you must have it is to guarantee the motion continuity. The real meaning of this is that the contact line and the number of the rollers is enough to cover the wheel's curve, in this case, a circumference. Besides, there are a certain number of rollers that makes the ideal proportion between having a small number of large rollers per wheel, and having a large number of small rollers per wheel [2].

In order to calculate the moving continuity, which is represented by ε, it is used the equation 1.

$$\varepsilon = \frac{N(y-2\theta_o)R}{2\pi R} = \frac{N}{2\pi}(y - 2\theta_o) \quad (1)$$

In the equation (1), five parameters are shown. Those parameters are used to design the rollers for the circular wheels parts (R, N, ε, y, $\theta_0$). R is the overall radius of the wheel; N is the desired number of rollers, y is the angle of the helical line rotated around the wheel's z-axis, as can be seen in the Figure 3; and $\theta_o$ is the initial value of the angle between the starting motion of point C moving along the helical line (Fig. 3).

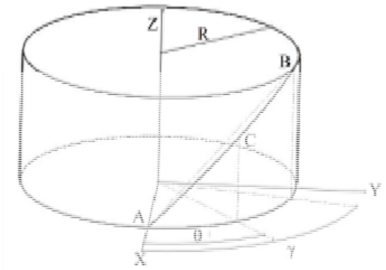


**Figure 3 – Rollers Scheme Configuration [3]**

In the Equation (1), a value of ε<1 indicates the rollers will be too small in relation with the number of rollers in the wheel (thus, the length of the roller will be too short and will not work). However, in the case when ε>1 the motion continuity can be guaranteed, but the ideal value it would be if ε=1, because in this case the rollers length satisfy all desired wheel characteristics. Then, the value for ε must be as close as possible of 1, because as ε grows the roller's length increases making the wheel thicker and the generatrix tends to oscillate making the curve inadequate. In this paper, our new design proposed is using a circular shape for the rollers, and the modification happen in the way how the rollers are connected to the hub and the materials used. An illustrative image of the new design proposed can be seen in the figure 4.

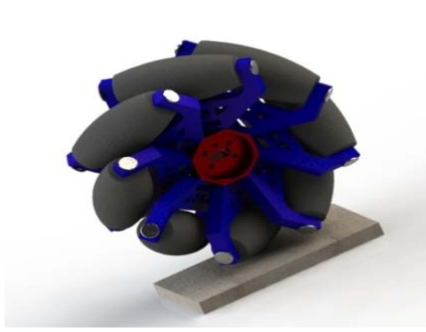

**Figure 4 – Proposed Wheel**

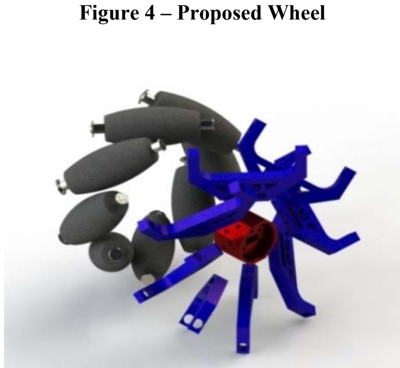

**Figure 5 – Exploded view**

In this design, the circular shape is being used to define the shape of the rollers. In this case, it is necessary to define the coordinates A, B and C of the figure 3. Those points are defined as follows:

$$A(R,0,0), B(R\cos\gamma, R\sin\gamma, R\gamma), \\ C(R\cos\theta, R\sin\theta, R\theta)$$

Then, the following definitions are used to establish the vector $\overrightarrow{AC}$ and vector $\overrightarrow{AB}$.

$$\overrightarrow{AC} = \begin{Bmatrix} R(\cos\theta - 1) \\ R\sin\theta \\ R\theta \end{Bmatrix} = \begin{Bmatrix} P_1 \\ P_2 \\ P_3 \end{Bmatrix}$$

$$\overrightarrow{AB} = \begin{Bmatrix} R(\cos\gamma - 1) \\ R\sin\gamma \\ R\gamma \end{Bmatrix}$$

