Simulation of DC motor for 3-Wheel Omni Drive using MATLAB Simulink

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Abstract

This paper presents a simulation of a DC motor for a 3-wheel Omni drive using MATLAB Simulink. The Omni drive system is a mechanism that allows for omnidirectional movement by independently controlling the speed and direction of three wheels arranged in a triangular configuration. The simulation aims to model the behaviour of the DC motor under different operating conditions, including variations in speed, torque, and control inputs. By accurately representing the motor dynamics, this simulation enables engineers and researchers to study the performance of the Omni drive system and optimize its control algorithms. The simulation results provide insights into the motor's response, power consumption, and efficiency, which are crucial for designing and fine-tuning of the overall Omni drive system. Additionally, the simulation facilitates the evaluation of different control strategies for achieving precise and agile movement in various applications such as robotic platforms and autonomous vehicles. The proposed simulation framework serves as a valuable tool for further development and analysis of Omni drive systems, ultimately leading to advancements in mobile robotics and automation technologies.

Keyword: DC motor, Omni, MATLAB, modelling, mathematical model

1. Introduction

The simulation of DC motor is a crucial aspect in the design and analysis of various robotic systems. Omni drive robots, also known as holonomic drive robots, are capable of moving in any direction without the need for complex steering mechanisms. These robots are widely used in industries, warehouses, and even in domestic environments due to their exceptional maneuverability and versatility [1]. This paper aims to simulate a DC motor for a three-wheel Omni drive system using MATLAB Simulink software. By creating a realistic and reliable simulation model help to analyze the motor performance under different operating conditions, response to control inputs, and optimize control algorithms. This simulation will provide valuable insights into the motor behavior as well as aiding in the design and development of efficient control strategies for the Omni drive system [2]. The simulation involves modelling the electrical and mechanical characteristics of the DC motor, including torque, speed, and power consumption. By accurately capturing the motor dynamics, analyze its response to different control inputs and external conditions, allowing for the development of efficient and robust control algorithms [3] [4]. Furthermore, the simulation enables the evaluation of various system parameters, such as gear ratios, motor ratings, and control strategies, in a virtual environment before implementing them in physical prototypes. This approach significantly reduces development time and costs while enabling fine-tuning of the motor's performance to meet specific requirements [5]. The outcome of this work is to finds applications in diverse fields, including automation, logistics, and transportation. By enhancing in-depth knowledge of the DC motor behavior in a 3-wheel Omni drive system help for the development of more agile and intelligent robots that can operate efficiently in complex environments. The insights gained from this simulation will assist in the development of robust control strategies and optimization techniques for enhancing the maneuverability, efficiency, and overall performance of mobile robotic platforms.

2. Methods

- **Motor Modelling**

The first step in simulating the DC motor for the three-wheel Omni drive is to develop an accurate mathematical model that represents the motor's electrical and mechanical characteristics. This model will incorporate parameters such as resistance, inductance, back reef, and rotor inertia. The motor model can be derived based on the motor data sheet or experimental measurements. [6] [7].

- **Motor Control System**

Once the motor model is established, the next step is to design a control system for the motor. This includes selecting appropriate control algorithms such as PID (Proportional Integral-Derivative) control or state feedback control. The control system will take inputs such as desired speed or torque and generate control signals to regulate the motor's behavior [8].

- **System Integration**

At this stage, the DC motor model is integrated into the three-wheel Omni drive system. The Omni drive system consists of three independently controlled motors, each responsible for driving a separate wheel. The motor models are connected to the wheels and their interaction with the chassis is taken into account [9] [10].

- **Simulating Motor Behavior**

Using MATLAB Simulink capabilities, the DC motor model is implemented and simulated within the Omni drive system. The simulation will consider various operating conditions, including different speeds, loads, and control inputs. The simulation will provide valuable insights into the motor's response, torque-speed characteristics, and efficiency [11].

- **Performance Analysis**

The simulated results were analyzed to evaluate the performance of the DC motor in the three-wheel Omni drive system. Parameters such as motor speed, torque, current, and power consumption have been monitored and compared against desired values or performance specifications [12]. This analysis helps in identifying any inefficiencies or limitations in the motor performance and guides further optimization.

