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Abstract of Thesis

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Title	Reinforcement Learning for Contact-Rich Assembly Tasks (接触を伴う組立作業の強化学習)

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General-purpose industrial robot manipulators play a more significant role in modern manufacturing industries, particularly in high-mix low-volume (HMLV) production industries. Part mating and insertion, also called Peg-In-Hole (PIH) tasks, are very common in the manufacturing industry. Though PIH tasks have been extensively researched, safely solving high-precision assembly in an ever-changing environment remains an open problem. Traditional methods require the design of manual engineered controllers and expertise to finetune the controller's parameters for a particular task. In HMLV production, where the task specifications change frequently, traditional methods are unfeasible due to the high cost required to redesign and finetune controllers for each new task.

Reinforcement Learning (RL) is a promising solution to the automation problem. RL methods have been proven successful at solving manipulation tasks autonomously. However, RL is still not widely adopted on real robotic systems because working with real hardware entails additional challenges, especially when using rigid position-controlled manipulators. These challenges include needing a robust controller to avoid undesired behavior that risks damaging the robot and its environment and constant supervision from a human operator.

The main contributions of this dissertation are; first, we proposed a learning-based force control framework combining RL methods with traditional force control to enable learning on industrial position-controlled robotic manipulators on real-world hardware. Second, a simulation-to-real (sim2real) method is proposed to reduce the burden of learning RL policies directly on real hardware. A physics simulator is used to emulate the robot dynamics and to provide the RL agent with a rich and diverse set of task conditions, after which the learned policies are transferred and finetune on the real robot. The proposed method is designed to enable the robotic agent to tackle assembly tasks even in the presence of uncertainty of the task's goal. Finally, we present a study for accelerating robot learning of contact-rich manipulation tasks based on Curriculum Learning (CL) combined with Domain Randomization (DR). The main idea is to guide the learning process by presenting the RL agent with tasks in increasing order of difficulty. The proposed methods have been empirically evaluated with various challenging industrial assembly scenarios in simulation and a real-world experimental setup. The results of such evaluations show the effectiveness of our proposed methods even when tackling high-precision contact-rich insertion tasks.

様式７

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

本論文は，ロボットが力を制御しながら作業を行う場合に，力制御のパラメータを強化学習に基づいて獲得する手法を提案するものである。特に，位置制御ロボットによる力制御の学習フレームワークの提案，Sim to Realを用いた物理シミュレーションに基づく学習手法の提案，ならびにカリキュラム学習を用いた学習時間の短縮について提案を行った．本研究は，従来まで産業用ロボットで困難であった力制御を広く利用可能にするために，力制御のパラメータ調整について新たな道筋をつけるものである。主査，副査で論文の審査をおこなった結果，いくつかの疑問点が挙げられた．それらは主に、強化学習の手法に手法の説明が不足していることに起因したものであり，説明を追加する必要性が指摘された．審査の際に出た疑問点に関する議論を中心に，最終審査をおこなった．最終審査ではBeltran君は全ての疑問に明確に回答した．これにより，主査，副査全員一致で本論文は博士（工学）として価値があるものと認められた．