Robotic wheel structures and their industrial applications based on motion simulations

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Abstract. The following work was done to analyze mobile structures with different arrangements of wheels. Software package Solidworks was utilized in modeling and analysis of the structures. Eight mobile structures were built by rearranging the placement of both driven and free wheels. Each structure has its own unique placement of wheels, hence giving the opportunity to understand the influence of the wheels’ placement on the functionality of the whole structure in terms of speed, stability, and other parameters. Therefore, eight mobile structures were analyzed, and the results were gathered. Adding more driven wheels or free wheels does not improve the performance of the mobile structures. The outcomes of the results illustrated that structure 6 tends to be more positive in terms of energy consumption, torque, and stability. Hence, adding more driven wheels does not improve the performance of the mobile structures.

1. Introduction

The selection of mobile structures for robots is a strenuous task since there are several ways to perform a locomotion system. These structures have diversity in terms of their types of wheels and therefore the degrees of freedom that the robot has. For example, free wheels used on trucks, driven wheels, or complex wheels like bi-directional wheels. Another factor that influences the design is the functionality that the robot will have. For example, in transport such as [1-2], applications it is necessary to calculate the weight that the system can handle. In contrast, machine vision inspection applications need greater stability from the locomotion system [3], so damping plays a crucial factor in device development. And in applications where it is necessary to place products in different positions, it is necessary to increase the degrees of freedom of the locomotion system like in agro-industrial applications [4-5].

With this in context, the objective of this study is to compare different mobile structures according to the mentioned applications. For this, a simulation test will be carried out, varying the different types of structures such as tricycle and differential. The test consists of simulating the weight that the robots can support, to calculate the torques and stability that these systems provide. The bidirectional wheel is not simulated but when this type of wheel is added one degree of freedom is added to the structure. Solidworks was the software selected due to its market share and its motion package [6].
2. Method

The first goal in modeling and analysis is to choose the right software package that would solve both suggested tasks. With its long reputation in the market, and ease of use, as well as the ability to perform various types of analysis, Solidworks has been selected as the primary tool for performing the required tasks. Solidworks is a powerful tool for modelling any simple or complex structure. An easy-to-use environment with a huge number of tools and functions allows the user to create any structures regards to their sizes, shapes, complexity etc. Similarly, it has built in many different static and dynamic analysis tools for fluids, electrics, mechanics and more.

Before any analysis, one mobile structure was built. Parts of the structure were modeled separately so that they could be modified and rearranged (assembled) to form various structures with different wheel arrangements throughout the analysis (figure 1). The parts of the structure are illustrated in figure 2 and go as follows: 1 – main body, 2 – connecter of the main body and the wheels, 3 – wheel bracket (both driven and free), wheel and floor. 8 structures were assembled with different wheel arrangements. The arrangement of the wheels can be seen in table 1 below.

Solidworks also was used to perform structural analyzes. Solidworks motion analysis tool (add in) was used to do the analysis. At the beginning, the assembled structure was opened (the necessary constraints were added to all structures during the assembly process; hence, no constraints were required) and after the add-in was activated. With Solidworks motion add-in, the necessary boundary conditions were added depending on the arrangement of the structure (table 1). The following boundary conditions were applied to all structures. The motors were applied to the drive wheels. Gravity and force were applied to the main body. Also, contacts were introduced between the floor and the wheels. Given values for the parameters can be viewed in table 2. All structures were given the same distance to travel with different arrangements of the wheels. The parameters added to the structures can be viewed in the table 2.

The results were gathered after each analysis. By analyzing one structure with the unique set of wheels the following results can be obtained: velocity, stabilization time, acceleration, initial torque 1, energy consumption and initial torque 2. All the gathered results from analyzed structures can be seen in table 3.
Table 1. Robotic structure wheels characteristics.

| Simulation | Traction | Free Wheels | Driven Wheels |
|------------|----------|-------------|---------------|
| Structure 1 | Rear     | 2           | 1             |
| Structure 2 | Rear     | 2           | 2             |
| Structure 3 | Rear     | 1           | 2             |
| Structure 4 | Frontiel | 2           | 1             |
| Structure 5 | Frontiel | 2           | 2             |
| Structure 6 | Middle   | 2           | 2             |
| Structure 7 | Doble    | 0           | 4             |
| Structure 8 | Doble    | 0           | 3             |

