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DESIGN AND MANUFACTURE OF TRAY FEEDING MODULE FOR AUTOMATIC KITCHEN

Van-Tinh Nguyen[1], **Tran Thanh Tung**[2*]

[1]School of Mechanical Engineering, Hanoi University of Science and Technology, Vietnam.
[2] Faculty of Engineering Mechanics and Automation, VNU University of Engineering and Technology, Viet Nam.

Abstract

The demand for scalable and hygienic food service automation in industrial settings such as factories, canteens, and institutional kitchens has grown rapidly in response to rising labor costs, service inconsistencies, and the need for operational efficiency. While robotic and AI-driven systems have advanced significantly in commercial food services, the adaptation of such technologies in high-throughput, industrial environments remains limited. This research addresses that gap by presenting the design and development of a modular tray feeding module specifically tailored for use in automatic kitchen systems. The proposed system automates the transfer, alignment, and dumping of meal trays using a combination of conveyor mechanisms, pneumatic actuators, and programmable controls. The study covers the mechanical design, control integration, and functional validation of the tray feeding module under simulated industrial kitchen conditions. Key innovations include a dual-position conveyor interface, a pneumatically actuated tray engagement mechanism, and a rotary dumping system capable of sequential ingredient delivery. Structural and performance analyses, including finite element modeling for stress and displacement, demonstrate high reliability and safety under operational loads. Experimental testing confirms the system's ability to operate continuously, accurately align trays, and manage sequential dumping with minimal intervention. This work contributes to the advancement of smart kitchen infrastructure by offering a robust, hygienic, and low-cost automation solution adaptable to diverse large-scale food service applications.

Keywords: *food service automation, tray feeding, automatic kitchen systems, mechanical design*

1. Introduction

In the current industrial food service landscape, particularly within factories and manufacturing zones, the daily challenge of delivering thousands of meals efficiently, hygienically, and cost-effectively remains a pressing issue [1-5]. Most existing operations still rely heavily on human labor for both cooking and tray-based meal distribution. While this traditional approach offers flexibility, it often results in increased operational costs, inconsistent service quality, and significant time consumption, particularly during peak mealtime hours. Globally, automated service systems are reshaping the landscape of food production and distribution. Advanced robotic arms, AI-driven kitchen assistants, and autonomous delivery platforms are increasingly being adopted in smart restaurants, hospital kitchens, and airline catering facilities [6-12]. These innovations are not only improving consistency and efficiency but also addressing critical challenges related to labor shortages, food safety, and sustainability.

Despite these advancements, most automation efforts remain concentrated in controlled or premium commercial environments. Industrial-scale kitchens, such as those in factories, military canteens, and large institutions, have largely lagged behind due to the complexity and high cost of adapting automation to high-volume, multi-shift operations. In this context, the development of a cost-effective, robust, and modular tray feeding system becomes particularly significant. It represents a step toward democratizing kitchen automation for mass catering settings, making high-efficiency solutions accessible beyond high-tech restaurants and into real-world production-scale applications.

Recognizing these limitations, this research draws inspiration from two emerging trends: (1) the automation of domestic kitchen tasks using intelligent mechatronic systems, and (2) the growing demand for scalable solutions in institutional food service. By bridging the gap between small-scale home automation and high-throughput industrial needs, we aim to develop a modular, automated tray feeding system tailored for

**Corresponding Author -E-mail: tranthanhtung@vnu.edu.vn*

large-scale meal preparation environments. The core objective of the tray feeding module is to enhance productivity, reduce dependence on manual labor, and improve the consistency and hygiene of meal tray handling in industrial kitchens. The integration of such a system not only optimizes time and cost in the cooking and serving process but also lays the foundation for a fully automated kitchen ecosystem capable of operating continuously with minimal human intervention.

This paper presents the detailed design and manufacturing process of this tray feeding module, including its mechanical layout, control system, and performance validation under simulated industrial kitchen conditions.

