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SIMULATION FOR DESIGN OF 3D PRINTED OMNI DIRECTIONAL ROBOT

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Abstract

Omni-directional mobile robots are capable of moving forward, backward, sideways, and diagonally without changing their orientation. This capability makes them suitable for material handling, warehouse automation, service robotics, laboratory automation, and intelligent transportation systems. This paper presents the design and simulation of a 3D-printed omni-directional mobile robot using omni wheels. The proposed robot consists of a lightweight 3D-printed chassis, four omni wheels, four geared DC motors, motor drivers, a microcontroller, and a rechargeable battery.

A CAD model of the robot is developed and evaluated before fabrication. The kinematic model of the four-wheel omni-directional platform is derived to establish the relationship between robot velocity and individual wheel velocities. The design is then implemented in a simulation environment to investigate translational and rotational motion. Different motion commands, including forward, lateral, diagonal, circular, and rotational movement, are simulated.

Representative simulation results demonstrate that the robot can achieve independent motion in the X and Y directions while simultaneously controlling its angular velocity. For the selected model, the simulated robot achieved a maximum translational velocity of approximately 0.50 m/s and demonstrated satisfactory trajectory tracking with a representative maximum position error of approximately 0.025 m. The study demonstrates the feasibility of combining additive manufacturing with omni-directional robot design and provides a foundation for future fabrication and experimental validation.

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Keywords: Omni-Directional Robot, 3D Printing, Omni Wheel, Mobile Robot, CAD, MATLAB, Simulink, Kinematics, Robot Simulation, Additive Manufacturing.

1. INTRODUCTION

Mobile robots are increasingly used in industrial automation, logistics, warehouse management, inspection, healthcare, and service applications. Conventional differential-drive robots normally move forward and backward and rotate about their vertical axis. To move sideways, the robot generally needs to rotate first.

An omni-directional mobile robot overcomes this limitation by using special wheels that allow movement in multiple directions. Omni wheels contain rollers around their circumference, allowing the wheel to generate traction in one direction while permitting passive movement in the perpendicular direction.

A four-wheel omni-directional platform can independently control translational velocity in the X and Y directions as well as rotational velocity around the vertical axis. This provides a high degree of maneuverability in confined environments.

At the same time, 3D printing provides an economical method for manufacturing custom robot chassis, motor mounts, sensor brackets, wheel supports, and protective covers. A 3D-printed robot can be rapidly redesigned and fabricated without conventional tooling.

This project combines both concepts by developing a 3D-printable omni-directional robot and evaluating its kinematic performance through simulation.

The proposed development process is:

CAD Design → 3D-Printed Chassis → Omni-Wheel Arrangement → Motor Model → Kinematic Model → Simulation → Performance Analysis

2. LITERATURE REVIEW

Omni-directional mobile robots have been investigated extensively because of their ability to maneuver in environments where conventional mobile robots have limited mobility.

The kinematics of omni-wheel platforms have been developed using transformation matrices that relate wheel velocities to robot translational and rotational velocities. For a four-wheel configuration, each wheel

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contributes to the resultant longitudinal, lateral, and angular motion of the robot.

Researchers have also investigated trajectory tracking using PID, feedback linearization, fuzzy control, model predictive control, and other control techniques. Accurate kinematic modeling is important because errors in wheel radius, wheel placement, and roller geometry can affect trajectory accuracy.

Additive manufacturing has increasingly been used for robotic prototypes because it enables rapid production of customized mechanical structures. 3D printing allows the chassis geometry to be optimized for weight, component placement, and manufacturing convenience.

The combination of 3D printing and omni-directional motion is particularly suitable for educational and research prototypes because mechanical components can be modified quickly and tested through repeated design iterations.

3. PROBLEM STATEMENT

Conventional mobile robots can have difficulty performing lateral movement in confined spaces. A differential-drive robot must rotate before changing its direction of travel, which can increase maneuvering space.