Table 2. Motion simulation parameters.

| Parameters          | Dimension | Value |
|---------------------|-----------|-------|
| Motor angular speed | RPM       | 100   |
| Force               | N         | 500   |
| Static Friction     | -         | 0.25  |
| Kinetic Friction    | -         | 0.35  |
| Time                | s         | 2     |
| Gravity             | m/s²      | 9.81  |

3. Results

After performing 8 simulations varying the number of driving wheels, free wheels and the position of the wheels, the results shown in table 3 are obtained. From each simulation, the linear speed, the stability time, the torque graph, and the energy consumption. In addition, the results are analyzed considering that the moment of greatest torque and consumption is from the start of the robot until it reaches its stability. All the results in table 3 are based on one motor, so in cases where the structure has two motors, it should be considered that the energy consumption will be double that shown in the table. All simulated structures have two degrees of freedom, so adding bidirectional wheels would increase the degrees of freedom to three in four-wheel drive structures.

Table 3. Motion simulation results.

| Simulation | Velocity (mm/s) | Stabilization time (s) | Acceleration (mm/s²) | Initial torque 1 (N-mm) | Energy consumption (W) | Initial torque 2 (N-mm) |
|------------|-----------------|------------------------|----------------------|------------------------|------------------------|------------------------|
| Structure 1 | 604             | 0.10                   | 6030                 | 5115                   | 54                     | -                      |
| Structure 2 | 604             | 0.10                   | 6040                 | 2700                   | 28                     | -                      |
| Structure 5 | 604             | 0.10                   | 6040                 | 2339                   | 24                     | -                      |
| Structure 4 | 594             | 0.10                   | 5940                 | 12442                  | 130                    | -                      |
| Structure 3 | 607             | 0.10                   | 6070                 | 2335                   | 24                     | -                      |
| Structure 6 | 613             | 0.10                   | 6130                 | 2090                   | 22                     | -                      |
| Structure 7 | 606             | 0.10                   | 6060                 | 9856                   | 32                     | 3096                   |
| Structure 8 | 606             | 0.05                   | 12120                | 5442                   | 55                     | 2626                   |
Structures 1, 2 and 3 are rear-wheel drive. On the subject of velocity and stability, no important differences are seen, most of them have a similar behavior to the one seen on figure 3. Regarding the torque in the motors, a decrease in approximately half of the touch is seen when another motor was added such as (structures 2 and 3), which is directly proportional to the energy consumption at that moment. Structure 2 has a higher torque, possibly due to the additional freewheel increasing the total friction force of the system.

![Figure 3. Structure 1 displacement and linear velocity.](image)

Structures 4 and 5 are front-wheel drive. The differences between these structures and the rear-wheel drive are notable in torque. It is more difficult to pull the structure than to push it. The increase in torque and energy consumption is considerable between structures 1 and 4. Figure 3 shows the linear velocity of structure 4 with constant disturbances in the route. Structure 5 has a similar behavior to rear-wheel drive structures.

![Figure 4. Structure 4 displacement and linear velocity.](image)

Structure 6 shows greater stability, a slight improvement in speed and acceleration. It has the least initial torque and energy consumption of all the structures as shown in figure 4. The behavior of the linear velocity graph is very similar to that of rear-wheel drive structures.
Figure 5. Structure 6 torque and energy consumption.

Structures 7 and 8 have double traction. The increase in drive wheels does not show significant improvements in linear speed. Structure 8 reaches the point of stability with greater acceleration than the others, but the time difference is very short. Torque differences were found between the front and rear wheels. The front wheels torque greater than that of the rear wheels as shown in figure 5.

Figure 6. Torque difference. (Blue) rear wheels. (Red) Front wheels.

4. Comparison of results
To conclude, the following work was done to perform analysis on mobile structures with different arrangement of wheels. Solidworks was utilized to analysis structures and find out the best arrangement of wheels. The following results were gathered from each simulation, the linear speed, the stability time, the torque graph, and the energy consumption. The results illustrated that the structure 6 was the one with the better outcomes compared to the others. Structure 6 can be used in logistic operation to transport pallets or materials. In operation that needs more stabilization as vision systems structure 8 can be another option.

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