1.1. Mechanical System Design

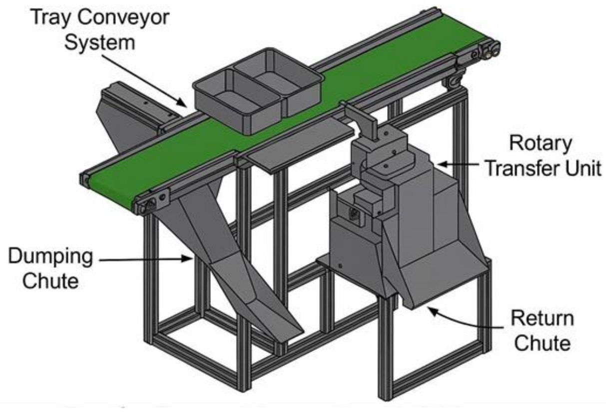
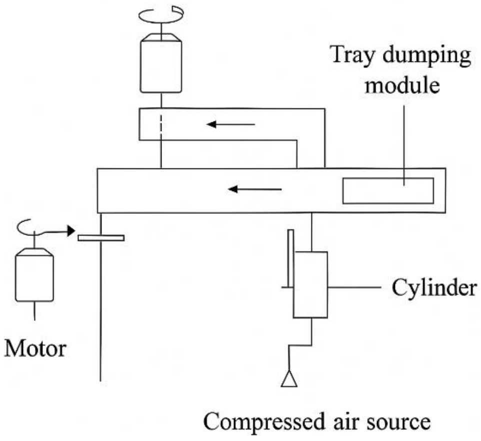


Fig. 1. 3D CAD design of the tray feeding module

The Fig. 1 illustrates the 3D CAD design of the proposed tray feeding module, which integrates mechanical handling, a conveyor-based transport system, and a dual-position operational layout. At the top of the system is a tray conveyor system featuring a food-safe green belt, driven by motorized rollers at both ends. This conveyor is responsible for transporting food trays loaded with ingredients to the processing area. Guide rails along the sides ensure that the trays remain properly aligned during movement, reducing the risk of jamming or misplacement. Positioned centrally below the conveyor is the rotary transfer unit, a pivotal mechanism that redirects trays to one of two functional positions. This unit consists of a rotary actuator and a gripping or pushing arm designed to engage with each tray as it arrives at the end of the conveyor. Once a tray is in position, the rotary unit rotates to align it with one of two chutes located beneath the structure. The dumping chute, located on one side, allows trays to tilt or slide, releasing their contents, typically meal ingredients, into a receptacle for cooking or mixing. The return chute, located on the opposite side, is used to collect empty trays, which are then directed toward a washing or recirculation station. The module is constructed on a rigid aluminum frame, utilizing extruded profiles, which provide structural stability while maintaining a lightweight and modular design. The open-frame architecture ensures accessibility for cleaning and maintenance, which is critical in kitchen environments where hygiene is paramount. All tray contact surfaces are designed using food-grade, non-stick materials, and the layout provides a clear separation between clean and used trays, minimizing contamination.



