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A Low-Cost Soft Gripper for Automated Pick-and-Place Systems

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ABSTRACT

The study introduces a pioneering low-cost soft gripper designed for the automation industry, specifically targeting sensitive handling requirements in the food and health sectors. Utilizing rubber or elastic composites, the gripper combines improved sensitivity and adaptability to handle delicate materials safely and efficiently, aligning with stringent industry standards. Central to the design is a pneumatic control system that ensures precise manipulation, allowing the gripper to adapt to varying object contours without causing damage. This innovation not only addresses the mechanical aspects of soft robotics but also integrates seamlessly with Industry 4.0 technologies through smart sensors and AI algorithms, enhancing operational intelligence and versatility. By leveraging additive manufacturing techniques, the design also achieves significant cost reductions, facilitating broader adoption. This study's soft gripper represents a critical step forward in the development of robotic systems that can perform complex tasks with high sensitivity and economic efficiency, promising transformative impacts on the automation capabilities of sensitive industrial sectors.

Keywords: Soft Robotics, Gripper Design, Pick-and-Place

1 Introduction

The inception of the Industrial Revolution marked the beginning of significant advancements in manufacturing, culminating in the creation of the first programmable robot in 1954. Today, the field of robotics faces new challenges, particularly in handling delicate materials safely and efficiently. Soft robotics, inspired by the adaptive nature of biological organisms, presents solutions to these challenges. Our work introduces a novel soft gripper that addresses the need for gentle handling in the automation industry without compromising on precision or cost [12].

Recent advancements in soft robotics have predominantly focused on the development of soft actuators and grippers, reflecting a growing recognition of their potential to revolutionize industrial automation, particularly in pick-and-place systems. Soft grippers, fabricated from materials such as silicone, exhibit unparalleled flexibility and adaptability, enabling the gentle handling of a wide range of objects, from fragile components to irregularly shaped food products [5,10]. These characteristics have catalyzed significant research into the optimization of soft gripper design for enhanced performance and cost-efficiency.

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The literature is replete with studies exploring various facets of soft gripper innovation. For instance, experiments with inflatable membranes [6] and the development of versatile gripping systems [8] have expanded the functional capabilities of soft grippers. Further, research into the simulation of elastomer actuators [9] and the utilization of shape memory materials [13] has enriched our understanding of the materials science underpinning soft robotics. The integration of pneumatic double-joint actuators has also been explored, enhancing the dexterity and efficiency of soft gripping mechanisms [16].

Current soft grippers, while versatile, often fall short in balancing cost, efficiency, and delicate handling capabilities. Our research addresses these gaps by developing a cost-effective, highly adaptable gripper that meets the rigorous demands of sensitive industrial environments. This means the field faces challenges in the form of high manufacturing costs and complexity in design and control systems, which hinder the broader adoption of soft grippers in industrial applications. Addressing these challenges, the current study aims to design and develop a new soft robot gripper that leverages low-cost additive manufacturing techniques without compromising on efficiency or functionality. This research endeavors to bridge the gap between the theoretical potential and practical implementation of soft grippers, focusing on system overview, mechanical design, pneumatic control, and automation design. It seeks to underscore the cost-effectiveness and usability of the new design, thereby contributing a novel solution to the ongoing discourse in soft robotics.

2 Materials and Methods

The genesis of the proposed soft gripper system was predicated on a foundational design philosophy that emphasizes cost-efficiency, ease of manufacturing, and operational versatility. Utilizing computer-aided design (CAD) software, the initial geometric and structural parameters of the gripper were conceptualized as shown in Figures 1 and 2. This phase was informed by an extensive review of biomimetic principles, aiming to emulate the adaptive grip dynamics observed in natural organisms [6]. The design intricacies were further refined through iterative simulations, ensuring optimal force distribution and material elasticity for handling a variety of objects. To evaluate the gripper's performance, we employed a series of empirical tests and simulations. Detailed parameters, such as air pressure ranges and grip force settings, were documented to ensure reproducibility. Our experiments simulated real-world pick-and-place tasks to validate the gripper's functionality across various object types.

