Title: System Identification and Control of Mobile Robot

Shreehan S Kate

I. INTRODUCTION

Robust control algorithms are essential in autonomous robotic systems to ensure accurate trajectory tracking and system stability, particularly when dealing with linearized approximations of inherently nonlinear dynamics. However, directly modelling and controlling such nonlinear systems can be analytically intractable and computationally expensive. A practical solution is to derive linear models that approximate the behavior of the nonlinear system around an operating point, and then design efficient controllers based on these models.

This report presents a systematic workflow using MATLAB and Simulink for system identification and control of a mobile robot. The core of this methodology is the Numerical Subspace State Space System IDentification (N4SID) algorithm, which estimates a discrete-time linear state-space model from real-world input-output data. The identified model is then converted into a continuous-time representation for controller synthesis.

A classical Proportional-Integral-Derivative (PID) controller is designed and tuned using the Ziegler-Nichols method, a widely used heuristic approach that provides a good balance between responsiveness and robustness. The PID controller operates in a closed-loop structure to control both the position and velocity of the robot. The resulting control system is evaluated through simulation, using the identified state-space model as the plant.

The goal of this project is to demonstrate that a data-driven, linear control strategy can effectively control a nonlinear robotic platform, offering a practical bridge between real-world system behavior and classical control theory. The workflow includes data acquisition, system identification, controller tuning, and validation via simulation.

All experiments were conducted using MATLAB R2024b and validated in Simulink. Simulation results show that the identified model accurately captures the system dynamics and that the designed PID controller ensures stable and responsive performance.

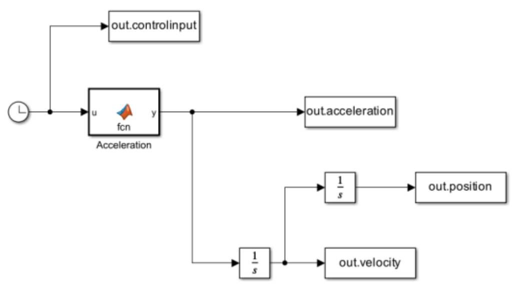
The following sections detail the methodology, implementation, results, and performance evaluation of the proposed control strategy.

II. METHODOLOGY

Data collection, system identification, controller design, and simulation-based validation comprised the four stages of the structured methodology used in the control system design process. The goal was to create a linear model of the mobile robot using actual data, then use a PID controller to accomplish precise and steady tracking.

2.1 Data Collection

Data was obtained from a mobile robot simulation, where the **control input** and resulting **acceleration** were recorded. A Simulink model (Figure 2) was used to convert acceleration to **velocity** and **position** using double integrators. This generated the dataset required for system identification in the form of input-output time series.



2.2 System Identification

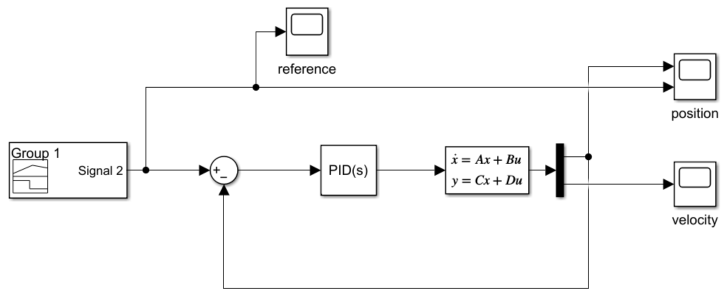
The dataset was structured into an iddata() object containing position and velocity as outputs and control input as the input. The **N4SID** algorithm was applied to identify a second-order discrete-time state-space model, capturing the linearized dynamics. The identified model was then converted to a continuous-time form using d2c(), and matrices A,B,C,D were extracted. The identification results revealed a sufficiently accurate approximation of the nonlinear system's behavior, enabling reliable controller synthesis.

2.3 Controller Design

A **PID controller** was designed using the **Ziegler-Nichols method**, where the ultimate gain and oscillation period were used to tune the proportional, integral, and derivative gains. The controller was applied to the position error between the desired reference and actual output. The complete closed-loop system (Figure 1) included the PID block, the identified state-space model, and feedback from both position and velocity.