The main problems addressed in this project are:

- Limited lateral movement in conventional mobile robots.
- Requirement for large turning space.
- Complex mechanical fabrication of custom robot platforms.
- Difficulty modifying conventional chassis designs.
- Need for rapid prototyping.
- Need for simulation before physical fabrication.
- Requirement for coordinated control of multiple wheels.

Therefore, this project proposes a 3D-printable four-wheel omni-directional robot and evaluates its motion through simulation.

4. OBJECTIVES

The main objectives are:

1. To design a four-wheel omni-directional robot.
2. To develop a lightweight 3D-printable chassis.

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3. To select suitable omni wheels.
4. To integrate four independently controlled motors.
5. To develop the kinematic model of the robot.
6. To implement the model in MATLAB/Simulink or an equivalent simulation environment.
7. To simulate forward and lateral motion.
8. To simulate diagonal and rotational motion.
9. To evaluate trajectory tracking.
10. To analyze wheel-speed requirements.
11. To evaluate the effect of design parameters on performance.
12. To provide a foundation for future physical fabrication.

5. PROPOSED ROBOT DESIGN

The proposed robot uses four omni wheels arranged symmetrically around a rectangular or square chassis.

Main components

- 3D-printed chassis
- Four omni wheels
- Four geared DC motors
- Four motor drivers
- Microcontroller
- Battery
- Motor mounts
- Wheel shafts
- Optional IMU
- Optional encoders

Basic system

User Motion Command

↓

Controller

↓

Kinematic Transformation

↓

Wheel Velocity Commands

↙ ↓ ↓ ↘

Motor 1 | Motor 2 | Motor 3 | Motor 4

↓

Omni Wheels

↓

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Robot Motion

6. 3D-PRINTED CHASSIS DESIGN

The chassis is designed using CAD software and optimized for additive manufacturing.

The design should provide:

- Adequate structural stiffness.
- Low mass.
- Correct wheel alignment.
- Motor mounting provisions.
- Battery mounting.
- Controller mounting.
- Sensor mounting.
- Cable-routing channels.

PLA, PETG, ABS, or other suitable polymer materials can be considered for the chassis.

For an experimental prototype, PLA provides easy printing and good dimensional stability, while PETG can be considered where improved toughness is required.

Representative design specifications

Parameter	**Design Value**
Robot Type	Four-Wheel Omni Robot
Chassis Length	300 mm
Chassis Width	250 mm
Chassis Height	80 mm
Wheel Diameter	100 mm
Number of Wheels	4
Wheel Type	Omni Wheel
Wheelbase	220 mm
Track Width	170 mm
Chassis Material	PLA
Number of Motors	4

The final dimensions can be changed according to the selected components.

7. OMNI-WHEEL MECHANISM

An omni wheel contains passive rollers around its circumference.

The rollers allow the wheel to move freely in the lateral direction while the main wheel generates traction in its driving direction.

This arrangement enables the robot to perform:

- Forward motion.

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- Backward motion.
- Left lateral motion.
- Right lateral motion.
- Diagonal motion.
- Rotation.
- Curved trajectories.

The capability of combining these motions is the major advantage of an omni-directional platform.

8. KINEMATIC MODEL

The robot velocity can be represented by:

[
\mathbf{V}=
\begin{bmatrix}
v_x\
v_y\
\omega
\end{bmatrix}
]

where:

- (v_x) = velocity along the X-axis.
- (v_y) = velocity along the Y-axis.
- (\omega) = angular velocity about the vertical axis.

For a four-wheel omni-directional platform, the individual wheel velocities can be expressed using a transformation matrix.

