

Design and Development of a Smart Automated Packaging System for Poultry Drumsticks

Sidhant Sanjay Kulkarni^{1,*}, Sakshi Mahendra Abhale¹, Asmita Amol Aher¹,
Shubham Kiran Sonawane¹, Prasad Kailas Aher¹, R.A. Kapgate¹

Abstract

The present work aims to design and implement an automated packaging system for poultry drumsticks that enhances operational efficiency, product quality, and adaptability. The integrated system offers a solution that complies with industrial quality and safety standards by sorting products, getting accurate weighing, and efficiently portioning food into 1-kilogram standardized units. By effectively reducing human involvement, operational inefficiencies, workforce requirements, and contamination hazards, the automation system becomes sufficiently adaptable to meet various production demands. As its primary innovation, the system replaces conventional wrapping techniques with a knotting wrapping method. Reduced use of materials, enhanced sanitation, faster processing, and less maintenance are just a few benefits of this strategy. Scalability is prioritized in the automation solution's design, which also offers flexible packaging choices that optimize operations and set the foundation for the future. These affordable food packaging solutions ensure hygienic practices and technological sophistication. In addition to these core functionalities, the proposed system integrates sensor-based monitoring and programmable control mechanisms to ensure consistent performance and precision throughout the packaging cycle. Advanced load cells and conveyor synchronization enable real-time weight verification and automatic rejection of non-conforming units, thereby minimizing product giveaway and ensuring uniformity. The system architecture is designed with modular components, allowing easy upgrades, maintenance, and customization according to varying production capacities and packaging requirements. The automation framework also incorporates safety interlocks and food-grade materials to comply with stringent food safety regulations and industry standards. By streamlining the workflow from sorting to final sealing, the system significantly reduces processing time while maintaining product integrity and freshness. Furthermore, data acquisition and monitoring features provide production analytics that support quality control, traceability, and decision-making processes. Economic analysis indicates that the reduction in labor dependency, material wastage, and operational downtime contributes to long-term cost savings and improved return on investment. The proposed solution not only enhances productivity but also supports sustainable practices by optimizing packaging material usage and reducing environmental impact. Overall, the developed automated poultry drumstick packaging system demonstrates a reliable, scalable, and innovative approach to modern food processing challenges, aligning with evolving industry demands and consumer expectations.

*Author for Correspondence

Sidhant Sanjay Kulkarni
E-mail: kulkarnisidhantmk@sanjivani.org.in

¹Student, Department of Mechatronics Engineering, Sanjivani College of Engineering, Singnapur, Maharashtra, India

Received Date: January 13, 2026
Accepted Date: February 27, 2026
Published Date: March 12, 2026

Citation: Sidhant Sanjay Kulkarni, Sakshi Mahendra Abhale, Asmita Amol Aher, Shubham Kiran Sonawane, Prasad Kailas Aher, R.A. Kapgate. Design and Development of a Smart Automated Packaging System for Poultry Drumsticks. International Journal of Machine Systems and Manufacturing Technology. 2026; 4(1): 1–7p.

Keywords: Knotting mechanism, precise weighing, hygiene, automation

INTRODUCTION

In modern poultry production, efficient and hygienic packaging systems are important to meet consumer expectations, regulatory standards, and operational demands. They play a key part in maintaining the newness and freshness of the product, avoiding contamination, and ensuring

food quality control throughout the supply chain. It also reduces the manual handling process and increases the shelf life of the product. Conventional methods of packaging poultry drumsticks involve manual sorting, weighing, and wrapping. This method introduces challenges such as inconsistent quality, drumstick contamination risks, labor dependencies, and increased operational costs [1]. These problems have drawn the attention of researchers, especially after the COVID-19 pandemic, because, after the pandemic, labor shortages, hygiene concerns, and changes in customer demand have prominently affected food production and packaging workflows [2]. Umate et al. [3] designed and developed a low-cost and simple orbital wrapping machine with a revolving ring system to address the wrapping process for different product shapes. Meng et al. [4] proposed a mechanical rope knotting mechanism specifically designed for agricultural bundling applications, which improved hygiene and operational efficiency by reducing material requirements. Gopalakrishnan and Singh [5] introduced an embedded system using load cells and stepper motors to achieve high-accuracy food weighing and packaging. Sahu et al. [6] designed a system using smart sensors and programmable logic controllers (PLCs) to enhance the accuracy and hygiene of automated meat packaging. Research has explored the development of efficient, sustainable, and biodegradable packaging solutions integrated with real-time sensing technologies [7]. Nguyen and Zhang [8] compared knotting and wrapping techniques regarding material efficiency and operational reliability. They concluded that knotting is more advantageous regarding cost and environmental concerns. Additionally, Plan Automation [9] in their report mentioned the importance and advantages of automated stretch wrapping machines, primarily addressing reducing film waste, increasing productivity, and enhancing product protection.

