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

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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 creativity, 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.

Keywords:Knotting Mechanism, Precise Weighing, Hygiene, Automation

1. Introduction

In modern poultry production, efficient and hygienic packaging systems are important in order to reach consumer expectations, regulatory standards, and operational demands. As they play key part in maintaining newness and freshness of product and avoid contamination and ensure food quality control throughout the supply chain. It also reduces manual handling process and enlarge the shelf life of product . The conventional methods of packaging poultry drumsticks involve manual sorting, weighing, and wrapping. This method introduceschallenges such as inconsistent quality, Drumstick contamination risks, labor dependencies, and increased operational costs [1]. These problems have sought the attention of researchers, especially after the COVID-19 pandemic, because, after the pandemic, the shortages of labor, 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 speciallydesigned for agricultural bundling applications.The system has improved hygiene and operational efficiency by reducing material requirements.Gopalakrishnan and Singh [5] introduced an Embedded system using load cells and stepper motors to get high-accuracy food weighing and packaging. Sahu et al. [6] designed thesystemusing smart sensors and programmable logic controllers (PLCs) to enhance accuracy and hygiene in automated meat packaging. Li et al. [7] elaborated on efficient, sustainable, biodegradable packaging materials and real-time sensor integration. Nguyen and Zhang [8] compared knotting and wrapping techniques regarding material efficiency and operational reliability.They concluded that knotting is more advantageousregarding 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].

2. System Components for the Knotting Mechanism

The designed ated drumstick packaging system is made up of a compact, modular configuration c omponents/partsthat are designed using SolidWorks and fabricated using 3D printing anc

Fig. 1 Sun gear with a diameter of 200mm **Fig. 2. Four 90mm diameter Planet gear**

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

Fig. 3. Meshing of Gears

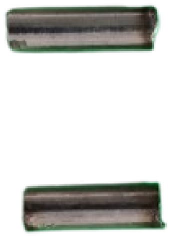

Fig. 4. 200 mm steel rods (8 mm diameter)

Fig. 5. MDF Holders to hold rods

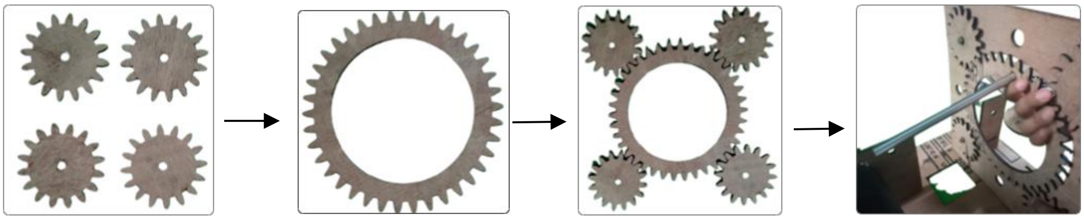

Fig.6. Flowchart of Gear Setup

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

Fig. 7. Base frame for mounting **Fig. 8. Conveyer steel rods**

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

Fig. 9. Rubber rings and Caps

Fig. 10. Stepper Motor

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 Fig. 10, the mechanism uses a pair of tailored tongs to grip and fix the wrapping thread around 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 Fig. 11. A PLA 3D-printed platform, as illustrated in Fig. 12, supports the motor that powers the tongs, guaranteeing longevity and excellent positioning accuracy. Fig. 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.

Fig. 11.Tongs for Knotting

Fig. 12. Solenoid Actuator

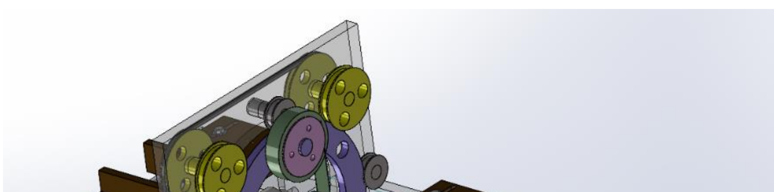

Fig. 13. Motor Stand

Fig. 14. Overall Assembled Model

3. 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 drumstick packaging is depicted in Fig. 14. The systemuses a thread-based knotting system guiding a thread through a spindle-driven mechanism that wraps and performs knotting around standardized 1 kg drumstick bundles.

