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Fast Perception-Action Loops with Proximity Sensors for Robotic Manipulators

Band 3

Yitao Ding

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Fast Perception-Action Loops with Proximity Sensors for Robotic Manipulators

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Yitao Ding, M.Sc.

Gutachter:	Prof. Dr.-Ing. Ulrike Thomas Prof. Kaspar Althoefer

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Abstract

Proximity sensors attached to the outer shell of robotic manipulators provide fast and occlusion-free perception capabilities of the robot's nearby environment. They offer a solution towards fenceless collaborative workspaces by closing the gap in perception between (3D depth) cameras and tactile/force sensing. The perception gap occurs at the robot's close range, where external cameras provide insufficient information due to noise, resolution, and occlusion, and where tactile sensors remain untriggered. This thesis examines the fast perception-action loop of such systems to increase safety with reactive obstacle and collision avoidance motions and proactive adaption for impact attenuation. The loop consists of three elements: proximity perception, reactive motion generation, and the proactive adaption of the robot parameters.

The first part of the safety chain shows an on-robot proximity perception system. The concept behind the system is to combine two sensors. Laser-based time-of-flight sensing is used for far-range while capacitive proximity detection covers the blind areas by wide-area detection. A novel custom-designed capacitive proximity sensor is presented that is robust against different grounding conditions of obstacles, a significant issue of conventional capacitive proximity sensors. The perception system has characteristic features by providing rich near-field information with a limited quantity of measurement points, minimizing the amount of redundant information, and thus increasing responsiveness.

Reactive motions require only a few data points for fast motion generation and benefit from these features, especially for collision avoidance, where instantaneous adjustments of the robot's trajectory are mandatory. This thesis proposes two methods, one based on finding an avoidance vector with sampling in orthogonal directions towards the obstacle and another one by extending quadratic optimization to integrate the avoidance task within optimization constraints. Compared to common repulsive motions for collision avoidance, the proposed motion generators are less restrictive. They make full use of the robot's redundancy for task retention and provide solutions for multi-obstacle whole-arm obstacle avoidance. The algorithms further focus on evasive motions to bypass obstacles to decrease the risk of the robot freezing problem appearing. A phenomenon in which the robot gets stuck in local minima where it stops before obstacles in an equilibrium state of attraction towards the goal and repulsion from the obstacle.

The third part addresses the issue that collisions cannot always be prevented because the required avoidance motion exceeds the robot's motion capabilities. The last safety layer relies on the anticipation of contacts with proximity sensors to enhance the effectiveness impedance controllers for impact attenuation. The first measure modulates the stiffness of the impedance controllers as required, allowing faster, more accurate motions during regular operation while maintaining safety. A high stiffness setup suppresses positional disturbances during regular operation of the robot for high accuracy. The stiffness decreases only before impacts with safety as highest priority. The second measure slightly modifies the joint configuration to decrease the effective inertia of the manipulator at the impact point.

Keywords: *Proximity Servoing, Proximity Perception, Capacitive Proximity Sensors, Reactive Motions, Obstacle Avoidance, Collision Avoidance, Impact Attenuation*

For my family and friends.

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