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Motion control algorithms for wheeled mobile robots with longitudinal slipping

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Abstract
This paper addresses the trajectory tracking control problem for wheeled mobile robots (WMRs) subject to unknown longitudinal slip and unmeasurable orientation angle. Conventional control strategies typically rely on idea nonholonomic constraints and require either known slip parameters or real-time sensory measurements, which are often impractical in real-world applications due to cost constraints and environmental uncertainties. To overcome these limitations, a novel observer-based adaptive control framework is proposed that reconstructs both unknown system states and parameters using only position feedback. A kinematic model incorporating longitudinal slip effects is first established. A reduced-order observer is then designed to estimate the unmeasurable orientation angle from available position coordinates via nonlinear estimation techniques. Subsequently, an adaptive backstepping controller integrated with Lyapunov-based parameter adaptation laws compensates for slip-induced tracking deviations. The closed-loop system is implemented in Simulink. The results show that the proposed scheme achieves effective trajectory tracking without the need for heading or velocity sensors.
Keywords
Wheeled mobile robot, longitudinal slipping, adaptive control, orientation angle observer.

Алгоритмы управления движением колесных мобильных роботов с продольным проскальзыванием

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Аннотация
В работе решается задача управления траекторным отслеживанием колесных мобильных роботов при неизвестном продольном скольжении и неподсчитываемом угле ориентации. Конвенционные методы, основанные на идеальных неголономных ограничениях и сенсорных измерениях, нецелесообразны в практике из-за стоимостных ограничений и экологических неопределенностей. Предлагается адаптивная управляющая структура на основе наблюдателя, реконструирующая неизвестные состояния системы по обратной связи по положению. Разработана кинематическая модель с учетом скольжения, редуцированный наблюдатель угла ориентации и адаптивный регулятор по методу обратного шага с законами адаптации по Ляпунову. Реализация в Simulink подтверждает эффективное отслеживание траектории без сенсоров курса и скорости.
Ключевые слова

колесной мобильный робот, продольное скольжение, адаптивное управление, наблюдатель угла ориентации.

Over the past two decades, Wheeled Mobile Robots (WMRs) have seen widely applied in industry, agriculture, and national defense. Motion control under nonholonomic constraints has been a key research focus, yet most strategies rely on the ideal ‘pure rolling without slipping’ assumption [1]. In practical, wheel slip on slippery or rough terrain violates these constrains and degrades tracking performance. Existing solutions often require known slip parameters or real-time sensor measurements, which are impractical and costly [2,3]. This work proposes an observer-aided adaptive control architecture for Wheeled Mobile Robots (WMRs) that eliminates dependency on high-cost external sensors by algorithmically reconstructing unmeasurable states and unknown parameters.

To solve the trajectory tracking control problem of wheeled mobile robot under unknown longitudinal slip parameters and orientation angle, this work proposes a comprehensive solution structured as follow. First, a WMR kinematic model is established that includes longitudinal slip effects and violates nonholonomic constraints. Subsequently, a reduced order observer is designed to solve the problem of unmeasurable orientation angles, which only uses position coordinate information to reconstruct orientation angle through nonlinear estimate technology. An adaptive nonlinear feedback controller is then developed using the backstepping method and Lyapunov direct method, which estimates the unknown slip parameters and adjusts the control input to compensate for slip-induced trajectory deviations. Finally, the proposed control system is implemented in Simulink, and its performance is verified under conditions of abrupt parameter variations for both straight-line and circular reference trajectories.

This work employs the backstepping technique and Lyapunov direct method to synthesize an adaptive tracking controller with a parameter adaptation law for WMRs experiencing unknown longitudinal slip. An observer is designed to estimate the unmeasurable orientation angle from available coordinate information. Finally, simulation experiments validate the system's tracking control performance and robustness.

References

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