Adaptive Robotic Gripping for Flexible Manufacturing: A Work-in-Progress Approach

1st Eliana Inca Cabrera
Department of Civil Engineering
University of Coimbra, ISISE; ARISE
Coimbra, Portugal
e.inca.cabrera@uc.pt

2nd Artur Mateus
Department of Civil Engineering
University of Coimbra, ISISE; ARISE
Coimbra, Portugal
artur.mateus@dec.uc.pt

3rd Catarina Fernandes
Department of Civil Engineering
University of Coimbra, ISISE; ARISE
Coimbra, Portugal
catarina.c.fernandes@uc.pt

4th Duarte Silva
Director Comercial Robótica
INAUTOM Robótica
Leiria, Portugal
duartesilva.robotica@inautom.pt

5th Fabio Roleiro
Engenheiro de Desenvolvimento
INAUTOM Robótica
Leiria, Portugal
fabioroleiro@inautom.pt

6th Gonçalo Fabião
Engenheiro de Desenvolvimento
INAUTOM Robótica
Leiria, Portugal
goncalofabiao.robotica@inautom.pt

***Abstract*—The increasing demand for flexibility in industrial manufacturing environments has driven the development of adaptive robotic manipulation systems capable of handling components with variable geometries. Conventional end-effectors are typically optimized for specific tasks, limiting their applicability in dynamic production contexts and leading to increased setup times and reduced operational efficiency. This work presents an ongoing research effort towards the development of an adaptive robotic gripping system based on a modular vacuum architecture combined with multi-axis reconfiguration and vision-assisted positioning. The proposed approach aims to enable automatic adaptation of gripping points according to object geometry, supporting flexible and reconfigurable manufacturing processes. The paper reviews relevant approaches in adaptive gripping and vision-guided manipulation, identifying current limitations in system integration and industrial applicability. A conceptual framework for the proposed system is introduced, highlighting its potential contribution to Industry 4.0 environments. Preliminary developments and ongoing work are also outlined.**

Keywords—Adaptive gripping, robotic manipulation, flexible manufacturing, vacuum gripper, machine vision, Industry 4.0

I. Introduction

The transition towards flexible and reconfigurable manufacturing systems is a key challenge in modern industrial environments. In sectors such as mould manufacturing, the variability of component geometries imposes significant constraints on conventional robotic manipulation systems.

Traditional grippers are typically designed for specific geometries or tasks, requiring frequent reconfiguration and leading to increased setup times. As a result, there is a growing interest in adaptive gripping systems capable of adjusting their configuration automatically in response to different objects.

This work addresses these challenges by exploring an adaptive gripping concept designed to support flexible industrial manipulation.

II. State of the Art

Recent research has focused on several approaches to adaptive robotic gripping [1], including modular gripper architectures [2], vacuum-based gripping systems [3], soft robotic solutions, and vision-guided manipulation. General reviews of robotic grippers highlight the evolution from task-specific rigid end-effectors towards more flexible and application-adaptable systems. Soft robotic grippers have also received significant attention due to their compliance, adaptability and ability to handle objects with complex or delicate geometries [4].

Vacuum-based systems are widely used in industrial applications due to their simplicity and robustness. However, their adaptability is often limited by fixed suction layouts. Modular and reconfigurable systems have been proposed to address this limitation, enabling variable positioning of gripping points.

In parallel, machine vision systems have been increasingly integrated into robotic manipulation [5,6], allowing object detection, pose estimation, and adaptive interaction strategies. Despite these advances, challenges remain in achieving efficient integration between sensing, actuation, and control in a unified system suitable for industrial deployment.

III. Proposed Concept

This work proposes an adaptive robotic gripping system integrating a modular vacuum-based gripper, a machine vision module and a supervisory control architecture. Unlike conventional fixed-layout vacuum grippers, the proposed system enables the multi-axis independent repositioning of multiple suction modules to accommodate components with varying geometries through vision-assisted configuration.

The proposed operating sequence consists of four stages. First, an RGB-D vision system acquires the object and reconstructs its three-dimensional geometry using image processing and object detection techniques. This information provides the geometric basis for defining suitable gripping locations on the object surface. The resulting point cloud or surface model is presented to the operator through a dedicated kiosk interface, which centralizes the interaction with the vision and control modules. The operator reviews the reconstructed object and defines the desired gripping locations, while the supervisory controller processes the selected coordinates and maps them into target positions for each suction module according to predefined geometric and operational constraints.

The positioning system then independently actuates the linear axes to automatically reconfigure the gripper. Motion along the X-axis distributes the suction modules laterally, sector-level motion along the Y-axis adjusts their longitudinal position, and individual Z-axis motion compensates for local surface variations, allowing each suction cup to conform to the target geometry. Once all modules have reached their target positions, the gripper is considered configured and ready for operation. The system then communicates the final configuration and tool-ready status to the main robot controller, allowing the adaptive gripper to be integrated into the programmed picking and handling cycle. This workflow defines the interaction between vision, user interface, gripper control and robotic manipulation while maintaining the proposed system at a proof-of-concept level.

IV. WORK-IN-PROGRESS STATUS

The current work focuses on the conceptual design and integration of the proposed system, including the development of the modular mechanical architecture (Fig. 1), the definition of the vision-assisted workflow (Fig. 2), and the identification of sensing and control requirements. Ongoing activities include the implementation of the supervisory control strategy, the integration of the vision and actuation modules, and the preparation of the experimental validation of the proposed concept.