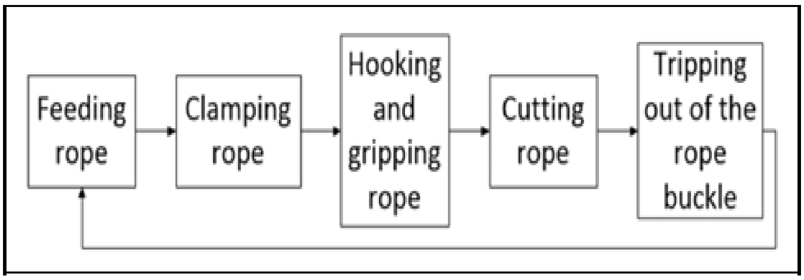

Fig. 15. Workflow of Knotting Process

The structure of the knotter is shown in Fig. 15. The overall consists of a rope clamping and feeding unit, a hook-and-grip mechanism for tying, and an automatic cutter to removeextra thread after knotting.

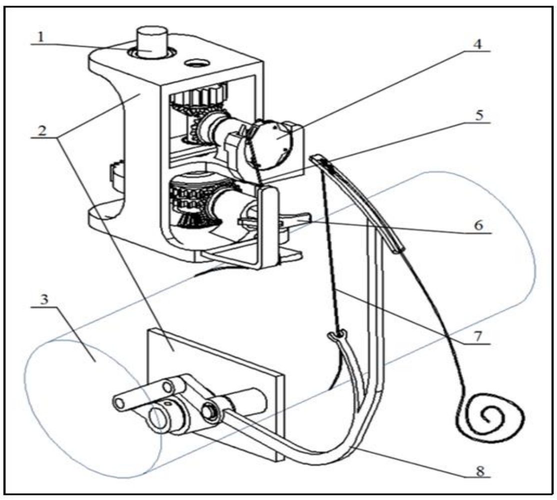

Fig. 16. Knotting Mechanism Structure (1.Spindle, 2. Frame, 3. Bound objects, 4. Rope clamping mechanism, 5.Cutter,

6.Rope hooking and griping mechanism, 7. Bundle rope, 8. Rope feeding mechanism)

TheHook and Grip Mechanism *and the Knotting steps* are shown in Fig. 16 and Fig. 17*,* respectively. Thesystem is 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.

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 is 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 keeping the overall weight of the system manageable. Additionally, the 3D-printed PLA components enable complex geometries to be produced with high dimensional accuracy, ensuring proper interfacing between moving parts. The combination of these materials contributes to reduced manufacturing costs while maintaining adequate mechanical strength for prototyping and testing purposes.

Furthermore, the frame incorporates adjustable mounting slots that allow fine-tuning of component positions during calibration. This feature enhances the adaptability of the system for different operational requirements and facilitates iterative design improvements. The assembly process follows a systematic integration sequence, where individual modules are first tested independently and then integrated into the complete setup. This modular and structured design methodology improves reliability, simplifies troubleshooting, and supports future scalability of the mechanism.

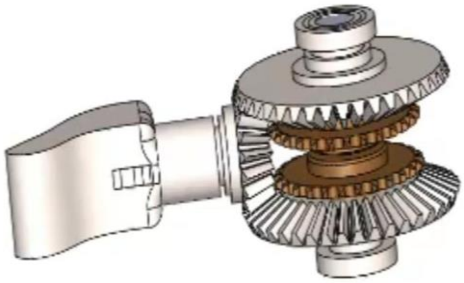

Fig. 17. Hook and Grip Mechanism

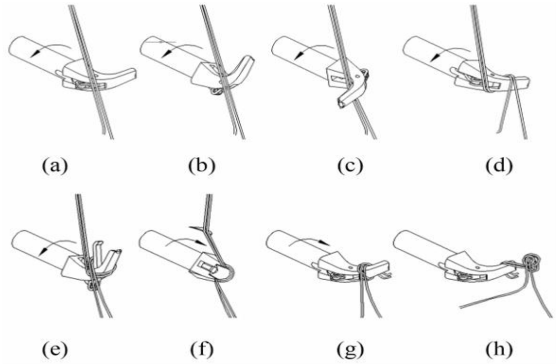

Fig. 18. Knotting steps

The designedmechatronics system integrateshardware, software, and control modules to facilitateflawless automation. Drumsticks move on speed-adjustable conveyor belts and go through the sorting, weighing, and knotting stages. Like 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 approachfor modern drumstick packaging in poultry.

4. Conclusion

This study introduces the design and development of an automated packaging system tailored explicitly for poultry drumsticks. The focus is on improving operational efficiency, maintaining product hygiene, and ensuring consistency in packaging. 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 accuracy in packaging and higher throughput. One of the key innovations of this system is replacing 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.

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