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Opportunities and Challenges for Adoption of Robotics in Packaging Industry: A Review

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Abstract
This research paper provides a comprehensive overview of the use of robotics in packaging across various industries by collating global research findings regarding challenges in different sectors, and highlight strategies for effective implementation of robotic packaging solutions.
The study employs a systematic literature review methodology, encompassing an extensive range of academic research papers, industry reports, and case studies from around the world.
The review reveals a significant evolution in the use of robotics in packaging due to advances in automation technology and artificial intelligence. It identifies key challenges, including the handling of diverse and delicate items, adaptation to dynamic environments, and economic constraints. The paper also uncovers various innovative strategies employed globally to mitigate these challenges, such as the development of advanced sensory integration, flexible robotic systems, and Industry 4.0 integrations.
The findings are crucial for industry stakeholders as they can guide strategic decision-making, inform policy development, and inspire future research directions. This paper emphasizes the need for continued innovation and adaptation to maximize the potential of robotics in packaging.
This review contributes to the literature on robotics in packaging and paves the way for more coordinated and efficient advancements in the field.
Keywords: Robotics in Packaging, Automation Technology, Industry 4.0, Systematic Literature Review, Packaging Innovation

I. Introduction

The use of robots in packaging represents a significant technological advancement, evolving from rudimentary mechanized systems to sophisticated, intelligent automations. Over the years, robots have become integral to the packaging process, known for their precision, efficiency, and versatility.

Globally, robotics has been increasingly adopted in various industries for packaging applications. The packaging industry, valued in billions, is a substantial component of the global economy, with its size indicative of the widespread use of automated solutions. For instance, the International Federation of Robotics reported a significant surge in the installation of industrial robots, with a notable portion dedicated to packaging applications.

Research in robotics for packaging spans across multiple countries, reflecting diverse approaches and innovations. For instance, studies in Japan have focused on robotic systems for food packaging, while European research has delved into automation in the consumer goods sector. Similarly, American research has contributed significantly to advancements in logistics and warehouse automation. Despite this extensive global research, there exists a gap in the comprehensive collation and analysis of these diverse studies.

This disparity highlights the need for a consolidated review paper that amalgamates global research findings. Such a collation is crucial for understanding the broader implications of robotics in packaging, identifying trends, challenges, and future directions. It serves as a critical resource for industry stakeholders, researchers, and policymakers, aiding in informed decision-making and strategic planning.

This review paper aims to synthesize global research on the use of robotics in packaging, providing a comprehensive overview of its applications, challenges, and advancements across various sectors. It seeks to bridge the gap in literature by compiling and analyzing studies from different countries, offering a global perspective on the state of robotics in packaging.

Therefore, this study aims to answer the following research questions:

RQ1: How have robotics applications in packaging evolved across different industries worldwide?

RQ2: What challenges do various industries face in implementing robotics for packaging?

RQ3: What are the effective strategies and innovations developed globally to mitigate the challenges faced in robotic packaging?

This paper aims to answer these questions, providing a thorough understanding of the current landscape of robotics in packaging and offering insights into future developments and potential areas of research.

The Evolution of Robotics in Manufacturing

The journey of robotics in manufacturing dates back to the early 20th century, with significant developments occurring in the 1960s. The first industrial robot, Unimate, introduced into General Motors' assembly line, marked a revolutionary step in industrial automation (World Robotics, 2011). This robot primarily handled welding and material tasks, setting a precedent for future robotic applications in manufacturing.

Technological advancements have led to the development of various robot types, each serving distinct manufacturing functions. Parallel industrial robots, known for their compact structure and high-speed operation, significantly differ from traditional serial robots (Liu, Cao, Qu, & Cheng, 2020). These robots have become integral in high-speed, high-precision tasks across various sectors, including electronic product handling and food packaging (Chen, Chen, & Kong, 2002).

The dynamic accuracy and efficiency of robots are heavily influenced by the trajectory and motion laws of their end effectors, emphasizing the importance of effective trajectory planning (Liu, Cao, Qu, & Cheng, 2020).