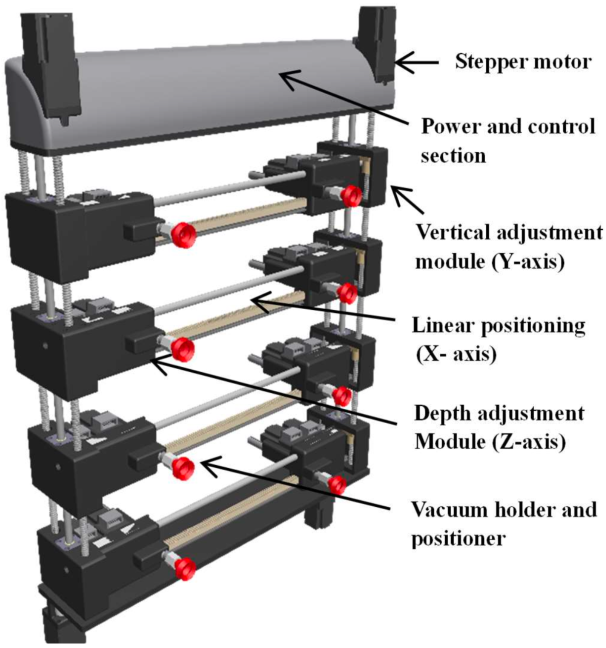

Fig. 1. Conceptual architecture of the adaptive robotic gripping system, showing modular vacuum-based gripping elements with multi-axis repositioning capability.

V. FUTURE WORK

This paper presented a work-in-progress approach towards the development of an adaptive robotic gripping system for flexible manufacturing applications. The proposed concept builds upon existing approaches in adaptive gripping and vision-guided manipulation, aiming to address current limitations in flexibility and integration.

Future work will focus on system implementation, experimental validation, and performance evaluation in industrial scenarios.

ACKNOWLEDGMENT

This work was carried out within the scope of the **ADAPTIHAND** project, reference **COMPETE2030-FEDER-01182500** (operation **no. 17338**), funded by the European Regional Development Fund (ERDF) through the Innovation and Digital Transition Programme (COMPETE 2030), under Portugal 2030 and the European Union.

This work was also supported by FCT/MCTES under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), under the references UID/4029/2025 (https://doi.org/10.54499/UID/04029/2025), UID/PRR/04029/2025 (https://doi.org/10.54499/UID/PRR/04029/2025) and UID/PRR2/04029/2025 (https://doi.org/10.54499/UID/PRR2/04029/2025), and under the Associate Laboratory Advanced Production and Intelligent Systems ARISE under reference LA/P/0112/2020 (https://doi.org/10.54499/LA/P/0112/2020).

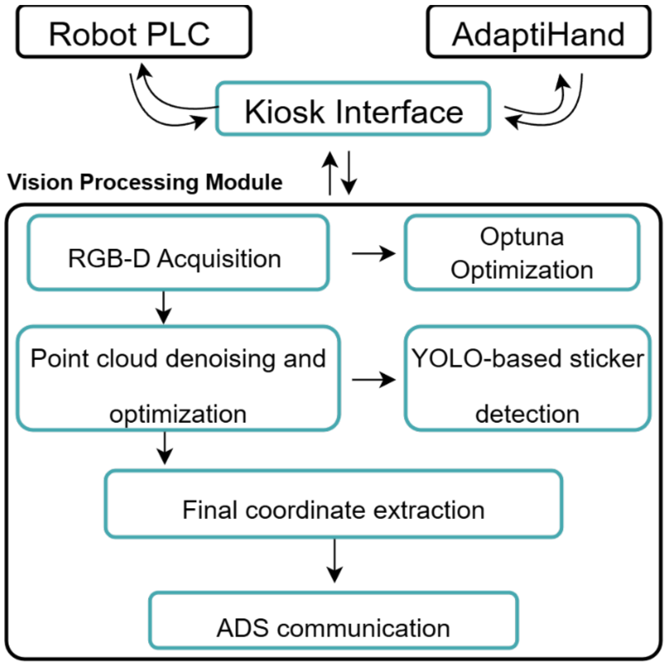

Fig. 2. Functional architecture of the system integrating control, vision and adaptive gripping

REFERENCES

[1] K. Tai, A.-R. El-Sayed, M. Shahriari, M. Biglarbegian, and S. Mahmud, "State of the art robotic grippers and applications," Robotics, vol. 5, no. 2, pp. 11, 2016. https://doi.org/10.3390/robotics5020011

[2] A. K. Ahmed, "Design of a new modular reconfigurable gripper," TEM Journal, vol. 11, no. 2, pp. 763–771, 2022. https://doi.org/10.18421/TEM112-35

[3] E. Brown, N. Rodenberg, J. Amend, A. Mozeika, E. Steltz, M. R. Zakin, H. Lipson, and H. M. Jaeger, "Universal robotic gripper based on the jamming of granular material," Proceedings of the National Academy of Sciences, vol. 107, no. 44, pp. 18809–18814, 2010. https://doi.org/10.1073/pnas.1003250107.

[4] Shintake, V. Cacucciolo, D. Floreano, and H. Shea, "Soft robotic grippers," Advanced Materials, vol. 30, no. 29, pp. 1707035, 2018. https://doi.org/10.1002/adma.201707035

[5] Z. Xie, Y. Wang, Z. Yu, and J. Zhang, "Learning-based robotic grasping: A review," Frontiers in Robotics and AI, vol. 10, pp. 1038658, 2023. https://doi.org/10.3389/frobt.2023.1038658

[6] G. Du, K. Wang, S. Lian, and K. Zhao, "Vision-based robotic grasping from object localization, object pose estimation to grasp estimation for parallel grippers: A review," Artificial Intelligence Review, vol. 54, pp. 1677–1734, 2021. https://doi.org/10.1007/s10462-020-09888-5