- **Optimization and Control Tuning**

Based on the performance analysis, the control algorithms and motor parameters can be fine-tuned to optimize the motor behavior [13] [14]. This may involve adjusting control gains, optimizing control strategies, or modifying motor parameters to achieve better performance, efficiency, and stability.

- **Validation**

The simulation results are validated against real-world experiments or benchmark data to ensure the accuracy and reliability of the simulation model [15]. Any discrepancies or deviations between the simulated and actual motor behavior are identified and addressed to improve the model fidelity [16] [17]. By following this methodology, the simulation of the DC motor for the three-wheel Omni drive in MATLAB Simulink provides a comprehensive understanding of the motor behavior and its impact on the overall system performance. It enables the development and optimization of control strategies for achieving precise motion control and enhanced maneuverability in mobile robotic platforms. [18] [19] [20]

3. Mathematical Model of Motor

For DC motor (RS775), designed the mathematical model and simulated it in virtual environment. DE motor is a widely used electromechanical actuator in control systems, which delivers rotational motion and, when combined with wheels, drums, or cables, can also generate transnational motion. Fig. 1 shows the electric model along with the rotor. In this system, the input is represented by the voltage source (V) applied to the motor armature, while the output is the rotational speed of the shaft. It is assumed that the rotor and shaft possess rigidity. The friction torque is proportional to shaft angular velocity.

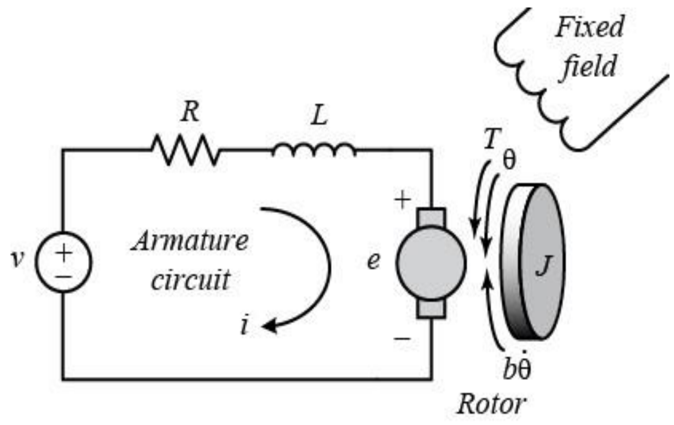

Fig. 1 Physical model DC motor

According to Newton's Second law and Kirchhoff's Voltage law,

$$J\ddot{\theta} + b\dot{\theta} = Ki \qquad \text{(Equation 1)}$$

$$L\frac{di}{dt} + Ri = V - Ki \qquad \text{(Equation 2)}$$

By eliminating I(s)

$$P(s) = \frac{\dot{\theta}}{V(s)} + \frac{K}{(Js+b)(Ls+R)+K^2} \qquad \text{(Equation 3)}$$

From above transfer function, angular velocity (θ˙) of DC motor is varied by changing voltage (V). Graph are plotted below as changing voltage causes increase in angular velocity results into increase in speed of robot. Fig. 2 represents the block diagram of transfer function of RS 775 DC motor. Armature voltage is starting block mentioned at the very left in the diagram. Using a sum block, it is subtracted from back emf of the DC motor. The difference between these voltages is then multiplied by a continuous transfer function block provided with initial states to get output as armature current. Armature current block is multiplied by a gain multiplier block to get developed motor torque as output. This torque value is then subtracted from the load torque by assigning a separate block to it as done previously. By multiplying this torque difference by transfer function using gain block, the speed of the motor as output was changing with time and displayed using the scope block.

Thus, by following the inter-connectivity made, output graphs of torque and speed of motor for respective weight load are generated. By performing a simulation of the DC motor in MATLAB Simulink verified the calculated torque and speed values for maneuvering Omni wheels and satisfied under peak conditions for the selected DC motor. Block diagram of mathematical model shown in Fig. 2 simulates DC motor, and graphs are plotted on the basis of output i.e. linear velocity and torque. Fig. 4 shows the linear velocity vs time, DC motor achieved speed of 6 m/s at 10th second. In Fig. 5 of torque vs time, torque increases suddenly in 1 second then it is maintained near 40 kg-cm.