Building upon these foundational contributions and addressing these challenges, the present work aims to design and develop an innovative, automated packaging system specifically for poultry drumsticks. The proposed system combines automated conveyors, precision sensors, and a unique mechanical knotting process to bundle drumsticks into uniform 1 kg chunks. A sustainable and effective packaging solution is achieved by substituting the knotting method for conventional stretch wrapping, which guarantees lower material consumption, improved sanitation, quicker processing, and less maintenance. Small-to-medium sized poultry processing facilities looking for contemporary automation in line with Industry 4.0 concepts would find the system very useful [10].

SYSTEM COMPONENTS FOR THE KNOTTING MECHANISM

The designed and developed automated drumstick packaging system is made up of a compact, modular configuration of electromechanical components/parts that are designed using SolidWorks and fabricated using 3D printing and laser cutting processes.

At the heart of the knotting mechanism lies a planetary gear setup, which includes a 200 mm diameter sun gear, as shown in Figure 1, and four 90 mm diameter planet gears made from 4 mm Medium-Density Fiberboard (MDF), as depicted in Figure 2. These gears are supported and aligned using 200 mm steel rods (8 mm diameter) as illustrated in Figures 3 and 4 and custom laser-cut MDF holders as shown in Figure 5 to ensure smooth motion transfer.



Figure 1. Sun gear with a diameter of 200 mm.



Figure 2. Four 90 mm diameter planet gear.



Figure 3. Meshing of gears



Figure 4. 200 mm steel rods
(8 mm diameter).



Figure 5. MDF holders to hold rods.

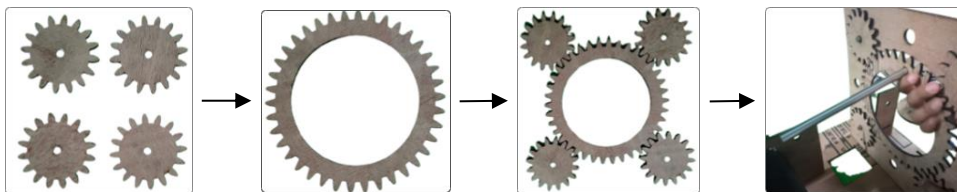


Figure 6. Flowchart of gear setup.

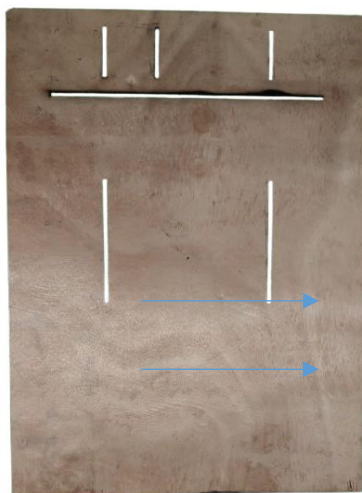


Figure 7. Base frame for mounting.

The assembly is mounted on a stable base frame designed for rigidity and mechanical alignment, as depicted in Figure 6, with additional rods arranged to act as conveyors for drumstick transportation during the wrapping process, as shown in Figure 7.



Figure 8. Conveyor steel rods.



Figure 9. Rubber rings and caps.



Figure 10. Stepper motor.



Figure 11. Tongs for knotting.



Figure 12. Solenoid actuator.

As shown in Figure 8, rubber rings and caps are utilized at the junction points to reduce vibration and secure gear positions effectively. As shown in Figure 9, a DC motor rotates the gear system, converting electrical energy into a mechanical drive for ongoing packing activities.

The knotting mechanism, which is proposed to substitute a mechanical knotting solution for traditional stretch wrapping to improve hygiene and material efficiency, is at the heart of the innovation. As illustrated in Figure 10, the mechanism uses a pair of tailored tongs to grip and fix the wrapping thread around the drumstick bundles. By converting electrical inputs into linear mechanical movement, a solenoid actuator makes it easier to open and close the tong tips, enabling accurate and prompt knot generation, as shown in Figure 11. A Polylactic Acid (PLA) 3D-printed platform, as illustrated in Figure 12, supports the motor that powers the tongs, ensuring longevity and excellent positioning accuracy. Figure 13 displays the system's wholly built perspective, demonstrating how all the parts have been integrated into a seamless automated packing configuration that can effectively produce standardized 1-kilogram drumstick bundles with little human assistance.



Figure 13. Motor stand.