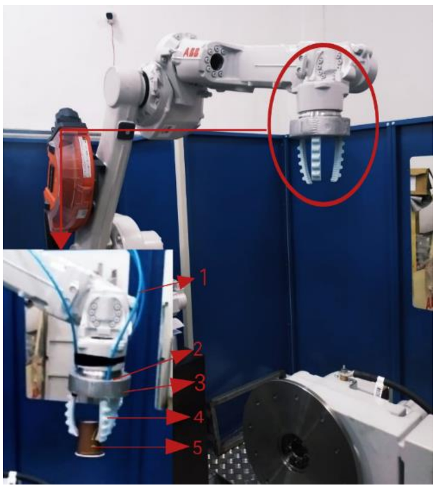

Figure 1. System Components

2.1 Fabrication and Material Selection

The fabrication process leveraged state-of-the-art additive manufacturing techniques, specifically fused deposition modeling (FDM), to prototype the gripper components with mold (PLA). A critical selection criterion for the gripper material was its elasticity and durability, leading to the choice of a custom-formulated silicone composite (RTV-2 Shore 20 Silicone, 10x20x150 mm). This material exhibited excellent deformation recovery and high tensile strength, essential for the gripper's repeated use in industrial settings [5].

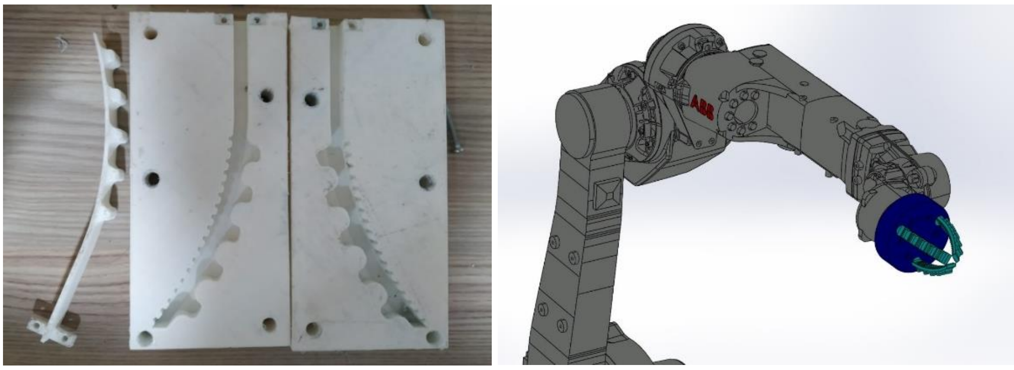

Figure 2. (a) Mold design holder shape and core (b) CAD Model of the Assembled Soft Gripper

2.2 Pneumatic Control System

Central to the gripper's operation is a pneumatic control system designed to modulate the grip force and actuation speed. The system's architecture was developed using Pneumatic Studio software, enabling precise control over the air flow and pressure within the gripper's chambers. This setup allowed for the gripper's adaptive functionality, accommodating objects of varying shapes and fragility as shown in Figure 3 [10].

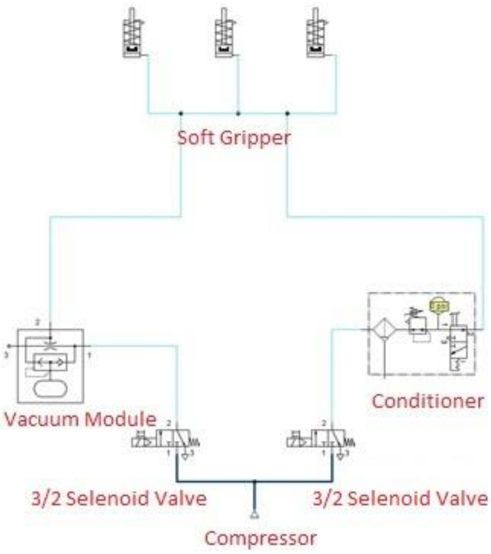

Figure 3. Pneumatic Control System Schematic

2.3 Testing and Evaluation

The gripper's performance was rigorously evaluated through a series of empirical tests, assessing its grip strength, object handling versatility, and operational durability. A bespoke testing rig was constructed, simulating real-world pick-and-place scenarios across a spectrum of object types, from delicate glassware to irregularly shaped produce. The evaluation process was augmented by finite element analysis (FEA) in ANSYS Workbench, providing insights into stress distribution and potential material fatigue under repeated use conditions in Figure 4.

