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AN ADAPTIVE EXTENSION OF VECTOR FIELD HISTOGRAM FOR LOCAL NAVIGATION IN DYNAMIC ENVIRONMENTS

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Abstract

Autonomous navigation in dynamic environments remains a challenging problem due to unpredictable obstacle motion and the limited predictive capability of classical reactive algorithms. The Vector Field Histogram Plus (VFH+) method is widely used for real-time local obstacle avoidance; however, it does not explicitly account for future obstacle states, which may lead to abrupt maneuvers and reduced trajectory smoothness. This paper proposes an adaptive predictive extension of the classical VFH framework designed for safe and smooth navigation in dynamic scenarios. The approach integrates a Constant Acceleration Kalman Filter for short-term motion prediction of dynamic obstacles, an adaptive exponential obstacle magnitude formulation for risk representation in the polar histogram, and a temporal memory mechanism with adaptive decay. Candidate steering directions are additionally evaluated using Time-to-Collision analysis combined with a short-horizon rollout strategy. Simulation results in MATLAB demonstrate improved safety margins, smoother trajectories, and enhanced robustness compared with classical VFH-based methods.

Keywords

Mobile robot navigation, Vector Field Histogram, dynamic obstacles, motion prediction, Kalman filter, time-to-collision.

АДАПТИВНОЕ РАСШИРЕНИЕ МЕТОДА ВЕКТОРНОЙ ГИСТОГРАММЫ ПОЛЯ ДЛЯ ЛОКАЛЬНОЙ НАВИГАЦИИ В ДИНАМИЧЕСКИХ СРЕДАХ

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Аннотация

Навигация мобильных роботов в динамических средах осложняется непредсказуемым движением препятствий и ограниченными прогностическими возможностями реактивных алгоритмов. Метод Vector Field Histogram Plus (VFH+) широко

применяется для локального обхода препятствий в реальном времени, однако не учитывает будущие состояния динамических объектов, что может приводить к резким манёврам и снижению плавности движения. В работе предлагается адаптивное прогностическое расширение алгоритма VFH, основанное на использовании фильтра Калмана с моделью постоянного ускорения, адаптивной экспоненциальной функции формирования весов препятствий и механизма временной памяти с затуханием. Дополнительно применяется анализ времени до столкновения и краткосрочное прогностическое моделирование движения. Результаты моделирования в среде MATLAB показывают повышение безопасности и плавности траектории по сравнению с классическими методами VFH.

Ключевые слова

Навигация мобильных роботов, векторная гистограмма поля, динамические препятствия, прогнозирование движения, фильтр Калмана, время до столкновения.

Autonomous navigation has become a fundamental research area in modern robotics, enabling intelligent systems to operate in complex and dynamic environments such as autonomous vehicles, aerial robots, and rescue systems [1]. Numerous local navigation methods have been developed, including Artificial Potential Fields, Dynamic Window Approach, and Vector Field Histogram algorithms [2]. Among them, the VFH+ method has gained recognition due to its computational efficiency and real-time performance. However, despite its effectiveness in static environments, VFH+ remains purely reactive and lacks predictive capability. This limitation reduces performance in dynamic scenarios with moving obstacles and may result in abrupt maneuvers and reduced motion smoothness [3]. Recent research has attempted to enhance reactive navigation by incorporating heuristic trajectory evaluation and predictive mechanisms [4].

The proposed approach extends classical VFH-based navigation by integrating prediction and time-aware decision making. Dynamic obstacles are modeled using a Constant Acceleration Kalman Filter, enabling short-term motion prediction while accounting for uncertainty. Predicted obstacle states are incorporated into an adaptive exponential magnitude formulation that maps collision risk into the polar histogram representation. To prevent outdated information from influencing navigation decisions, a temporal prediction memory with adaptive decay is introduced. Furthermore, candidate steering directions are evaluated using Time-to-Collision analysis combined with a short-horizon rollout simulation that considers predicted obstacle motion and robot kinematic constraints. The final steering direction is selected using a multi-criteria cost function including goal alignment, obstacle density, smoothness, and predicted collision risk.

Simulation experiments conducted in MATLAB demonstrate improved safety margins, smoother trajectories, and enhanced robustness compared with classical VFH-based approaches. The integration of prediction and risk-aware evaluation allows earlier and more stable avoidance behavior in dynamic environments. Future work will focus on real-world experimental validation and computational optimization of the predictive module.

Literature

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