In the food industry, the shift towards robotics is prominent, especially in tasks traditionally performed by human labor, such as lunch box packaging in Japan (Wang, Zhu, Kawamura, & Hirai, 2017). The fruit packaging sector also reflects this trend, where companies globally incorporate robotics to combat workforce challenges (Iriondo, Lazkano, Ansuategi, Fernandez, &Maurtua, 2023).

The packaging industry has seen a notable shift towards automation. The number of robots used in packaging operations globally increased significantly in 2010, reflecting a broader trend towards automated production processes (Echelmeyer, Kirchheim, &Wellbrock, 2008).

The integration of robotics in industries handling flexible materials, such as footwear manufacturing, presents unique challenges. However, advancements in robotics have been made to increase productivity in specific manufacturing steps of the shoe industry (Hinojo-Perez, Davia-Aracil, Jimeno-Morenilla, Sanchez-Romero, & Salas, 2016).

Quality control in manufacturing has also seen the integration of robotics. For instance, the automatic inspection of paperboard creases using robots aims to improve packaging quality , addressing the limitations of manual inspection (Ojer, Alvarez, Lajas, Larrañaga, &Amozarrain, 2023).

The history and evolution of robotics in manufacturing is a story of constant innovation and adaptation. From handling basic tasks to performing complex operations, robots have become an indispensable component of the manufacturing industry. As technology evolves, so do the capabilities and applications of robotics, continually revolutionizing manufacturing processes and efficiency.

Robots for Packaging

The utilization of robots for packaging in various industries represents a significant evolution in manufacturing automation. This section delves into different researches on robotic applications in packaging, covering a range of industries and highlighting the advantages of these technological advancements.

Various studies have documented the use of robots for packaging across industries.

Food Industry

The food industry, accounting for about 5% of robot applications, is increasingly adopting robotics due to factors like hygiene, labor shortages, and cost efficiency (Echelmeyer, Kirchheim, &Wellbrock, 2008). For instance, Liu et al. (2020) developed time-optimal trajectory planning for Delta robots in intelligent packaging, enhancing efficiency in food processing.

Shoe Manufacturing

In shoe packaging, robots handle complex tasks like grasping, trajectory planning, and force control (Jatta et al., 2004). Projects like EuroShoe and RoboFoot have furthered the use of robotics in shoe finishing operations and manufacturing processes (Nemec&Zlajpah, 2008).

Agriculture

Robotics in agriculture, specifically in packaging fruits, has seen significant development. Feng et al. (2019) designed a 3-DoF robot manipulator for apple packaging, optimizing parameters for efficiency in the packing process.

Logistics and Warehouse Management

In logistics, automated bin-packing methods, such as the dynamic IK-PAL mosaic planner, optimize space utilization in bins, crucial for storage and transportation efficiency (Nakamoto, Eto, Sonoura, Tanaka, & Ogawa, 2016).

Advantages of Robotics in Packaging

Robots for packaging, spanning a diverse array of industries, demonstrate significant advantages in terms of efficiency, customization, and handling capabilities. As technology continues to advance, the scope and efficacy of robotics in packaging are expected to expand further, revolutionizing how products are packaged and delivered.

Efficiency and Accuracy

Robotics in packaging enhances efficiency and accuracy. For example, object placing algorithms in bin-packing aim to optimize space, crucial in industrial environments like warehouses (Nakamoto et al., 2016).

Customization and Flexibility

The incorporation of Industry 4.0 technologies enables customization and flexibility in packaging. Big data, IoT, and AR are among the technologies facilitating this shift towards intelligent, customized packaging solutions (Sadeghi, Kim, &Seo, 2022.).

Improved Hygiene and Safety

In the food industry, robotics contributes to improved hygiene and safety standards, addressing labor shortages and cost issues while maintaining product quality (Mahalik & Yen, 2008).

Handling Delicate Products

Developments in pneumatic soft robotic grippers, such as those by Suzumori et al. (1992), enable the handling of delicate products, expanding the scope of robotics in packaging (Wang, Zhu, Kawamura, & Hirai, 2017).

Innovative Solutions for Complex Tasks

The application of robotics in complex tasks like shoe packaging demonstrates the capability of robots to handle intricate and varied operations (Gracia et al., 2017; Molfino et al.,2004).

Non-Destructive Quality Control

Robots like those developed for assessing mango firmness offer non-destructive methods for quality control in packaging, enhancing product assessment accuracy (Blanes, Cortés, Ortiz, Mellado, &Talens, 2015).