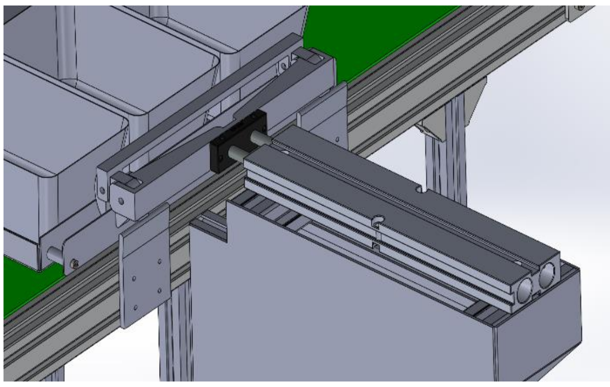


Fig. 2. Automatic tray feeding principle diagram

The automatic tray feeding process is designed to ensure a seamless and hands-free transfer of pre-portioned food ingredients into the cooking system, as shown in Figure 2. Initially, raw materials are pre-arranged and loaded into standardized trays. These trays are then placed onto the input end of the conveyor belt system. As the conveyor advances, each tray is transported to a predetermined processing position. At this point, a pneumatically actuated cylinder engages, pushing the tray from the conveyor into the tray dumping module. Within this module, the tray is positioned over the target dumping area, typically aligned with a cooking pot or heating station, where the ingredients are discharged. This action may be performed through tilting or mechanical pushing, depending on the design. Once the ingredients have been removed, the empty tray is returned to the conveyor path. The tray is then guided downstream, where it is either successfully poured, a secondary cylinder is activated, a cleaning station is prepared, or the tray is prepared for reuse in the next cycle. This sequence ensures a fully automated, efficient, and hygienic handling of meal ingredients, significantly reducing manual labor and enhancing process throughput in industrial kitchens.

1.2. Conveyor system design

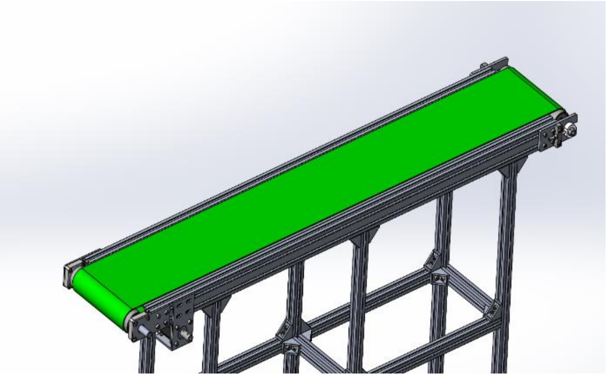


Fig. 3. Conveyor system 3D CAD design

The conveyor system consists of four primary elements: the conveyor belt, drive motor, belt support structure, and the associated transmission mechanism, as illustrated in Figure 3. The conveyor belt is a continuous loop made from durable, food-grade polyurethane material, stretched between two rollers and supported underneath by a rigid aluminum frame to maintain belt flatness and alignment. Tray transport is achieved through a motor-driven transmission system designed for efficient and controlled movement.

Given the following operational and design parameters for a horizontal belt conveyor system used in an automated tray feeding module:

Tilt angle of the conveyor belt: α = 0° (horizontal configuration)
Conveyor belt speed: v = 10 m/min = 0.18 m/s
Conveyor throughput capacity: Q = 0.14 kg/min
Tray mass: m_{tray} = 300 g = 0.3 kg
Food mass per tray: m_{food} = 300 g = 0.3 kg
Total load per tray: $m_{load} = m_{tray} + m_{food}$ = 0.6 kg

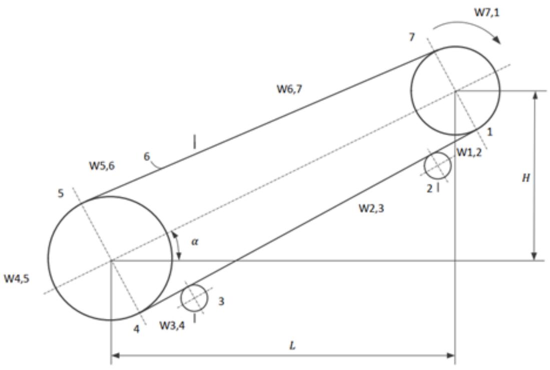


Fig. 4. Belt drive diagram

Refer to the belt diagram from the Fig. 4, where:

- Segments W6,7 and W2,3 represent the upper and lower runs of the conveyor belt.
- Points 4, 5, 6, 7 represent the driven drum (idler pulley).
- Points 1, 2, 3 represent the drive drum, powered by an electric motor.
- Belt length = L, vertical lift = H=0, as the conveyor is horizontal.
- Tray loading occurs on the upper belt segment from point 6 to point 7.
- The belt moves at a constant speed v=0.18 m and carries a load of m_{load}=0.6kg per tray.
- Divide the ribbon into segments 1 → 7 as shown in the figure, $S1$ S in order are the tensions at those points.
  According to the formula:
  $S_{i+1} = S_i \pm W_i$
  In which:
  + S_i : belt tension at point i
  + S_{i+1}: belt tension at point i + 1
  + W_i : resistance force at the interval between two consecutive points i and (i+1)

Fig. 5 illustrates the tension distribution across the different segments of the conveyor belt as it cycles through the system.