The unit vector parallel to$\overline{AB}$ is denoted as:

$$\vec{u} = \frac{\overrightarrow{AB}}{|\overrightarrow{AB}|} = \frac{\overrightarrow{AB}}{R\sqrt{2 - 2\cos\gamma + \gamma^2}} = \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix}$$

Where: $u_1 = \frac{\cos\gamma - 1}{D} u_2 = \frac{\sin\gamma}{D} u_3 = \frac{\gamma}{D}$

And $D = \sqrt{2 - 2\cos\gamma + \gamma^2}$

Using this information, it is possible to find the curvature of the roller with the best efficiency. However, in order this there is a need to rotate vector $\overrightarrow{AC}$ around vector $\vec{u}$ by an angle equal to $\tau$ [3]. This angle will generate several contact-lines around vector u. Below, the following equations are obtained using this method.

$$\begin{aligned} P_1' = {} & [\cos\tau + u_1^2(1 - \cos\tau)]P_1 \\ & + [u_2u_1(1 - \cos\tau) - u_3\sin\tau]P_2 \\ & + [u_3u_1(1 - \cos\tau) + u_2\sin\tau]P_3 \\ P_2' = {} & [u_2u_1(1 - \cos\tau) + u_3\sin\tau]P_1 \\ & + [\cos\tau + u_1^2(1 - \cos\tau)]P_2 \\ & + [u_3u_2(1 - \cos\tau) - u_1\sin\tau]P_3 \\ P_3' = {} & [u_3u_1(1 - \cos\tau) - u_2\sin\tau]P_1 \\ & + [u_3u_2(1 - \cos\tau) + u_1\sin\tau]P_2 \\ & + [\cos\tau + u_3^2(1 - \cos\tau)]P_3 \end{aligned}$$

As a result, the roller's surface equation is given as:

$$x = x(\theta,\tau) = R + P_1'$$
$$y = y(\theta,\tau) = R + P_2'$$
$$z = z(\theta,\tau) = P_3'$$

Then, in order to get a circular silhouette for the roller having the best possible efficiency, it is used the roller's surface equation and after determined the maximum and minimum radius of the roller.

Defining the number of rollers, it is possible to determine the other parameters of the equation, which are $(L_r, \alpha, l_w)$. $L_r$is the length of the roller; $\alpha$ is the angle between roller and hub axes; $l_w$ is the width of the wheel; By using those parameters it is possible to find the maximum and minimum radius of the roller. If the number of rollers N is known, the roller length can be obtained by [6]:

$$L_r = 2R\frac{\sin{}^{\varphi}/_{2}}{\sin\alpha} = 2R\frac{\sin{}^{\pi}/_{N}}{\sin\alpha}$$
$$\varphi = \frac{2\pi}{N}$$

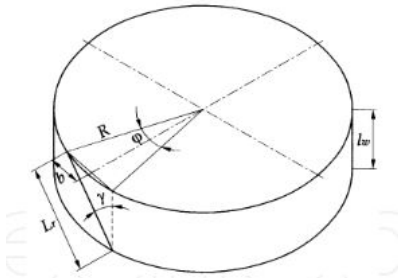


**Figure 6 - Wheel parameters [7]**

Then, the wheel width will be:

$$l_w = L_r\cos\alpha = 2R\frac{\sin{}^{\pi}/_{N}}{\tan\alpha}$$

From those it is possible to obtain the maximum radius of the roller, which is described in the equation below [8]:

$$r_{max} = R - \left(\frac{L_r\sin\alpha}{2\tan{}^{\pi}/_{2}}\right) \qquad (2)$$

And the minimum radius is obtained using the following equation:

$$r_{min}^2 + (2R - 2r_{max})r_{min} + R^2\left(\sin{}^{\varphi}/_{2}\right)^2 + r_{max}^2 - 2Rr_{max} = 0 \qquad (3)$$

In those equations, $r_{max}$ and $r_{min}$ represent respectively the maximum radius and minimum radius of the roller.