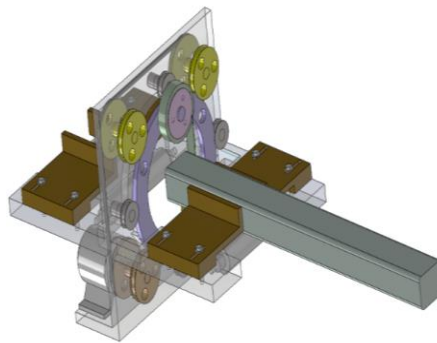


Figure 14. Overall assembled model

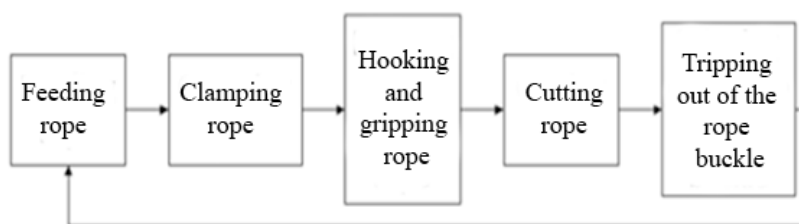


Figure 15. Workflow of knotting process.

SYSTEM DESIGN AND METHODOLOGY

The proposed automated packaging system is designed and developed to overcome the drawbacks and limitations of traditional stretch wrapping by implementing a *mechanical knotting mechanism* for poultry drumstick packaging. This design addresses crucial needs, such as reduced material consumption, enhanced hygiene, automation, and consistent product handling. The workflow of the drumstick packaging is depicted in Figure 14. The system uses a thread-based knotting system guiding a thread through a *spindle-driven mechanism* that wraps and performs knotting around standardized 1 kg drumstick bundles.

The structure of the knotter is illustrated in Figure 15. The overall system consists of a *rope clamping and feeding unit*, a *hook-and-grip mechanism* for tying, and an *automatic cutter* to remove extra thread after knotting.

The *hook-and-grip mechanism and the knotting steps* are shown in Figures 16 and 17, respectively. The system was assembled and mounted on a modular mechanical frame designed using SolidWorks. It is fabricated with *laser-cut MDF* and *3D-printed PLA components* for low-cost and design precision (Figure 18).

The modular configuration of the mechanical frame ensures ease of assembly, maintenance, and component replacement without affecting the overall structural integrity of the system. The design approach emphasizes compactness and stability, allowing the mechanism to operate efficiently while minimizing vibrations during operation. Each component was precisely aligned within the frame to maintain proper synchronization between the hook-and-grip units throughout the knotting cycle.

The use of laser-cut MDF provides structural rigidity while maintaining a manageable overall weight of the system. Additionally, the 3D-printed PLA components enable complex geometries to be produced with high dimensional accuracy, ensuring proper interface between moving parts. The combination of these materials contributes to reduced manufacturing costs while maintaining adequate mechanical strength for prototyping and testing (Figure 18).

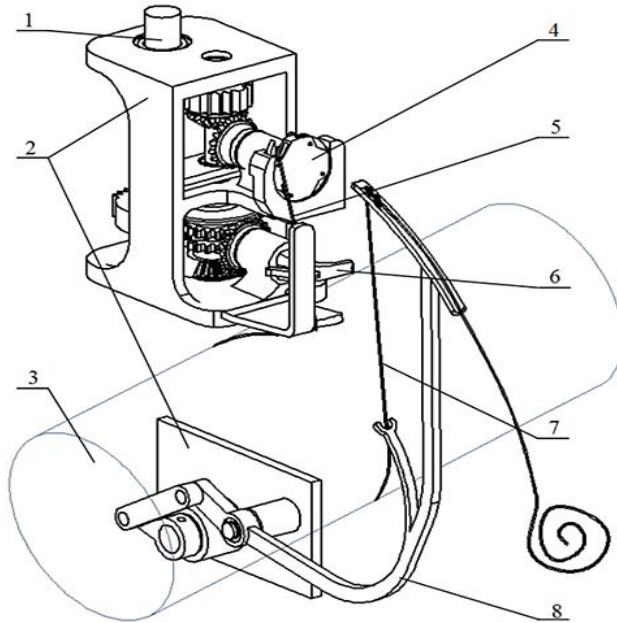


Figure 16. Knotting mechanism structure. (1) Spindle, (2) frame, (3) bound objects, (4) rope clamping mechanism, (5) cutter, (6) rope hooking and gripping mechanism, (7) bundle rope, and (8) rope feeding mechanism.

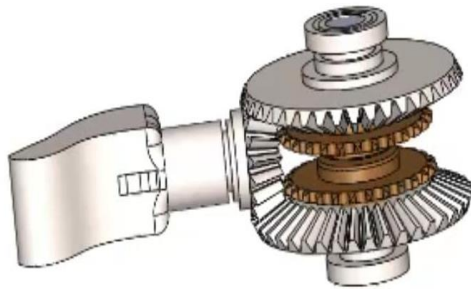


Figure 17. Hook-and-grip mechanism.

