Learning Robots to Work on the Construction Site

Autonomous and Collision-Free Manipulation in Complex Environments using Reinforcement Learning

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Subject Area
Data Science

Project Partner
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Introduction: HILTI AG, headquartered in Schaan, Liechtenstein, presented the first semi-autonomous construction site robot called Jaibot at the end of 2020. Other manufacturers from the fastening technology sector have now also jumped on the robotics technology track, as shown by the recently presented Baubot from the german company Fischer or also Basil from the US start-up Canvas. The development of an autonomous robot system with the ability to independently localize itself in a room or the collision-free manipulation of a multi-axis robot still represent a very high technical challenges and is a current and upcoming field of research. Robot programming using classical control theory reaches its limits in complex environments where a system has to react to temporally changing conditions or a multitude of moving obstacles. The analytic or concentrated modeling of a control plant is no longer possible. Using realistic physical simulation environments such as NVIDIA Isaac Sim or Gazebo, a digital robot twin can be trained using reinforcement learning (RL) to fulfil complex tasks and react to changing environments without explicitely being programmed.

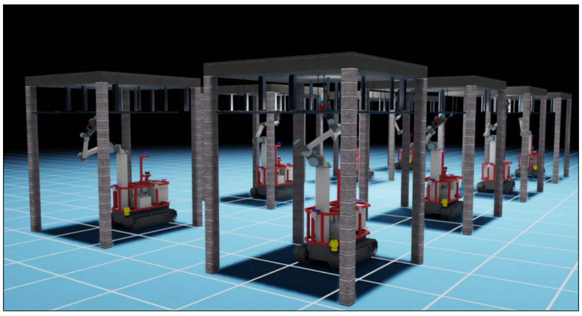
Objective: The aim of this master's thesis is to develop a complete simulation pipeline with NVIDIA Isaac Sim. The focus of this work was on following core topics:

- Generation of synthetic images for automatic drill hole detection
- RL policy for data-based control of a six-degree of freedom manipulator
- 3D reconstruction of the scanned environment based on RGB-D data respectively point clouds
- Collision-free path planning of a manipulator in a complex environment
- Comparison of classical path planning algorithms and data-based approaches
- Transfer of simulation to reality «sim-to-real»

Result: The first step in the setting process for stud anchors is the millimeter-precise detection of drilled holes in a ceiling. Due to tolerances and inaccuracies in the robot's mechanics, the drill hole must be detected using an imaging process. Within the scope of the work, classical computer vision (CV) algorithms, such as hough transformation for drill hole detection were compared with deep learning (DL) based approaches, like the YOLO detector in terms of their accuracy and robustness. Various simulations were developed, such as an end-to-end simulation with classic path planning algorithms. Several experiments were performed to realise a data-based policy for collision-free path planning with the help of RL. For this purpose, point cloud data from the RGB-D camera were reduced to a low-dimensional latent vector, that was used as additional state input for the RL algorithm. Due to limited GPU memory, it was not yet possible to train a vision-based RL task successfully. In a final step, the Python based path planning algorithms such as RMPflow or RRT were transferred from the simulation to a real robot and then validated in the real world (sim-to-real).

Jaibot Robot: a semi-autonomous drilling robot from HILTI.
https://ifdesign.com/de/winner-ranking/project/hilti-jaibot/

Massive parallel training within NVIDIA Isaac Gym as enabler for training RL-policies in complex environments.
Own presentment



Training curve of the reward over 4000 training epochs showing a steady improvement of the fulfilment of the task.
Own presentment