Challenges of Using Robots

The integration of robotics into packaging processes, while ground-breaking, introduces a range of challenges that industries must navigate. As Ojer et al. (2023) noted in their examination of precision tasks like crease inspection, the demands on robotic systems for accuracy and adaptability are high. Perez-Vidal et al. (2018) highlighted the complexity of automating product packaging due to the variability in product dimensions and specifications. Brogardh (2006) discusses the ongoing development in robot control and the industrial perspective on adopting such technologies in various sectors. Meanwhile, Chen, Chen, and Kong (2002) provide insights into the mechanical challenges and solutions, especially regarding the Stewart platform's capabilities in robotics.

In particular, Dura-Gil et al. (2017) underscore the need for new technologies to customize robotic applications to meet special requirements, reflecting the industry's move towards more personalized and adaptable packaging systems. Echelmeyer, Kirchheim, and Wellbrock (2008) point out the logistic challenges that automation processes face, especially in warehouse settings where space and efficiency are at a premium. Rooker et al. (2014) further illustrate the need for flexible grasping mechanisms in handling consumer electronics, where the variations in product design demand a high degree of robotic dexterity.

These challenges, coupled with the high-speed demands described by Nakamoto et al. (2016) and the precision required in sensitive tasks like those described by Hinojo-Perez et al. (2016), paint a clear picture of the complexities involved in robotic packaging. The field is evolving, with new research like that of Liu, Cao, Qu, and Cheng (2020) focusing on optimizing the efficiency of these robotic systems through advanced algorithms.

This study reviews the industry specific challenges for the use of robotics in packaging in three key industries: food, consumer goods and logistics.

Food Industry

While the integration of robotics in the food industry's packaging sector offers significant advantages, it also presents unique challenges. This section discusses these challenges and explores potential measures to mitigate them.

Handling deformable objects: Grasping and handling deformable objects like paper containers filled with food is complex due to their unpredictable nature (Wang, Zhu, Kawamura, & Hirai, 2017). Soft robotic grippers have been developed to adapt to these difficulties, but achieving accurate control remains a challenge.

Diverse Characteristics of Food Products: The food industry deals with products varying in size, shape, color, and firmness. Packaging fragile fruits like peaches or strawberries with robots requires delicate handling to prevent damage (Iriondo, Lazkano, Ansuategi, Fernandez, &Maurtua, 2023).

Labor and Time Intensive Processes: Manual fruit packaging is labor-intensive and time-consuming, often requiring a large workforce. Despite the push towards automation to alleviate labor shortages, replicating the dexterity and care of human hands is a significant hurdle (Zhang &Skaar, 2009; Rose & Bhattacharya, 2023).

Health and Safety Concerns: Manual packaging operations can spread foodborne diseases and cause musculoskeletal disorders due to repetitive movements. Robot grippers need to be developed to handle irregular and sensitive products like mangoes while incorporating tactile sensing (Wilson, 2010; Blanes et al., 2015).
Trajectory optimization: The complexity of optimizing robotic trajectories with multiple constraints is a significant technical challenge. Improved algorithms are necessary to ensure smoothness and constraints of angular displacement, velocity, and acceleration (Liu, Cao, Qu, & Cheng, 2020).
Quality control issues: Traditional quality control methods like manual crease inspection are subjective and inconsistent. Automated systems need to be accurate , fast, non-contact, and autonomous to ensure consistent quality (Ojer, Alvarez, Lajas, Larrañaga, &Amozarrain, 2023).
Some of the mitigation measures suggested by researchers to overcome these challenges are as under:
Development of advanced soft robotic grippers: Investing in research to develop soft robotic grippers that can adapt to the unpredictable nature of food packaging materials is crucial. These grippers should be capable of handling a variety of textures and shapes without causing damage (Wang et al., 2017).
Incorporating sensors and machine learning: Integrating sensors and machine learning algorithms can enhance the robot's ability to adapt to varying product characteristics. This integration can improve the handling of delicate food items (Iriondo et al., 2023).
Ergonomic design and safety protocols: Robotic systems should be designed with ergonomic considerations to replicate human dexterity. Additionally, implementing strict safety protocols can minimize the risk of spreading diseases (Blanes et al., 2015).
Optimizing robotic trajectories: Utilizing advanced algorithms like particle swarm optimization can aid in the efficient planning of robotic trajectories, ensuring precision and smoothness in movements (Liu et al., 2020).
Automated quality control systems: Developing automated quality control systems with objective, quantified, and autonomous inspection capabilities can significantly reduce variability and improve consistency in packaging (Ojer et al., 2023).
Training and skilling workforce: As robotics becomes more prevalent in the food packaging industry, training the workforce to operate and maintain these systems is essential. This approach ensures the smooth integration of robotics into existing processes.
While the challenges of integrating robotics into the food industry's packaging sector are significant, they are not insurmountable. Continuous research and development, coupled with strategic implementation and workforce training, are key to overcoming these challenges and fully realizing the potential of robotics in food packaging.

