# Genetic Algorithm-Optimized Fractional-Order SMC for Wheeled Robots

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The First National Conference on Emerging Trends in Engineering and Technology (NC2ET'25)

*January 14 -15, 2025. University Mustapha Stambouli of Mascara. Algeria.*

NC2ET'25

# Genetic Algorithm-Optimized Fractional-Order SMC for Wheeled Robots

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***Keywords:***
*-Fractional Order Sliding Mode Control.*

*-Wheeled Robot.*

*-Genetic Algorithm Optimization.*

*-Trajectory Tracking.*

*-Disturbance Compensation.*

***Abstract*** – This paper presents a Genetic Algorithm-Optimized Fractional-Order Sliding Mode Control (GA-FOSMC) approach for trajectory tracking of wheeled robots, focusing on disturbance compensation. The proposed method aims to enhance the tracking accuracy of wheeled robots while mitigating the effects of external disturbances such as external forces, sensor noise, and model inaccuracies. A fractional-order sliding mode control (FOSMC) framework is designed, incorporating a disturbance vector to adjust the control inputs for robust performance. The controller parameters are optimized using a Genetic Algorithm (GA) to minimize the tracking error. The simulation results demonstrate that the proposed GA-FOSMC controller effectively compensates for disturbances, ensuring precise trajectory tracking while maintaining stability. The approach is validated through simulation, showing its potential for real-world robotic applications where disturbance rejection and optimal performance are essential.

## I. INTRODUCTION

Autonomous wheeled robots are gaining prominence due to their applications in transportation, industrial automation, and search-and-rescue missions [1-3]. A key challenge for these robots is trajectory tracking, where they must accurately follow predefined paths while compensating for disturbances and nonlinear dynamics. These discrepancies arise from external factors like friction, wind, and sensor noise, as well as model uncertainties, which can lead to errors, performance degradation, or instability [4-6].

To tackle this, Sliding Mode Control (SMC) has proven effective due to its robustness to disturbances. However, traditional SMC often suffers from chattering, especially in fast-moving systems [7-9]. To overcome this, fractional-order sliding mode control is introduced, incorporating fractional derivatives to smooth control inputs and enhance robustness to noise, offering improved stability and precision [10,11].

Further, the optimization of FOSMC parameters, such as the sliding surface coefficients and fractional order, is critical to system performance. Genetic Algorithms are used to search the parameter space and find optimal values, ensuring high accuracy and robustness in trajectory tracking [12].

This work focuses on GA-optimized FOSMC for wheeled robots tracking circular and flower-shaped trajectories while addressing external disturbances. Simulations demonstrate the approach's effectiveness in improving tracking performance and stability, showcasing its potential for autonomous robot applications.

## II. SYSTEM MODELING

The kinematic model of the wheeled robot is described by the following set of differential equations:

$$\begin{aligned} \dot{x} &= v\cos(\theta) + d_x \\ \dot{y} &= v\sin(\theta) + d_y \\ \dot{\theta} &= w + d_\theta \end{aligned} \tag{1}$$

where

- $v$ is the linear velocity,
- $w$ is the angular velocity,
- $\theta$ is the robot's orientation,

- $d_x, d_y, d_\theta$ are the disturbances in the x, y, and angular directions, respectively.

The disturbances are modeled as:

$$d(t) = \begin{bmatrix} d_x(t) \\ d_y(t) \\ d_\theta(t) \end{bmatrix} \quad (2)$$

where the disturbance vector $d(t)$ is added to the system's state equation. These disturbances affect the robot's position and orientation during trajectory tracking, and thus, the controller must compensate for them to ensure accurate motion.

## III. FRACTIONAL-ORDER SLIDING MODE CONTROL

### A. Sliding mode control overview

SMC relies on defining a sliding surface $S(t)$ to ensure the system converges to the desired trajectory. For a wheeled robot, the error dynamics are given as:

$$e_x = x_d(t) - x(t), \; e_y = y_d(t) - y(t) \quad (3)$$

where $x_d, y_d$ are the desired positions and $x, y$ are the actual positions.

The sliding surface for classical SMC is:

$$S(t) = \dot{e}(t) + \lambda e(t) \quad (4)$$

where $\lambda$ is a positive gain ensuring exponential convergence.

### B. Fractional-order sliding surface

FOSMC extends the sliding surface to include fractional derivatives:

$$S_\alpha(t) = D^\alpha e(t) + \lambda e(t) \quad (5)$$

where $D^\alpha$ represents the fractional derevative of order $\alpha$ $(0 < \alpha \leq 1)$.