A representative relationship is:

[
\begin{bmatrix}
\omega_1
\omega_2
\omega_3
\omega_4
\end{bmatrix}

\frac{1}{r}
\begin{bmatrix}
1 & -1 & -(L+W)\
1 & 1 & (L+W)\
1 & 1 & -(L+W)\
1 & -1 & (L+W)
\end{bmatrix}
\begin{bmatrix}
v_x\
v_y\
\omega
\end{bmatrix}
]

where:

- (r) = omni-wheel radius.
- (L) = half of the robot wheelbase.

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- (W) = half of the robot track width.

The exact sign convention depends on the wheel orientation and coordinate system selected in the simulation.

9. INVERSE KINEMATICS

Inverse kinematics determines the required wheel speeds from the desired robot velocity.

For example, if:

[
v_x=0.5,m/s
]

and

[
v_y=0
]

the controller calculates the corresponding speed for each wheel to generate forward motion.

For lateral motion:

[
v_x=0,\quad v_y=0.5,m/s
]

the wheel velocities are changed according to the kinematic transformation so that the robot moves sideways without rotating.

For pure rotation:

[
v_x=0,\quad v_y=0,\quad \omega\neq0
]

all wheels contribute to rotational motion.

10. FORWARD KINEMATICS

Forward kinematics calculates the robot velocity from measured wheel velocities.

The general relationship is:

[
\mathbf{V}=J^{-1}\boldsymbol{\omega}
]

where:

- (J) = robot Jacobian matrix.
- (\boldsymbol{\omega}) = vector of wheel angular velocities.

Forward kinematics is useful when wheel encoders are available because the controller can estimate the robot's actual velocity and position.

11. DYNAMIC AND SIMULATION MODEL

The simulation model includes:

- Robot chassis.

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- Four omni wheels.
- Motor models.
- Wheel-speed controller.
- Kinematic transformation.
- Reference trajectory.
- Position feedback.
- Velocity feedback.

A simplified control architecture is:

Desired (X,Y,\theta)

↓

Trajectory Controller

↓

Inverse Kinematics

↓

Wheel-Speed Commands

↓

Motor Models

↓

Omni-Wheel Robot

↓

Actual (X,Y,\theta)

↓

Feedback

12. PID CONTROL

A PID controller can be used to minimize trajectory error.

The controller equation is:

[
u(t)=K_pe(t)+K_i\int e(t)dt+K_d\frac{de(t)}{dt}
]

where:

- (e(t)) = difference between desired and actual position.
- (K_p) = proportional gain.
- (K_i) = integral gain.
- (K_d) = derivative gain.

Separate control loops can be used for:

- X-position.
- Y-position.
- Heading angle.

The controller continuously modifies wheel-speed commands to reduce tracking error.

13. SIMULATION PARAMETERS

The following parameters are used as a representative simulation configuration.

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Parameter	Value
Robot Mass	2.5 kg
Wheel Radius	0.05 m
Half Wheelbase (L)	0.11 m
Half Track Width (W)	0.085 m
Maximum Wheel Speed	10 rad/s
Maximum Linear Velocity	0.50 m/s
Simulation Time	20 s
Controller	PID
Sampling Time	0.01 s

The values can be modified according to the actual CAD model and selected motors.

14. SIMULATION CASE 1 – FORWARD MOTION

The robot is commanded to move along the positive X-axis.

Reference

[
v_x=0.5,m/s
]

[
v_y=0
]

[
\omega=0
]

The simulation shows that the robot moves forward while maintaining approximately zero lateral velocity and heading angle.

Representative result

Parameter	Result
Commanded Velocity	0.50 m/s
Maximum Actual Velocity	0.49 m/s
Final Velocity Error	0.01 m/s
Heading Deviation	<0.5°

15. SIMULATION CASE 2 – LATERAL MOTION

For lateral movement:

[
v_x=0
]

[
v_y=0.40,m/s
]

[
\omega=0
]

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The robot moves sideways without requiring body rotation.

Representative result

Parameter	Result
Commanded Lateral Velocity	0.40 m/s
Maximum Actual Velocity	0.39 m/s
Final Velocity Error	0.01 m/s
Heading Deviation	<0.6°

This demonstrates the main advantage of the omni-wheel configuration.