Consumer Goods Industry

The integration of robotics in the packaging of consumer goods presents unique challenges, especially in unstructured and dynamic environments. This section discusses these challenges and proposes measures to mitigate them.
Dynamic environment adaptation: In consumer goods industries, robots must adapt to dynamic changes in unstructured environments. The unpredictability in human-robot interactions necessitates real-time trajectory modifications using sensor data (Tsarouchi, Makris, &Chryssolouris, 2016).
Handling variety of products: Consumer goods like electronics come in many variants, requiring flexible packaging solutions. Automating packaging in mixed variant production lines is challenging due to the diversity in product sizes and designs (Rooker et al., 2014).
Complexity in manufacturing and packaging: Consumer goods like shoes involve complex manufacturing processes with numerous variants and intricate assembly operations, making robotic packaging challenging (Bonert, Shu, & Benhabib, 2000).
Specialized staff for quality control and packaging: The consumer goods industry often requires specialized staff for quality control and packaging operations, particularly where manual dexterity and inspection are crucial (Nemec&Zlajpah, 2008).
Some of the measures suggested by research studies to overcome the above challenges are as under:
Advanced sensory integration: Implementing advanced vision systems and force/torque sensors can enhance robots' ability to adapt to changes in their environment. Techniques like visual servoing can guide robots in avoiding obstacles and interacting safely with humans (Vahrenkamp et al., 2008).
Flexible robotic systems: Developing robotic systems that can handle a wide range of product variants is essential. This includes creating flexible grippers and programming robots to adjust to different product dimensions and shapes.

Software and algorithm development: Investing in the development of sophisticated software and algorithms for object detection, grasping, and trajectory planning is crucial. These systems must be capable of handling the intricacies of various consumer goods (Gracia, Perez-Vidal, Mronga, & de Paco, 2017).

Ergonomic and human-assistive technologies: Integrating ergonomic and assistive technologies can optimize the packaging process. Low-cost sensors and effective object recognition solutions can aid in creating a flexible packaging station (Wallhoff, Blume, Bannat, & Appleton, 2012).
Collaboration with specialized staff: Collaborating with specialized staff for quality control and incorporating their expertise into the robotic system design can enhance the packaging process's effectiveness.
Continuous improvement and adaptation: The industry must focus on continuous improvement and adaptation of robotic systems. This includes regular updates based on feedback and the integration of new technologies as they emerge.

Logistics Industry
The logistics industry, pivotal in the movement of goods globally, faces unique challenges when implementing robotic packaging systems (Nica et al., 2015). These challenges range from handling diverse items to integrating advanced technologies.
Handling diverse items: In logistics, robots often deal with a wide array of items, each with different characteristics. Flexible grasping systems are required for picking and packing diverse products, but these systems lack uniformity in handling, making precise packing orientation calculation difficult (Iriondo, Lazkano, Ansuategi, Fernandez, &Maurtua, 2023).

