Trajectory and Flow Optimization for Multi-Part, Multi-Location Pick-and-Place Tasks Using Nonlinear Model Predictive Control

Amanuel Abrdo Tereda, *Graduate Student Member, IEEE*, Sun Yi, Jagannathan Sankar, Yimesker Yihun, and Richard Holdbrook

***Abstract*—This paper presents a comprehensive trajectory and flow optimization framework in multi-part, multi-location pick-and-place operations using Nonlinear Model Predictive Control (NLMPC). The proposed system enables a single robotic manipulator to execute multiple sequential pick-and-place actions across spatially distributed locations within a single operational cycle, significantly improving throughput and flexibility in industrial automation tasks. A central contribution of this work is the introduction of terminal cost penalization in the NLMPC formulation, targeting joint velocity and acceleration at the end of the trajectory to enable smooth and precise motion termination. Additionally, Euclidean distance constraints are incorporated to enhance the final pose accuracy of the end effector. The system is validated through extensive simulation experiments using a KINOVA Gen3 robotic arm in both obstacle-free and obstacle-present environments, where object and obstacle positions are predefined. Results show that penalizing the cost function improves end-effector precision, reducing Euclidean distance error by 35.9% in the obstacle-free case and 10.6% in the obstacle-present scenario. The NLMPC framework also maintains collision avoidance and respects joint limits. Penalizing joint velocity and acceleration leads to smoother stops, increased placement precision, and reduced mechanical wear, while applying Euclidean distance constraints ensures accurate final positioning of the end-effector. The method is computationally efficient and runs in real time on a standard CPU. Although the simulations assume known object locations, the framework is extensible to real environments with integrated perception. Open-source code and videos are provided to support adoption and replication.**

***Index Terms*—Multi-part pick-and-place, NLMPC, path-planning, optimization, obstacle avoidance, cost function penalization, industrial automation, KINOVA Gen3 robotic arm.**

I. Introduction

THE impact of pick-and-place robots on the manufacturing industry is profound, significantly contributing to automation, efficiency, and precision across diverse applications. Multi-part pick-and-place systems, capable of handling multiple objects from different locations to various destinations