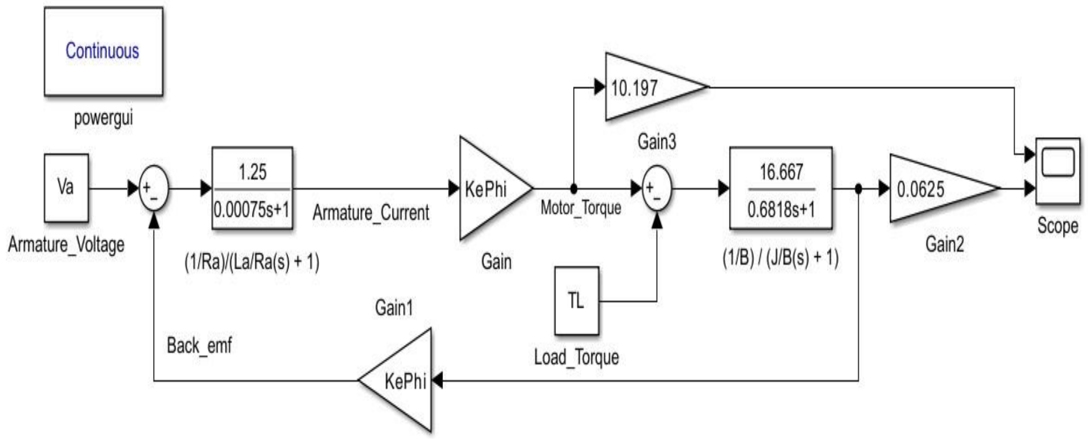

Fig. 2. DC motor model in Simulink Matlab

4. System Integration

In the simulation of a DC motor for a three-wheel Omni drive system using MATLAB Simulink, a system integration involves integration of the motor model with the kinematics and dynamics of the overall system. This step ensures that the motor’s behavior is accurately represented within the context of the Omni drive mechanism. Kinematics Modelling: The kinematics of the three-wheel Omni drive system determines the relationship between the motor inputs (speed and torque) and the resulting motion of the robot. [21] The kinematic model includes parameters such as wheel radii, wheel positions relative to the center of the robot, and the orientation of the wheels. These parameters are used to calculate the linear and angular velocities of the robot based on the motor inputs [22] [23]. Omni-directional refers to the ability to move in any direction. In the realm of mobile robots, the occupied robot space encompasses three dimensions: by using the variables ‘x’ and ‘y’ to denote robot position and ‘ω’ to represents its orientation, the robot possesses the ability to move freely in any direction, irrespective of its current position or orientation. As a result, it can generate simultaneous linear angular velocities V_x and V_y. By employing an Omni-directional motion method, the values of V_x and V_y can be regulated, providing the robot with three degrees of freedom (DOF). A holonomic motion system is characterized by having a configuration that requires the same number of degrees of freedom as the number of coordinates needed to describe the system’s configuration [23]. With a holonomic motion system, the movement of the robot can be planned without any restrictions. The concept of holonomic is employed as shown in Fig. 3 use to determine the angle, denoted as α, which represents angle of motor axis with respect to x-axis from x-axis of robot coordinate frame. Each α value, such as α_1 = 30 degree, α_2 = 150 degree, α_3 = 270 degree, corresponds to a motor axis angle from x axis of robot co-ordinate frame. In Fig. 3 the drive axis of wheel is at 90 degree or π/2 for each α. To break down the vector into its x and y components, simple trigonometry is utilized [24] [25].

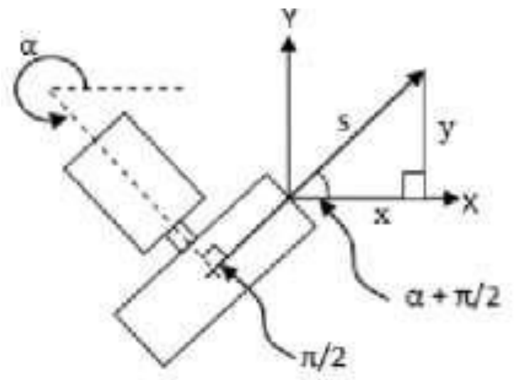

Fig. 3. Omni Wheel Velocity Configuration

The application of inverse kinematics is employed to calculate the angular velocity of a measuring wheel [26]. The inverse kinematic equation, which describes the relationship between the speed of a DC motor and a three-wheeled robot, is expressed as Equation:

$$\begin{pmatrix} x \\ y \\ w \end{pmatrix} = \begin{pmatrix} \cos\left(\alpha 1 + \frac{\pi}{2}\right) & \cos\left(\alpha 2 + \frac{\pi}{2}\right) & \cos\left(\alpha 3 + \frac{\pi}{2}\right) \\ \sin\left(\alpha 1 + \frac{\pi}{2}\right) & \sin\left(\alpha 2 + \frac{\pi}{2}\right) & \sin\left(\alpha 3 + \frac{\pi}{2}\right) \\ 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} S1 \\ S2 \\ S3 \end{pmatrix} \quad \text{(Equation 4)}$$

Let S_1 represent the velocity of motor-1, S_2 denote the velocity of motor-2, and S_3 represent the velocity of motor-3. While x corresponds to the x-axis and y denotes the y-axis, each rotation of the robot is assigned a value of either 1, -1, or 0. Additionally, there exists a rotational component denoted as ω, allowing the robot to rotate along its Z-axis.

$$\omega = S_1 + S_2 + S_3 \quad \text{(Equation 5)}$$

The overall rotation of the robot is determined by summing the speeds of each motor, regardless of whether a motor turns in the opposite direction, resulting in the combined magnitude of the robot's rotation.

5. Simulating Motor Behavior

The voltage source (V) applied to the motor's armature serves as the input to the system, while the rotational speed of the shaft ($\dot{\theta}$) represents the output. The rotor and shaft are considered rigid, and a viscous friction model is assumed, indicating that the friction torque is proportional to the angular velocity of the shaft.

The physical parameters considered for this model:

Moment of inertia of the rotor (J) 0.0409 $kg.m^2$

Motor viscous friction constant (B) 0.6 N.m.s

Electromotive force constant (Ke) 0.01 V/rad/sec

Motor torque constant (Kt) $18.3*10^{-3}$ N.m/Amp

Electric resistance (Ra) 0.8 Ohm

Electric inductance (La) $0.6*10^{-3}$ H

Inputs:

Voltage = 20 V

External load acting on wheel can be calculated as:

$F = \mu N$
$F = 0.42 * 8.3$
$Torque\ (T) = F * D * fos$
$T = 0.42 * 8.3 * 6.25 * 1.2 = 26.15\ Nm$

Mathematical model can be simulated on the basis of above parameters and given inputs. Provided the observation table/experimental readings with suitable units is tabulated, From the mathematical modelling of DC motor as stated in the design phase, the graphs of Omni wheel speed in rad/s and torque variation with time are obtained as per the variation in load input of medicines over the mechanism. Transfer function of DC motor with the motor parameters are developed as stated. The results are depicted in Fig.4 and Fig..5.