The results show a gradual increase in belt tension from S_1 to S_7, indicating the accumulation of load as the tray advances along the conveyor. Starting at 3.5 N at point S_1, the tension increases slightly through each segment: 3.68 N (S_2), 4.35 N (S_3), 4.56 N (S_4), 4.88 N (S_5), and 4.89 N (S_6), reaching a peak of 5.92 N at S_7. This peak tension occurs just before the tray enters the dumping module, where the belt carries the full combined weight of the tray and contents, and maximum effort is required for positioning and stability. To ensure operational reliability and avoid sagging-induced misalignment, the deflection of the conveyor belt on both the loaded and unloaded branches must remain within prescribed limits. The maximum allowable belt deflection is assessed using the standard formula:

$$y_{max}=\frac{(q+q_b)l^2}{8S_{min}} \leq [y] = 0.03l$$

Where,

q: load per unit length due to trays (kg/m),
q_b: self-weight of the belt per unit length (kg/m),
l: distance between support rollers (m),
S_{min} : minimum allowable tension in the belt (N),
[y]: maximum allowable deflection, typically 3% of the span.

a) Loaded Branch Analysis
$l_{cl}=0.28m$
$q+q_b=0.4+0.64=1.04kg/m$
$S_{min}=3.5N$

And results: y_{max} = 0.003 m, [y] = 0.0084 m. Thus, the belt satisfies the allowable deflection requirement on the loaded branch.

Unloaded Branch Analysis
$l_{ck}=0.51m$
$q+q_b=0.4+0.64=1.04kg/m$
$S_{min}=3.5N$

And results y_{max} = 0.001 m, [y] = 0.015 m. As a result, the belt also satisfies the deflection condition on the unloaded branch.

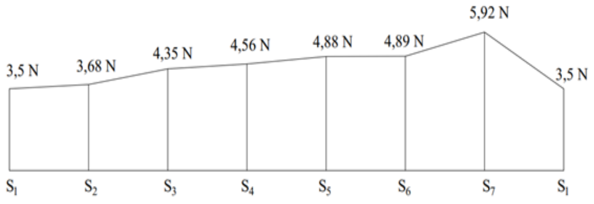


Fig. 5. Tension diagram on conveyor belt

To ensure that the conveyor system operates safely under mechanical loads, a structural strength analysis was performed using Finite Element Analysis (FEA). The simulation results, visualized in Figure 6, show the von Mises stress distribution across the component, with values ranging from 6.2×10^1 to 4.83×10^5 N/m². The stress concentration appears higher near the supports and loading points, but remains well within the material's safe working limits.

The maximum von Mises stress recorded is σmax = 0.483 MPa. This value is compared to the material's yield strength, denoted in the simulation as σyield = 580 MPa.

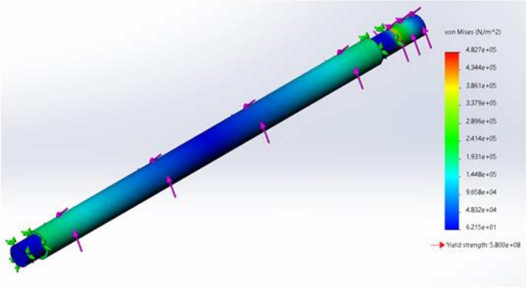


Fig. 6. Finite element analysis distribution along a shaft

The extremely high safety factor confirms that the selected material and cross-section offer excellent resistance to mechanical stress under operating loads. No yielding or permanent deformation is expected under normal conditions, and the structure is significantly over-engineered—offering additional robustness against unexpected impacts or dynamic forces.