2.4 Simulation and Validation

The final closed-loop architecture was implemented in Simulink (Figure 1), integrating the identified system and PID controller. Reference inputs were provided as piecewise signals, and system outputs were logged for performance analysis. The simulation verified the controller's ability to track reference trajectories with minimal overshoot and quick settling.



III. RESULTS

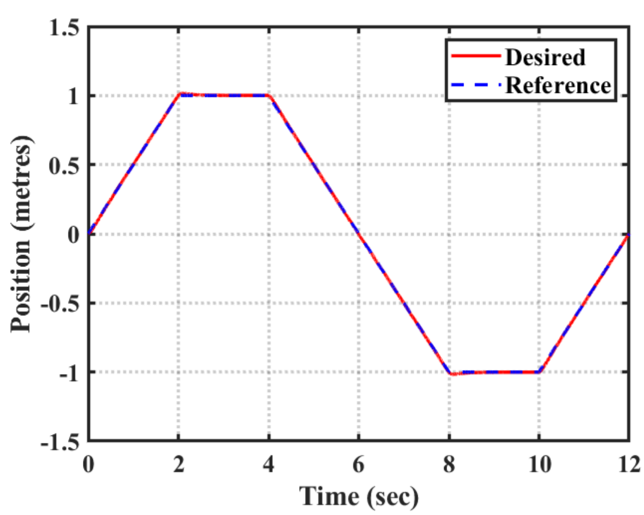
The closed-loop control system was implemented in Simulink using the identified linear model and the tuned PID controller.

Obtained gains after tuning:

$$\mathbf{K_p = 12.69;\ K_i = 2.94;\ K_d = 3.461}$$

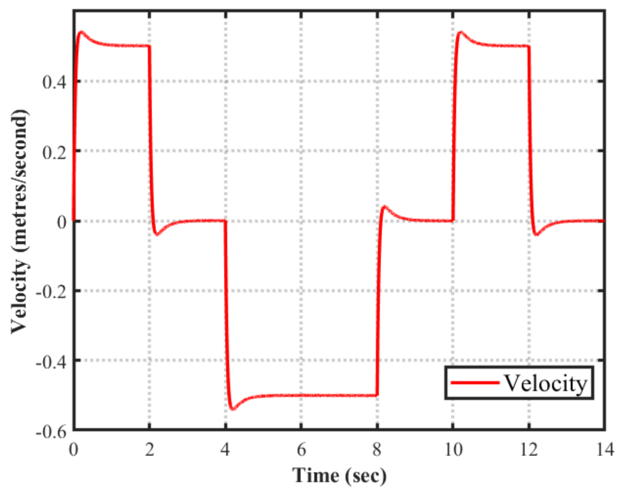
4.1 Position Tracking

As shown in Figure 3, the system exhibits accurate position tracking with minimal steady-state error. The controller successfully drives the system output to follow the reference signal with negligible overshoot and no oscillations. The settling time remains well within acceptable bounds. The identified model effectively captures the robot's dynamic behavior, enabling the linear controller to perform reliably even under nonlinear operating conditions.



4.2 Velocity Response

Figure 4 illustrates the velocity response of the system. The control input generates smooth and continuous velocity profiles, free from abrupt spikes or noise-induced instability. The controller ensures a rapid and stable adjustment of the robot's velocity in response to position errors, which contributes to the overall smoothness of the trajectory.



IV. CONCLUSION

This project successfully demonstrates the application of data-driven system identification and classical PID control to a nonlinear mobile robot platform. By leveraging the N4SID algorithm, a reliable linear state-space model was obtained from real input-output data, enabling effective controller design using well-established linear techniques. The Ziegler-Nichols-tuned PID controller achieved accurate position tracking and stable velocity response in closed-loop simulations. Despite the underlying nonlinear dynamics, the linear approximation proved sufficient for robust and responsive control, validating the practicality of this approach for real world robotic systems. Future work may explore adaptive or learning-based control strategies to further enhance performance and generalization.