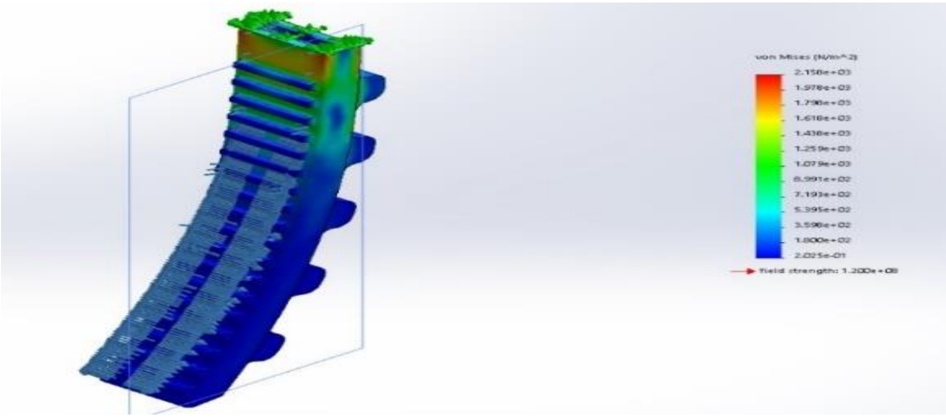

Figure 4. Pneumatic simulations with FEA

Another important topic while designing Soft gripper is ease of use. So that it is intent to carry out the transport process without deforming it. To ensure that the gripper switches on and off automatically, a mechanical trigger is required first. The solenoid valve performs this process. To receive the valve signal, we must first physically connect the inputs and outputs to the controller. In order for these connections to work synchronously with the robot, we have to define the inputs and outputs, as shown in Figure 5, which we have connected by receiving from the controller part in the Robostudio to the signal part via the I / O system. As show in Figure 5, the I / O signal part is defined which enables the controllers to operate synchronously.

Figure 5: Robotstudio smart components

3 Results and Discussions

The implementation of the novel soft gripper design was subjected to a rigorous empirical evaluation to ascertain its mechanical integrity, operational efficiency, and adaptability in handling diverse materials. The pneumatic actuation mechanism, central to the gripper's functionality, facilitated a responsive and adaptable gripping action, characterized by its ability to modulate force based on the object's geometry and material composition [14]. The bending angles and deformation under varying loads were systematically recorded, revealing the gripper's capacity for significant mechanical flexibility and durability under operational stresses [4].

Parallel to mechanical testing, simulation exercises employing advanced computational models offered predictive insights into the gripper's performance across a spectrum of operational scenarios. These simulations, validated through subsequent real-world applications, underscored the gripper's proficiency in executing precise and delicate pick-and-place tasks, thus substantiating its utility in industrial settings where such capabilities are paramount as shown in Figure 6 [2].

The real-world applicability of the soft gripper was further evidenced through a series of controlled experiments focusing on the manipulation of fragile items, such as glassware and perishable goods. These tests demonstrated not only the gripper's adept handling but also its potential to mitigate the risk of product damage, thereby enhancing operational safety and efficiency [11].

A pivotal aspect of the soft gripper's development was its economic feasibility. A comprehensive cost analysis revealed the production costs of the soft gripper to be significantly lower than those associated with conventional robotic grippers, highlighting its potential for widespread adoption across various sectors of the manufacturing industry [8]. This cost efficiency, coupled with the gripper's demonstrated performance, underscores its value proposition as a transformative tool in the automation landscape.