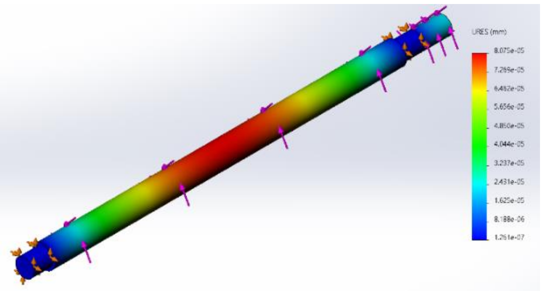


Fig. 7. Total Displacement Analysis (URES) from FEA result

In addition to evaluating von Mises stress, the total displacement (URES) field was computed to assess the structural deformation of the cylindrical member under mechanical loading. Figure X shows the simulation results, with color-coded displacement values ranging from 1.26×10^{-7} mm (deep blue) to 8.08×10^{-5} mm (bright red).

The displacement is largely symmetric, peaking at the center of the span—consistent with the classical bending behavior of a simply supported beam under uniformly distributed load. The maximum displacement of approximately 0.081 mm occurs in the middle section, far below any critical tolerance that might affect conveyor alignment, belt tracking, or tray stability. This result confirms that the designed shaft or beam component exhibits excellent stiffness under applied forces.

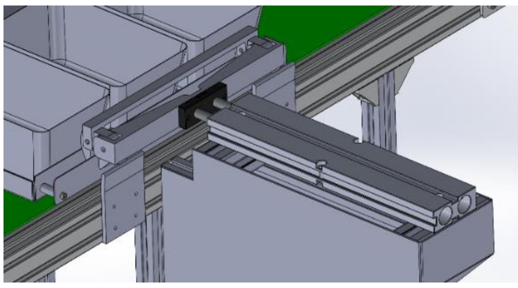


Fig. 8. Tray Level Module Construction

The tray level module, as shown in Figure 8, is responsible for transferring trays into and out of the tray filling station in an automated kitchen line. Its construction leverages a combination of mechanical actuators, pneumatic systems, and a modular aluminum frame for durability and hygiene compliance. At the heart of the module are two core mechanisms: the tray-push mechanism and the tray-pull mechanism. The push mechanism, mounted on linear guide rails, is actuated by a pneumatic cylinder to slide the tray from the conveyor into the filling station with high precision. Once the filling process is complete, the tray pull mechanism, also powered by pneumatic actuation, retracts the tray back onto the conveyor, allowing it to continue downstream. The system utilizes a double-acting pneumatic cylinder, coupled with a control valve, to direct motion, ensuring smooth, responsive, and repeatable tray handling.

Input data: Tray size 160x300x25 mm, made of 304 stainless steel, safe for use in food. Tray width 20 mm. The tray used in the automated kitchen system is specifically designed to support efficient handling, food safety, and compatibility with the mechanical components of the conveyor and tray-filling modules. As illustrated in Figure 9, each tray is composed of three distinct compartments, allowing for the separation of different food ingredients or portions during meal preparation. The tray dimensions are 160 mm (width) × 300 mm (length) × 25 mm (depth), optimized for both capacity and compact stacking on the conveyor system.

The material selected is 304-grade stainless steel, which provides excellent corrosion resistance, mechanical durability, and full compliance with food safety standards. This material ensures the tray is easy to clean, resistant to staining, and suitable for repeated contact with both hot and cold food items. Each tray includes side ears (handles) with a width of 20 mm, which serve as mounting and gripping features for the push-pull mechanisms in the tray level module. These ears allow for precise engagement during tray transfer and provide clearance for smooth alignment with mechanical guides or actuators. The tray's geometry features gently sloped internal walls to facilitate easy pouring of contents and minimize residue retention, thereby enhancing its hygienic performance.

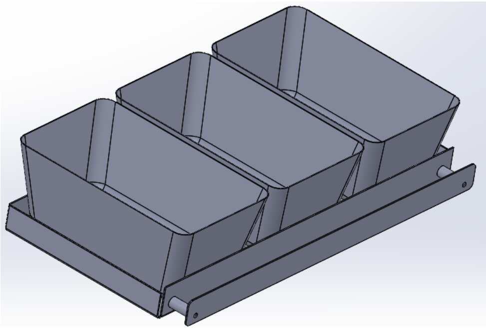


Fig. 9. 3D model of the tray design

The tray retention and movement in the automated kitchen system are facilitated by a hook-type engagement mechanism, as shown in Figure 10. This design ensures a secure mechanical interface during both the pushing and pulling phases of the tray handling process.