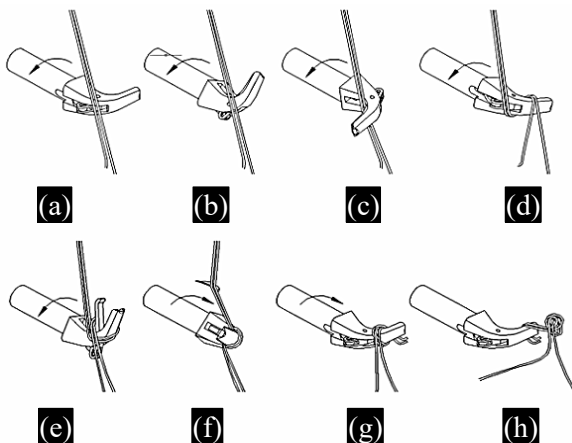


Figure 18. (a) and (h) Knotting steps.

Furthermore, the frame incorporates adjustable mounting slots that allow the fine-tuning of the component positions during calibration. This feature enhances the adaptability of the system to different operational requirements and facilitates iterative design improvements. The assembly

process follows a systematic integration sequence, in which individual modules are first tested independently and then integrated into a complete setup. This modular and structured design methodology improves reliability, simplifies troubleshooting, and supports the future scalability of the mechanism.

The designed mechatronics system integrates *hardware, software, and control modules* to facilitate flawless automation. Drumsticks move on speed-adjustable conveyor belts and undergo sorting, weighing, and knotting stages. Similar to the proximity sensor, the sensor module ensures drumstick detection, and the load cell provides *accurate weighing*. The tongs, DC motor, and solenoid enable quick and precise knotting. The microcontroller-based embedded system synchronizes all mechanical actions and controls other parameters like the speed of the conveyor, accurate weighing, and knotting. The design system ensures scalability and adaptability to various product sizes and shows a practical, sustainable, and hygienic approach for modern drumstick packaging in poultry.

CONCLUSION

This study introduces the design and development of an automated packaging system tailored explicitly to poultry drumsticks. The focus is on improving operational efficiency, maintaining product hygiene, and ensuring packaging consistency. The system combines sorting, precise weighing, and a unique knotting-based wrapping method to automate packaging, ensuring standardized 1 kg portions. By reducing the need for manual intervention, this system minimizes labor dependency and lowers the risk of contamination. It also offers enhanced packaging accuracy and higher throughput. One of the key innovations of this system is the replacement of traditional stretch wrapping with a mechanical knotting technique. This method presents several benefits, such as reduced material usage, better sanitation, easier maintenance, and greater environmental sustainability. The system's modular hardware design and software configurability also make it adaptable to different product specifications and scalable to meet future production needs. This solution offers a practical and cost-effective approach to automating food packaging, especially for small-to-medium scale poultry processing operations. Future developments could include integration with IoT-based monitoring platforms, robotic arms for product handling, and compatibility with various meat product formats, further expanding the system's versatility and commercial potential.

REFERENCES

1. Dhanorkar S, Kulkarni M. Automation in poultry packaging: a review of trends, technologies, and challenges. *Food Tech Today*. 2022;8(1):27-33.
2. Karthik S, Rao V. Industry 4.0 solutions in food packaging systems. *Int J Ind Autom*. 2023;11(2):87-94.
3. Umate R, Sheikh P, Dhakate M, Gaikwad R, Lolusare S. Design and fabrication of orbital wrapping machine. *Int J Mech Eng*. 2020;7(2):34-39.
4. Meng Y, Chen H, Liang Y, Qin J, Zhao Q, Wei J. Research on innovative design of a new rope knotter. *Adv Mech Eng*. 2019;11. doi:10.1177/1687814019878320.
5. Gopalakrishnan R, Singh A. Microcontroller-based weighing and packaging system for food products. *J Autom Control Eng*. 2019;7(2):55-59.
6. Sahu R, Patel S, Pradhan B. Smart meat processing using PLC and sensor-driven automation. *Int J Food Eng Technol*. 2021;5(3):140-147.
7. Cazón P, Cazón D, Vázquez M, Guerra-Rodriguez E. Rapid authentication and composition determination of cellulose films by UV-VIS-NIR spectroscopy. *Food Packag Shelf Life*. 2022;31:100791. doi:10.1016/j.fpsl.2021.100791.
8. Nguyen TH, Zhang R. Material reduction in packaging: knotting vs traditional wrapping techniques. *J Sustain Manuf*. 2021;12(4):211-218.
9. Bedard M. (2017). 8 Benefits of Using an Automatic Stretch Wrapping Machine. [online] Plan Automation. Mettler Toledo Solutions. Available from: <https://www.planautomation.com/blog/8-benefits-of-using-an-automatic-stretch-wrapping-machine>
10. Kumar A, Tiwari P. Application of mechatronics in the food industry: an overview. *J Food Eng Autom*. 2020;9:45-52.