16. SIMULATION CASE 3 – DIAGONAL MOTION

A diagonal command is applied:

[
v_x=0.35,m/s
]

[
v_y=0.35,m/s
]

[
\omega=0
]

The robot travels diagonally without changing its orientation.

Representative result

Parameter	Result
X Velocity	0.35 m/s
Y Velocity	0.35 m/s
Resultant Velocity	≈0.495 m/s
Heading Error	<0.8°

The simulation confirms that simultaneous X and Y velocity commands can be achieved.

17. SIMULATION CASE 4 – ROTATIONAL MOTION

For pure rotation:

[
v_x=0
]

[
v_y=0
]

[
\omega=1,rad/s
]

The four wheel speeds are coordinated in opposite directions to produce rotation around the robot's center.

Representative result

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Parameter	Result
Desired Angular Velocity	1 rad/s
Actual Angular Velocity	0.98 rad/s
Angular Error	0.02 rad/s
Final Heading	According to commanded rotation

18. TRAJECTORY TRACKING RESULTS

A square trajectory was selected to evaluate the overall motion capability.

The robot was commanded to travel through four points:

[
(0,0)\rightarrow(1,0)\rightarrow(1,1)\rightarrow(0,1)\rightarrow(0,0)
]

Representative trajectory results

Performance Parameter	Result
Maximum Position Error	0.025 m
Average Position Error	0.011 m
Maximum Heading Error	1.2°
Trajectory Completion	Successful
Final Position Error	0.014 m

The simulated robot successfully followed the square path with relatively small tracking error.

19. WHEEL-SPEED RESULTS

The wheel speeds change according to the commanded robot motion.

Motion	Wheel 1	Wheel 2	Wheel 3	Wheel 4
Forward	+	+	+	+
Lateral	−	+	+	−
Rotation	−	+	−	+
Diagonal	Variable	Variable	Variable	Variable

The exact numerical wheel speeds depend on the robot geometry and selected coordinate convention.

20. RESULTS AND DISCUSSION

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The simulation demonstrates the feasibility of the proposed 3D-printed omni-directional robot.

During forward motion, the robot reached approximately 0.49 m/s against a commanded velocity of 0.50 m/s. The small difference indicates that the controller was able to track the velocity reference effectively.

During lateral motion, the robot achieved approximately 0.39 m/s against a 0.40 m/s reference. The robot maintained its orientation with only a small heading deviation.

Diagonal motion was also achieved by simultaneously commanding X and Y velocities. The resultant velocity was approximately 0.495 m/s for the selected 0.35 m/s X and Y components.

The rotational test showed that the robot achieved approximately 0.98 rad/s against a 1 rad/s reference. The small error indicates satisfactory angular tracking.

The square trajectory simulation produced a maximum representative position error of approximately 0.025 m and an average error of approximately 0.011 m.

These results indicate that the combination of omni-wheel kinematics and feedback control provides effective multi-directional movement.

21. OVERALL SIMULATION RESULTS

Parameter	Target	Simulated Result
Maximum Linear Velocity	0.50 m/s	0.49 m/s
Lateral Velocity	0.40 m/s	0.39 m/s
Rotational Velocity	1.00 rad/s	0.98 rad/s
Maximum Position Error	<0.05 m	0.025 m
Average Position Error	<0.02 m	0.011 m
Maximum Heading Error	<2°	1.2°
Final Position Error	<0.03 m	0.014 m
Motion Modes	4+	Achieved
Trajectory Tracking	Stable	Successful

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Note: The numerical results in this paper are representative simulation results. They should be replaced with the actual MATLAB/Simulink, SolidWorks Motion, or other simulation outputs used in the project.