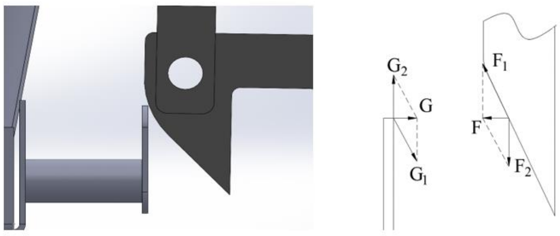


Fig. 10. Force diagram of the hook and tray mechanism

The maximum displacement of the hook mechanism during tray engagement and removal is constrained by the mechanical layout and operating cycle time. In this system, the hook travel is limited to less than 20 mm, which is sufficient to engage the 20 mm wide tray ear securely. o ensures smooth operation with margin for tolerance and mechanical backlash, a travel distance of: L=15 mm is selected as the nominal stroke length of the hook during actuation.

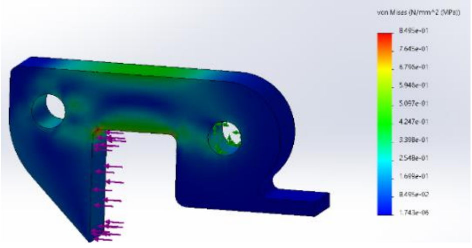


Fig. 11. The von Mises stress distribution on the hook geometry

The structural integrity of the tray hook component was verified through a finite element analysis (FEA), which simulated the von Mises stress distribution under expected operational loads. As shown in the figure, the hook was subjected to a horizontal force of approximately 7.92 N, representing the maximum pulling or pushing force during tray engagement. The boundary conditions included fixed constraints at the mounting holes, while the contact edge was subjected to the applied force. The analysis revealed a maximum von Mises stress of approximately 0.849 MPa, concentrated near the curved contact region of the hook, where force is transferred. This stress level is significantly lower than the yield strength of common structural materials, such as aluminum 6061-T6 (240 MPa) or stainless steel 304 (215 MPa). With a resulting safety factor exceeding 250, the design is structurally robust and demonstrates excellent mechanical reliability. No critical stress concentrations or deformations were observed, confirming that the hook geometry is well-suited for repeated operation under moderate mechanical loads in the automated kitchen environment.

In addition to the stress evaluation, a displacement analysis (URES) was conducted to assess the total deformation of the hook component under the applied tray handling load. The results, presented in the figure, show the distribution of displacement magnitudes across the hook geometry. The maximum displacement recorded is approximately 0.034 mm, occurring at the free end of the hook where the force is applied. This minimal deformation confirms the hook's high stiffness and its ability to maintain geometric stability during operation. The areas near the mounting hole remain effectively rigid due to fixed constraints, while the rest of the body shows a gradual, uniform displacement gradient, indicating well-distributed load transfer. This level of deflection is negligible in the context of the system's mechanical tolerances and confirms that the hook will not experience functional misalignment or fatigue-induced wear during repeated cycles.

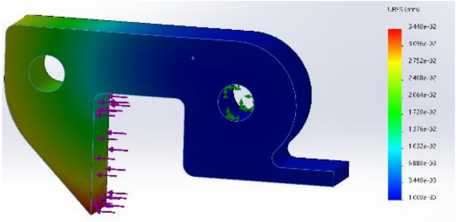


Fig. 12. Displacement (URES) simulation result for the hook component

2. Results and discussion

The completed prototype of the automatic tray feeding module was assembled and tested under controlled laboratory conditions, as shown in Figure 13. The system comprises a dual conveyor layout mounted on aluminum extrusion frames, a tray-filling station centrally located between the conveyors, and a tray push-pull module actuated via pneumatic or linear actuators. The tray used for testing is fabricated from stainless steel, positioned on the right conveyor, and transported to the dumping module on the left. The entire structure is mounted on a wooden platform for vibration isolation and ease of repositioning during evaluation.

