The Faculty of Engineering

POPULAR SCIENTIFIC ABSTRACT

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[Fast Setup of Robotic Material Processing with Quality Guarantees using Set Invariance]

This thesis proposes a comprehensive pipeline for the fast deployment of robots for high-quality manufacturing processing tasks. The thesis focuses on surface treatment applications as an example of the process. A popular way to achieve a fast setup is to transfer human skills to a robot by leveraging Programming by Demonstration (PbD). However, the current works are not reliable and flexible enough to ensure good performance and to generalize force-relevant tasks.

To remedy the above-mentioned challenges, this thesis proposes a model-based skill transfer framework for the robotic system. As an example of the robotic manufacturing process, this thesis develops the robotic polishing system based on human demonstrations.
To this end, human polishing skills are encoded using Material Removal Rate (MRR) and Material Removal (MR) based on Preston's equation. MRR/MR profiles are estimated during human demonstration and transferred to the robot through an MRR/MR tracking controller in the robot. This framework is also generalized into a new geometry, showing a successful skill transfer performance. However, if there exist kinematic errors between a given workpiece and a robot, the system cannot guarantee the quality of the process perfectly.

To resolve this issue, this thesis proposes the contact-based workpiece calibration method for robotic automation systems. Most workpiece calibration methods use vision devices, so they require advanced knowledge to set up the calibration system. On the other hand, this thesis proposes an easy and kinesthetic calibration method that lets users grab and move a robot onto the workpiece to collect the data and then estimates the pose of it. The method first estimates the collected contact data that includes the surface normal and contact point and then finds putative correspondences between 3D CAD model and the estimated data. By leveraging a robust non-minimal solver with Graduated Non-Convexity (GNC), the pose of the workpiece is estimated relative to the robot and used to reduce the kinematic discrepancy.

Lastly, this thesis considers the safety filter at the end of the pipeline. To this end, we leverage Control Barrier Functions (CBFs) to ensure safety guarantees, for example, contact force bounds and uses these bounds to provide quality guarantees in robotic surface polishing. However, since there exists model uncertainty in robotic systems, this thesis proposes a novel theoretical method for combining Gaussian Process (GP) with Robust adaptive Control Barrier Functions (RaCBFs) to reduce the uncertainty. Furthermore, since an unknown input delay might occur in the robotic system, which leads to safety violations, this thesis proposes a method for ensuring safety guarantees in the presence of input delay. The method estimates the unknown input delay and uses the estimated input delay to predict the future state with the system model. With the bounds of estimation and state prediction errors, robustness is enforced in the safety condition of CBFs.