## IV. SIMULATION OF THE MECANUM WHEEL

With the objective of determining the best silhouette for the roller, a program was created using the software MATLAB. In order to get the best result, 1000 interactions were made, with the number of rollers set between 6 and 10, and the width of the wheel and the moving continuity coefficient randomly chosen in a set of values. The width range is from 4 to 12 centimeters and the moving continuity coefficient was set from 1.01 to 1.08.

To obtain the roller's surface curve, the parameters $\alpha,\theta_o,\tau$ and R were defined previously. In the end, the desired parameters were: $\alpha = 45°,\theta_o = 11°,\tau = 70°$. About the parameter R, it was defined based in the objective of the project as it will be discussed in the next topic.

### A. Characteristics of the project

One of the objectives of the project is using this new design for mecanum wheels in wheelchairs. With that, the maneuverability of the wheelchair will increase and then make the life of the users easier. The characteristics of this mecanum wheel were chosen based in the characteristics of the wheelchair. Therefore, the maximum speed of the wheelchair was fixed in 5 Km/h, and the weight capacity, a person of 80 kilograms. Based on that, the radius R of the mecanum wheel should be 114.61 millimeters. Four mecanum wheels and the body were connected with revolute joints and the driving torque was applied to each revolute joint. The main characteristics of the wheel are listed in the table 1.

The data showed in the table 1 were generated by MATLAB and was subsequently exported to SOLIDWORKS, where a 3D model of the roller is generated. The roller is generated by simply rotating the curve by 360°.

| Width (cm) | Maximum radius of Roller (mm) | Minimum Radius of Roller (mm) | Helical Line Angle (°) | Roller Length (cm) | Continuity Coefficient |
|---|---|---|---|---|---|
| 7.453769 | 24.635106 | 15.910935 | 67.46838 | 10.54122 | 1.010408 |

**Table 1 – Parameters to define the curve of the roller**

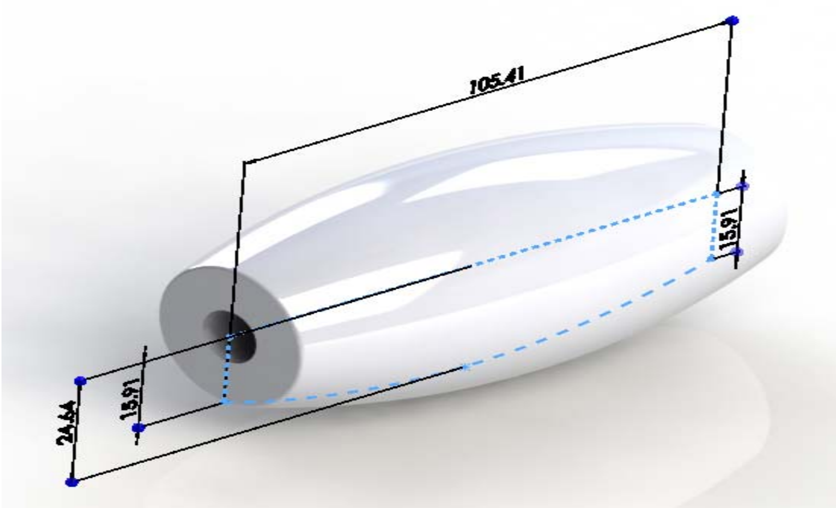


**Figure 6 – Roller's 3D model (Dimensions in milimiters)**

## V. RESULTS

### A. Moving Continuity Coefficient

As it was mentioned before, this coefficient is important to define if the mecanum wheel is capable of keeping the continuity of the movement and it value should be bigger than 1, however as close as possible of 1. Based on that, it was performed simulations with different values for the number of rollers, having a range set between 6 and 10 rollers. In the end the best performance was obtained when the number of rollers was established in 8. This happened because with 9 and 10 rollers, the rollers would touch each other during the displacement provoking undesirable vibrations. Using 6 and 7 rollers, the length of the rollers is too big, making the wheel thicker and the curve that generates the roller, inadequate.