The fractional derivative can be approximated using a discrete-time Caputo derivative:

$$D^\alpha e(t) \approx \frac{e(t) - e(t - \Delta t)}{\Delta t^\alpha} \quad (6)$$

The control law for FOSMC is designed to ensure sliding mode conditions:

$$\dot{S}_\alpha(t) + \eta S_\alpha(t) = 0 \quad (7)$$

## IV. GENETIC ALGORITHM OPTIMIZATION

### A. Optimization proplem

The GA is used to optimize the parameters of the FOSMC controller (e.g., $\alpha$, $k_1, k_2, \lambda$) to improve the robot's trajectory tracking performance. The optimization problem is formulated as:

$$\min_{\alpha, k_1, k_2, \lambda} \sum_{t=0}^{T} \left( e_x^2(t) + e_y^2(t) \right) \quad (8)$$

where $T$ is the simulation time.

### B. GA optimization process

The GA starts by initializing a population of possible solutions (sets of $\alpha$, $k_1, k_2, \lambda$) and iteratively evolves the population by selecting, recombining, and mutating individuals based on their fitness, which is defined by the tracking error over time. The optimized parameters are then used to control the robot.

## V. RESULTS

The simulation results demonstrate tracking performance for circular and flower-shaped trajectories, with external disturbances ([0.1; 0.5; 0.2] m/s) added to test controller robustness.

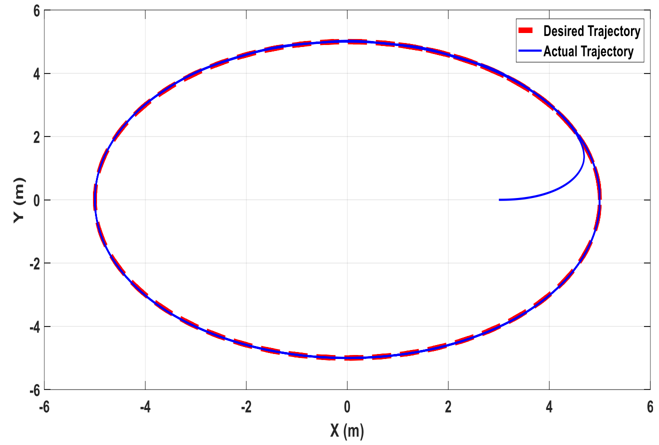


Fig.1 Wheeled Robot Trajectory Tracking.

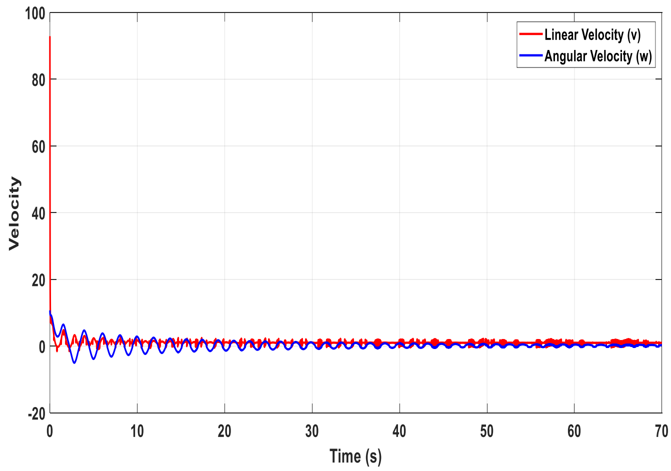


Fig.2 Control Inputs: Linear and Angular Velocities.

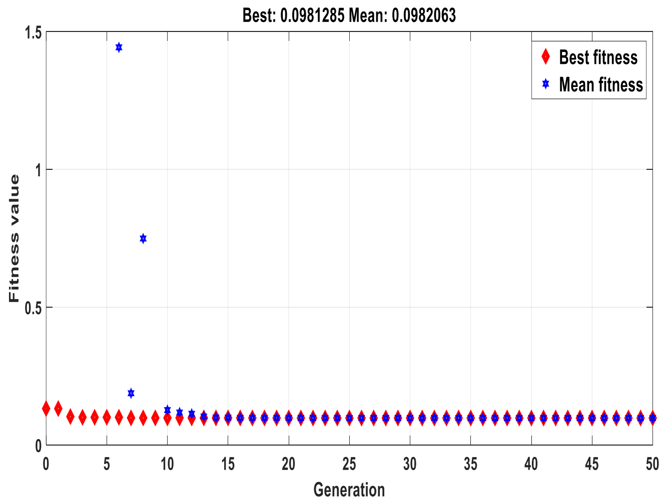


Fig.3 Best fitness over iterations.