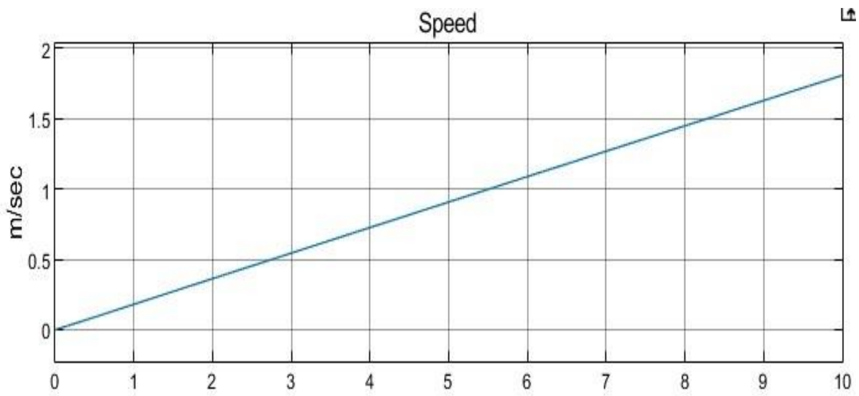

Fig. 4. Speed Vs Time

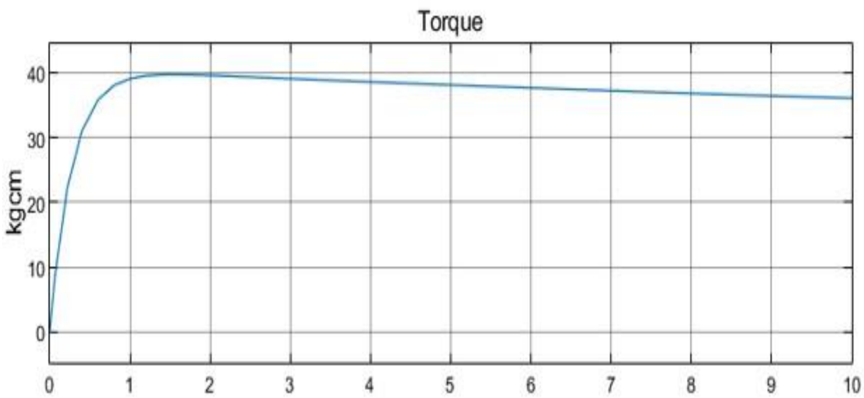

Fig. 5. Torque vs Time

6. Performance Analysis and Validation

The maximum robot velocity for Omni wheels is not to be exceeded 2 m/s which can cause toppling and dynamic instability of the robot. This is ensured and verified from Fig 6. Which shows the maximum velocity obtained is 1.7 m/s at 10th second and torque does not exceed 40 kg-cm which is the limiting value of torque for RS775 DC motor. Thus, the motor used is capable of lifting and transmitting loads for its maximum capacity. Iterations are also performed to check the values of torque and speed required for each Omni wheel if the weight is of intermediate value of 3 kg, the results obtained are as follows:

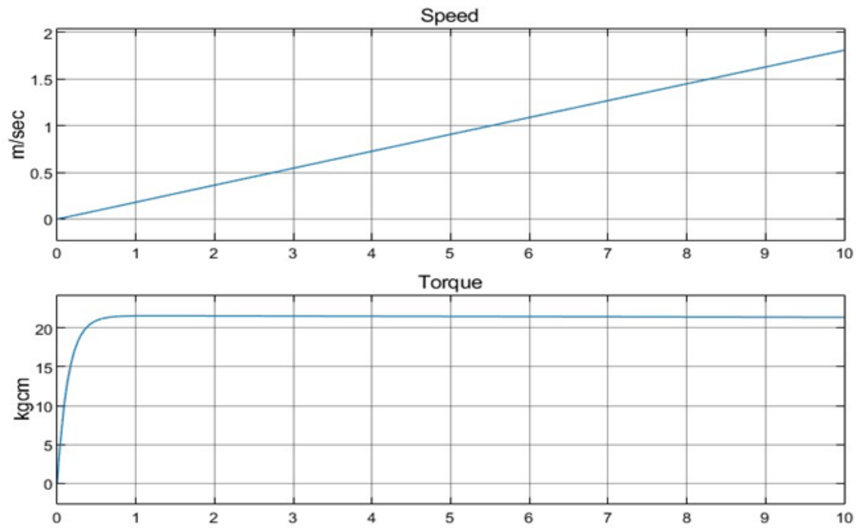

Fig. 6. Speed and Torque iterations for 3 kg load

From the above results, it can be concluded that the maximum torque required for carrying 3 kg weight is around 22 kg-cm and the selected motor is able to perform the transportation with desirable velocity limit of 1.7 m/s. ROS implementation can be used to develop a real and visual environment which can be used for testing the robot for obstacle detection, navigation and test for feedback signal monitoring.

7. Conclusions

The simulation of a DC motor for a three-wheel Omni drive system in MATLAB has provided valuable insights into the behavior and performance of the motor within the context of the overall robotic platform. By accurately modelling and integrating the motor with the kinematics and dynamics of the system, we have gained a deeper understanding of its response to control inputs, its influence on the robot's motion, and its interaction with the surrounding environment. The simulation has served as a valuable tool for evaluating and validating the motor's behavior before implementing it in real-world applications. By using MATLAB, we were able to create a realistic and reliable model that closely resembles the actual motor characteristics and dynamics. This simulation has enabled us to save time.

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