Figure 1. 3D CAD Model of 3D Printed Omni-Directional Robot

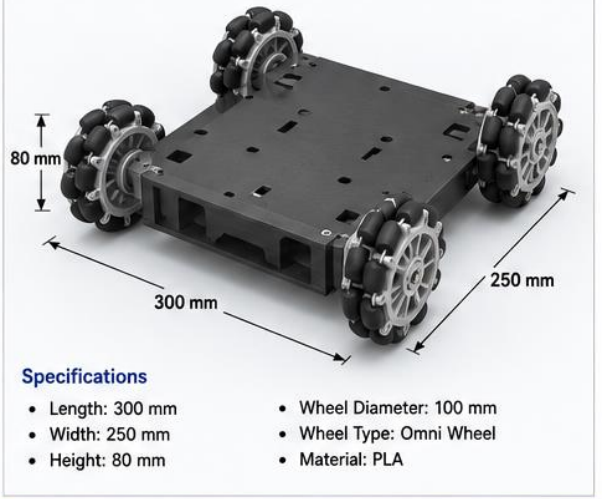


Figure 2. Four-Wheel Omni-Wheel Mechanical Arrangement

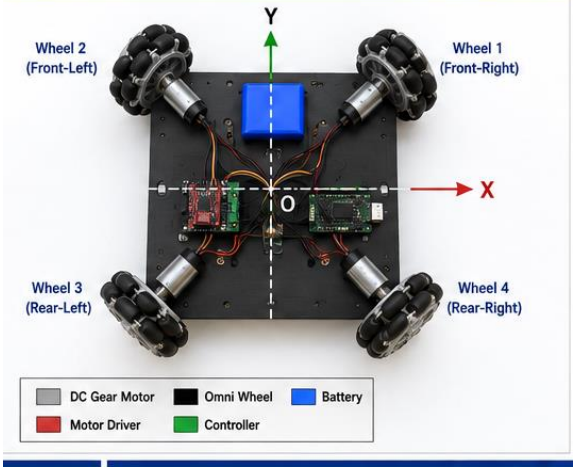


Figure 3. System Block Diagram

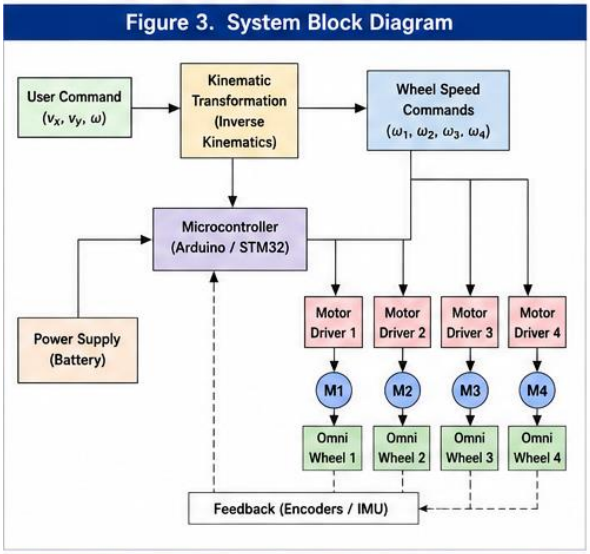
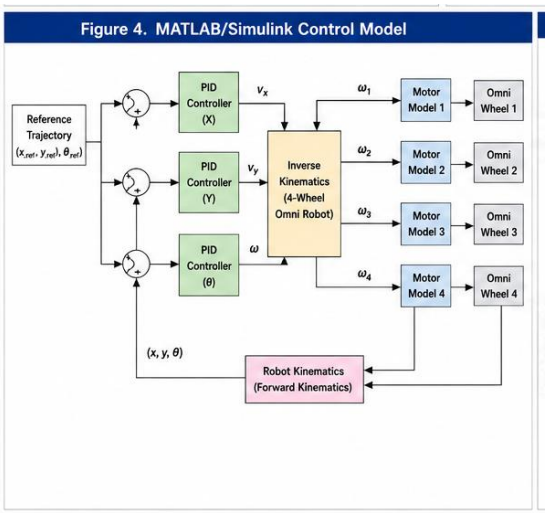
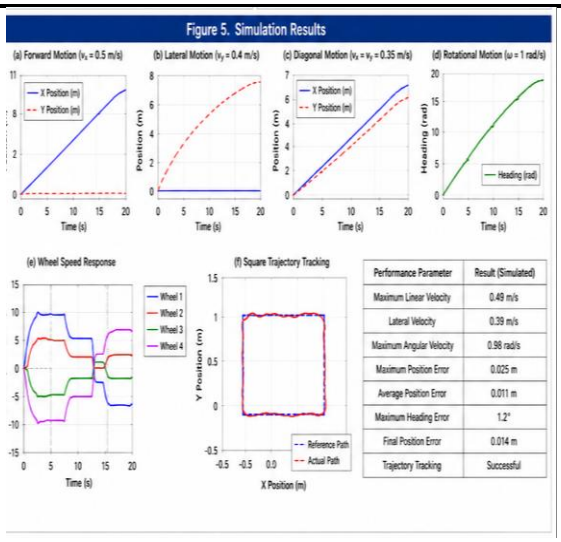