In the table 2, it is shown the main parameters that were fixed to generate the curve of the roller when the number of rollers is set in 8. The maximum radius of the roller was fixed with a range between 20 and 26 millimeters, and the results are shown in the figure 7.

As it can be observed in the graph of the figure 7, as smaller as it is the Maximum radius, the Roller length will increase and consequently the wheel have to be thicker, and the generatrix tends to oscillate making the curve inadequate to create the roller. Because of that the best results found was when the Maximum radius was set from 24 to 26 millimeters as it is shown in the table 3.

| Number of Rollers | Rotational axis of the wheel (α) | Starting angle of the Helical Line ($\theta_o$) | Rotation of the wheel contact line around the roller axis of rotation (τ) | Radius of the wheel |
|---|---|---|---|---|
| 8 | 45º | 11º | 70º | 114.610062 mm |

**Table 2 – Fixed parameters to define the curve of the roller**

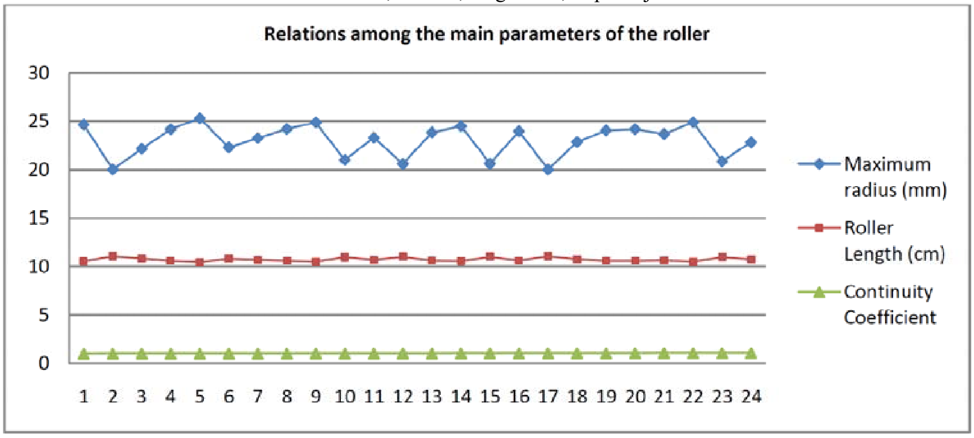


**Figure 7 – Relation among the main parameters (Maximum radius range: 20 to 26 millimeters)**

| Maximum radius (mm) | Minimum Radius (mm) | Helical Line Angle (°) | Roller Length (cm) | Continuity Coefficient |
|---|---|---|---|---|
| 24.635106 | 15.910935 | 67.46838 | 10.54122 | 1.010408 |
| 24.158495 | 15.434324 | 68.09165 | 10.59706 | 1.024259 |
| 25.297833 | 16.573662 | 68.15391 | 10.46358 | 1.025642 |
| 24.190321 | 15.466149 | 68.43402 | 10.59333 | 1.031867 |
| 24.859516 | 16.135344 | 68.48648 | 10.51493 | 1.033033 |
| 24.48645 | 15.762278 | 69.37247 | 10.55864 | 1.052721 |
| 24.046134 | 15.321963 | 69.97339 | 10.61022 | 1.066075 |
| 24.168332 | 15.44416 | 70.05571 | 10.59591 | 1.067905 |
| 24.87485 | 16.150679 | 70.57224 | 10.51313 | 1.079383 |

**Table 3 – Results of the parameters when Maximum radius range is between 24 and 26**

## VI. CONCLUSIONS AND DISCUSSIONS

In this study, it was performed the analysis of how it was obtained the geometry of the roller accordingly with the proposal of the project. The simulations performed using MATLAB and SOLIDWORKS were used to achieve the best optimal roller curvature to give a better maneuverability for the vehicle using this mecanum wheel. Finally, this new design will be used in a power autonomous wheelchair, whose concept design is shown in the Figure 8.

**Figure 8 – Concept design of the wheelchair**

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