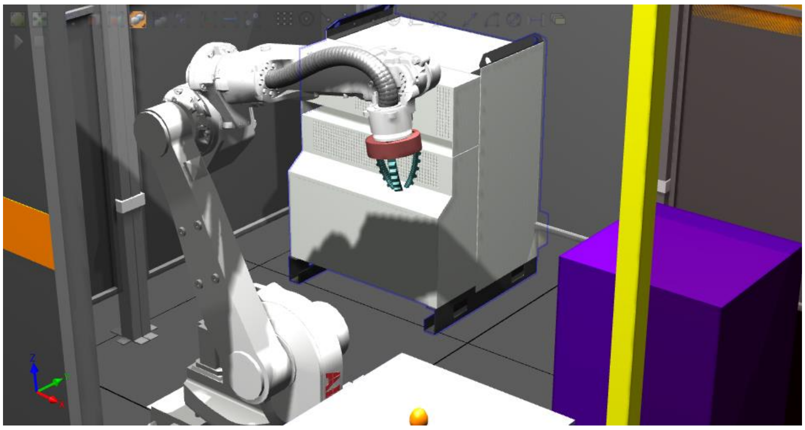

Figure 6. Automation simulation from robotstudio

The results presented herein, supported by rigorous empirical testing and comprehensive cost analysis, affirm the soft gripper's potential to redefine efficiency and safety in automated pick-and-place operations. Notably, the integration of low-cost materials and innovative design principles contribute to a paradigm shift in the approach to robotic manipulation, particularly in industries where the handling of delicate or irregularly shaped objects is commonplace. Future investigations will aim to extend the gripper's capabilities, incorporating advanced sensor technologies and AI-driven control algorithms to further enhance its adaptability and operational intelligence [7].

4 Conclusions

This study has successfully demonstrated the design, implementation, and validation of a low-cost soft gripper, tailored for industrial applications, especially in automating pick-and-place tasks. The utilization of RTV-2 molded silicone, in conjunction with a pneumatic actuation system, has yielded a gripper capable of delicate and precise object manipulation. This approach not only minimizes potential damage to the objects handled but also introduces a degree of dexterity reminiscent of human hand movements, thereby expanding the operational capabilities of industrial robot arms [1].

Our findings highlight the soft gripper's potential to reduce operational costs and enhance safety in automated systems. The gripper's low production costs and high functionality make it a viable alternative for industries requiring delicate object handling. Furthermore, the application of the finite element method (FEM) for system analysis has substantiated the gripper's operational efficiency under designated pressure ranges, thereby affirming its suitability for varied industrial tasks [3,17].

The potential for innovation within the realm of soft robotics remains vast. Future research will endeavor to integrate advanced sensory feedback mechanisms into the soft gripper design, enabling more sophisticated object recognition and manipulation capabilities. The exploration of smart materials with enhanced actuation properties and resilience could further augment the gripper's adaptability and longevity. Moreover, the integration of machine learning algorithms promises to refine the gripper's decision-making processes, facilitating autonomous adjustments to grip strength and technique based on real-time assessment of object characteristics. This advancement will not only increase the operational efficiency of automated systems but also expand their applicability to more complex and nuanced tasks.

Future research will focus on integrating sensory feedback to enhance object recognition and manipulation. We also plan to explore smart materials to further improve the gripper's performance and durability. Tailoring gripper designs to cater to the unique demands of sectors such as healthcare, agriculture, and consumer goods could unlock new possibilities for automation technologies, driving further innovations in Industry 4.0 applications.

5 Declarations

5.1 Competing Interests

There is no conflict of interest in this study.

5.2 Authors' Contributions

1. MEA: Organizing and reporting the data, taking responsibility for the explanation and presentation of the results,

2. AB: taking responsibility for the experiments, taking responsibility for the creation of the entire manuscript.

3. MSD: Taking responsibility for the literature review during the research, taking responsibility for the explanation and presentation of the results, taking responsibility for the experiments.

4. MK: Developing ideas or hypotheses for the research and article, planning the materials and methods to reach the results, supervising.

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