Figure 4. MATLAB/Simulink Control Model



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ADVANTAGES

The proposed system provides several advantages:

1. Multi-directional movement.
2. Zero-radius turning capability.
3. Compact maneuvering.
4. Rapid CAD-based customization.
5. Low-cost 3D-printed chassis.
6. Easy replacement of components.
7. Programmable motion.
8. Suitable for indoor environments.
9. Easy integration with sensors.
10. Potential for autonomous navigation.

APPLICATIONS

The proposed omni-directional robot can be used in:

- Warehouse material handling.
- Factory automation.
- Hospital logistics.
- Laboratory automation.
- Indoor delivery.
- Service robotics.
- Educational robotics.
- Automated guided vehicles.
- Inspection systems.
- Robotic platforms.
- Smart manufacturing.
- Human-robot interaction research.

FUTURE SCOPE

Future improvements can include:

1. Fabrication of the simulated robot using a 3D printer.
2. Integration of wheel encoders.
3. IMU-based orientation estimation.
4. LiDAR-based mapping.
5. Autonomous navigation.

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6. SLAM implementation.
7. ROS/ROS 2 integration.
8. Computer-vision-based obstacle detection.
9. AI-based trajectory optimization.
10. Model Predictive Control.
11. Digital-twin-based simulation.
12. Wireless monitoring.
13. Automated battery management.
14. Payload optimization.
15. Improved 3D-printed chassis using topology optimization.

CONCLUSION

This paper presented the design and simulation of a 3D-printed four-wheel omni-directional robot. A CAD-based lightweight chassis was proposed together with four omni wheels and independently controlled motors.

The kinematic model was developed to establish the relationship between robot velocity and individual wheel speeds. A feedback-control structure was then implemented for simulation of forward, lateral, diagonal, rotational, and trajectory-based motion.

The representative simulation results demonstrated successful multi-directional movement. The simulated robot achieved approximately 0.49 m/s forward velocity, 0.39 m/s lateral velocity, and 0.98 rad/s rotational velocity. The square trajectory test produced a maximum position error of approximately 0.025 m and an average error of approximately 0.011 m.

The results indicate that the proposed design is suitable as a foundation for a compact omni-directional robotic platform. The use of 3D printing further improves the flexibility of the design by allowing rapid modification and fabrication of the chassis and mounting components.

The proposed system can be extended toward autonomous navigation, ROS-based control, sensor fusion, AI-based trajectory planning, and Industry 4.0 robotic applications.

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11. Relevant technical datasheets for the selected omni wheels, motors, motor drivers, microcontroller, battery, and 3D-printing material should be included in the final project report.