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RESEARCH ON AN AUTOMATIC CONTROL SYSTEM FOR A MANIPULATOR FOR MOVING OBJECTS

Abstract. The aim of this work is the development and research of methods for automatic planning and motion control of a robotic system consisting of a manipulator ("hand") and a multi-fingered grasping device ("wrist") during object grasping and manipulation operations. The relevance is driven by the limitations of remote control in hazardous environments and the need to increase the reliability and versatility of automatic manipulations, especially when performing power (enveloping) grasps using not only the wrist's fingers but also the links of the hand itself. The research focuses on developing a unified approach to controlling the "hand + wrist" system, analyzing the grasp properties for such a combined system, developing methods for planning the coordinated motion of all links, and creating a control system that ensures trajectory tracking.

Key words: robotic system, manipulator, grasping device, object grasping, power grasp, motion planning, motion control, grasp theory, Jacobian matrix, grasp quality criteria.

Introduction. The use of robots for manipulation in hazardous or inaccessible environments is often limited by the shortcomings of remote control. Automatic control systems are an alternative but require effective methods for planning and executing operations, particularly object grasping. Traditional approaches often treat grasp planning (selecting contact points on the wrist) and manipulator (hand) motion planning as separate tasks. This limits the system's capabilities, especially when performing power grasps where the object contacts not only the fingers but also other links of the wrist or even the hand. Using the hand's links for grasping allows manipulating larger objects and increases holding reliability at low friction coefficients. However, methods for planning and controlling the coordinated motion of the entire "hand + wrist" system as a single entity have not been sufficiently studied. The aim of this work is to develop such methods for the automatic execution of grasping and transportation operations

Methods and Materials. The work is based on the analysis of existing "hand + wrist" type robotic systems and their control methods. The fundamental principles of grasp theory are applied, particularly the concepts of the grasp matrix (G) and the Jacobian matrix (J). Unlike classical approaches that consider the "wrist + object" system, matrices for the complete "hand + wrist + object" system (J_{PKO}) are analyzed here. It is shown that the Jacobian matrix of such a system differs from the wrist's Jacobian matrix by the presence of additional columns corresponding to the hand's degrees of freedom.

Based on the analysis of the null spaces and ranges of the matrices G and J_{PKO} , conditions for ensuring desired grasp properties (feasibility, determinacy, non-defectiveness, controllability, non-hyperstaticity) are formulated specifically for the combined system. It is proven that using the hand's degrees of freedom allows achieving desired properties (e.g., controllability or non-defectiveness) even when a grasp performed solely by the wrist does not possess them.

An approach for planning the coordinated motion of all system links has been developed. It includes:

1. Grasp Planning: Determining the hand and wrist configuration that ensures the desired grasp properties for the "hand + wrist + object" system. A modified approach based on a discretized reachability space is used.

2. Trajectory Planning: Calculating the system's motion trajectory from the initial position to the grasping configuration and further to the target position with the object. A modification of the RRT (Rapidly-exploring Random Trees) method, adapted for the "hand + wrist" system, is used, considering the need to change configuration for power grasping and collision avoidance. The Velocity Field Control (VFC) method is applied to generate local wrist trajectories when enveloping the object.

To control the system's motion along the calculated trajectory, a controller is used that ensures asymptotic tracking in the joint space despite uncertainties in the system dynamics.

Modeling of the developed methods was performed in the ROS software environment for a model of the Kawasaki FS020N manipulator with a Schunk WSG-50 two-finger gripper (Fig. 1).

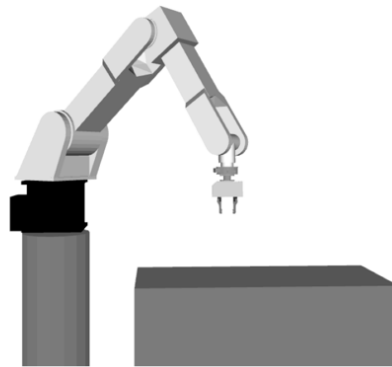


Fig. 1. Software model of the experimental setup

A comparative analysis of grasp quality (using various criteria) was performed for cases of grasping only with the wrist and with the "hand + wrist" system. Physical experiments were conducted on real equipment to verify the modeling results and the performance of the control system (Fig. 2).

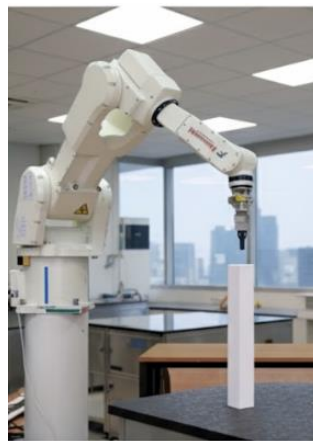


Fig. 2. Process of grasping a bulky object

Conclusions. Methods for planning and control for automatic grasping and manipulation of objects by a "hand + wrist" type robotic system have been developed and investigated. The proposed approach, unlike existing ones, considers the hand and wrist as a single system, allowing the use of the hand's degrees of freedom to ensure reliable power grasps, manipulation of larger objects, and increased overall payload capacity. Mathematical conditions for ensuring desired grasp properties for the "hand + wrist + object" system have been formulated, and criteria for the quality of such grasps have been analyzed. Algorithms for planning the coordinated trajectory of the hand and wrist links have been developed. Results from computer modeling and physical experiments confirmed the effectiveness of the proposed methods and the advantages of using the entire "hand + wrist" system for performing power grasps. It was shown that grasps utilizing the hand links exhibit better quality metrics.