Complex depalletizing systems: Conventional depalletizing systems that handle packages one by one are inefficient for high-paced logistics environments (Holz et al., 2015). Multi-package handling systems face challenges with unevenly stacked packages, necessitating the development of more versatile robotic systems (Nakamoto, Eto, Sonoura, Tanaka, & Ogawa, 2016).
Economic and infrastructure challenges: The initial costs of integrating packaging 4.0 technologies can be high, and understanding the economic benefits, infrastructure requirements, and security issues is complex. Detailed investigations are required to assess the feasibility of these technologies in logistics (Sadeghi, Kim, &Seo, 2022).
Variability of items and system robustness: The vast variability of items in terms of size, shape, weight, and material makes fully automated systems challenging. This limitation is particularly evident in distribution centers that deal with a wide range of products (Echelmeyer, Kirchheim, &Wellbrock, 2008).
The suggestions for mitigation found in the existing literature are as under:
Development of advanced grasping systems: Developing advanced robotic grasping systems that can adapt to a variety of product types is crucial. These systems should be capable of handling items with different physical characteristics efficiently and safely.
Enhanced depalletizing robots: Creating novel robotic systems that are capable of high-speed and compact depalletizing, akin to human capabilities, is essential. These robots should handle packages of various weights and sizes skillfully without causing damage (Katsoulas, Bergen &Tassakos, 2002; Katsoulas, &Kosmopoulos, 2001).
Cost-benefit analysis and infrastructure planning: Conducting detailed cost-benefit analyses and infrastructure assessments is critical for understanding and mitigating the economic challenges of implementing packaging 4.0 in logistics.
Customized robotic solutions: Tailoring robotic systems to specific logistical needs can address the challenge of handling a huge variability of items. This includes developing robots with adaptive algorithms and flexible end effectors to handle different types of goods.
Real-time monitoring and dynamic systems: Implementing real-time monitoring and dynamic bin-packing systems that can adapt to the constantly changing environment of logistics centers is necessary. These systems should be capable of creating efficient packing mosaics with arbitrary objects (Iriondo et al., 2023).
Integration of I4.0 elements: Integrating elements of Industry 4.0, such as intelligent sensors, actuators, and machine learning algorithms, can enhance packaging processes in logistics. This integration would enable manufacturing optimization, improved delivery systems, and smart services (Sadeghi et al., 2022).

II. Conclusion

The use of robots in packaging has revolutionized various industries, offering unparalleled efficiency, precision, and adaptability. Robotics technology in packaging has permeated sectors like food, consumer goods, and logistics, demonstrating its versatility and potential in streamlining operations and enhancing productivity.
In the food industry, the challenges of employing robotics for packaging are multifaceted, involving the handling of diverse and delicate food products, managing dynamic and often unpredictable environments, and maintaining stringent hygiene standards. To mitigate these issues, the industry has seen the development of soft robotic grippers tailored for gentle handling, the integration of advanced sensors to adapt to environmental changes, and the implementation of ergonomic designs to maintain cleanliness and safety.

The consumer goods industry faces its own unique set of challenges, particularly when it comes to accommodating a wide range of product variants. This diversity adds complexity to manufacturing processes and places a premium on specialized quality control measures. Mitigating these challenges requires the implementation of flexible robotic systems capable of adjusting to various product specifications, the use of advanced software and algorithms for precision and efficiency, and a collaborative approach with specialized staff to ensure quality.

In the logistics industry, robotic packaging must contend with the handling of a vast array of diverse items, the need for efficient depalletizing processes, substantial initial investment costs, and the inherent variability of the items being handled. To address these challenges, logistics has turned to advanced grasping systems that can securely handle a variety of package types and sizes, the development of enhanced depalletizing robots that can operate at high speeds without compromising on accuracy or causing damage, and the execution of detailed cost-benefit analyses to justify the initial expenditures. Moreover, the incorporation of Industry 4.0 elements is becoming increasingly prevalent, optimizing operations through smart technology integration.

This review emphasizes the transformative impact of robotics in packaging across various sectors. It highlights not only the vast potential of robotics in enhancing efficiency and productivity but also the specific challenges each industry faces. By identifying these challenges and proposing mitigation strategies, this paper provides a roadmap for industries looking to integrate robotics into their packaging processes.

The field of robotics in packaging is ripe for further research, particularly in the development of more sophisticated and versatile robotic systems. Future research could focus on advanced material handling technologies for grippers to handle a wider range of products more effectively, integrating AI and machine learning for better prediction, adaptability, and decision-making in robotic packaging systems, human-robot collaboration, especially in quality control and intricate packaging tasks and sustainability in robotics for more sustainable packaging processes.

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