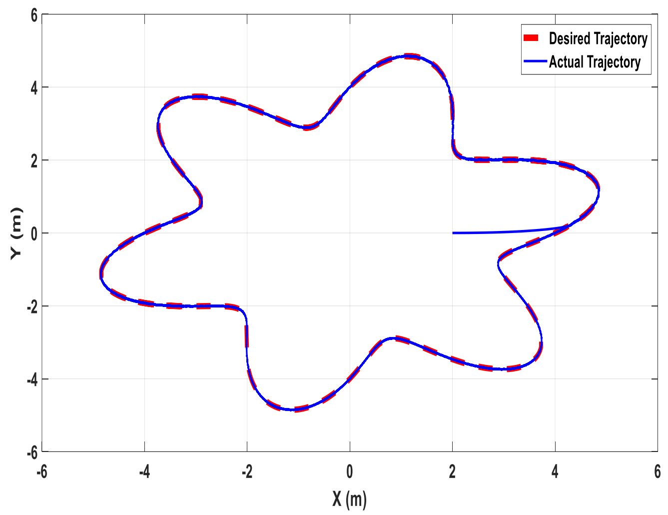


Fig.4 Wheeled Robot Trajectory Tracking.

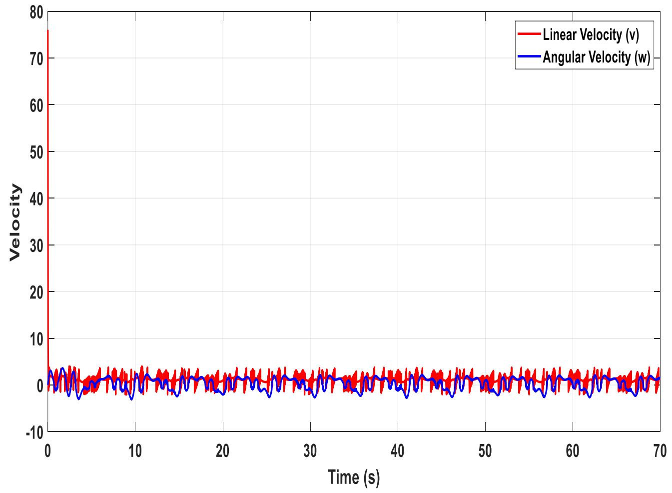


Fig.5 Control Inputs: Linear and Angular Velocities.

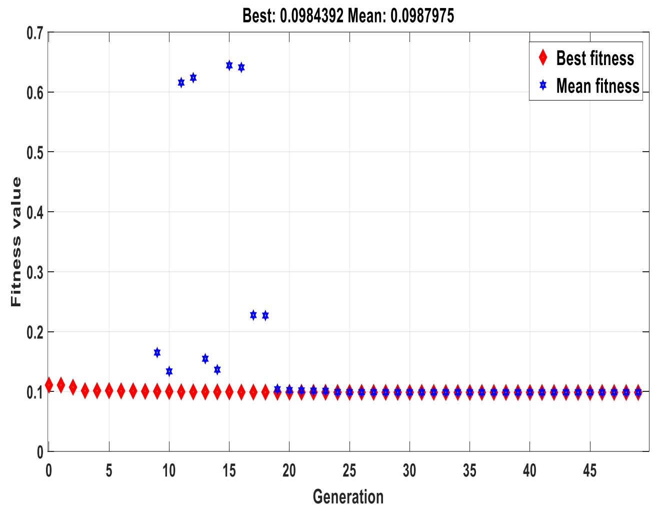


Fig.6 Best fitness over iterations.

## VI. DISCUSSION

- Figures 1 and 4 clearly illustrate that the robot effectively tracks both circular and flower-shaped trajectories, demonstrating the precision of the GA-FOSMC in addressing nonlinear dynamics and external disturbances. The circular path highlights smooth and consistent tracking, while the flower trajectory showcases the controller's capability to handle complex and rapidly changing shapes with minimal deviations.

- Subsequently, as depicted in Figures 2 and 5 the optimized FOSMC effectively mitigates the chattering commonly associated with conventional sliding mode controllers, enabling smooth transitions in control actions. Additionally, the stability of control inputs under applied disturbances highlights the controller's robust disturbance rejection capability.

- The fitness plot (Figures 3 and 6) illustrates the optimization process, showing the Genetic Algorithm's convergence to an optimal solution within a finite number of iterations. The rapid decline in fitness value during the early iterations highlights the algorithm's efficiency in exploring the search space, while the final fitness value underscores the enhanced tracking accuracy and robustness achieved through parameter optimization.

## VII. CONCLUSION

This work demonstrates the effectiveness of fractional-order sliding mode control for trajectory tracking of wheeled robots, even in the presence of disturbances. By incorporating genetic algorithm optimization, the controller parameters are fine-tuned to maximize performance. The controller successfully compensates for disturbances in both the x, y, and angular directions, ensuring robust and stable performance under uncertain conditions. The approach provides a reliable solution for trajectory tracking in real-world robotic applications, and future work can explore more complex disturbance models and dynamic environments.

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