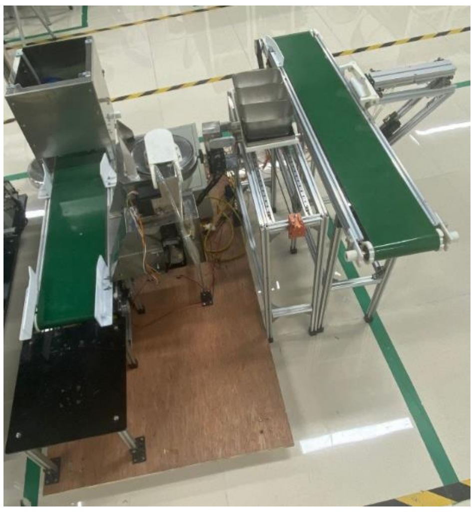


Fig. 13. The completed prototype of the automatic tray feeding modul

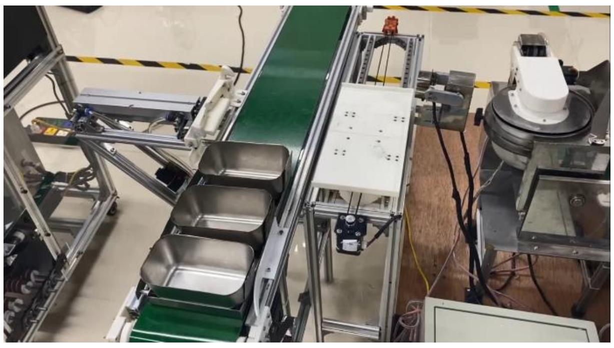


Fig. 14. The initial state of the system

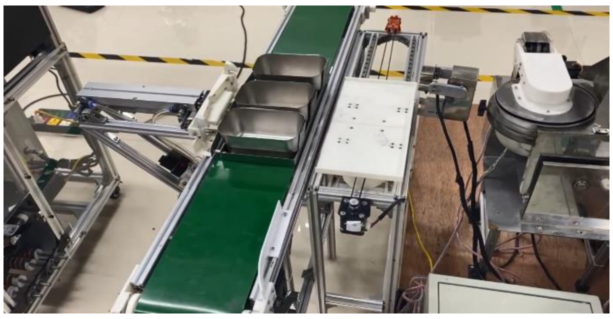


Fig. 15. Tray alignment and system readiness at t = 0.1s

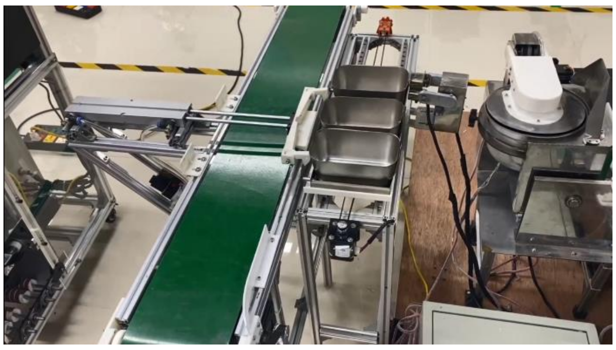


Fig. 16. Experimental setup at t = 0.5s

The Fig. 14 captures the initial state of the automated tray feeding system at the beginning of a cycle. Three stainless steel food trays have just arrived at the processing zone via the green belt conveyor, guided by side rails to maintain alignment. The white tray-handling platform is in the standby (HOME) position, ready to receive the next tray for engagement. The pneumatic pushing mechanism is fully retracted, and the rotary dumping unit remains at its rest position.

At t = 0.1 seconds (Fig. 15), the tray feeding system is in a state of readiness immediately preceding actuation. The tray stack has arrived in position at the front of the conveyor, and the pneumatic pusher is fully retracted, aligned precisely with the side ear of the leading tray. The white pushing mechanism is positioned just millimeters behind the tray flange, awaiting the control signal to initiate motion.

At t = 0.5 seconds (Fig. 16), the tray pushing mechanism has reached its maximum forward extension, completing the transfer of the leading tray from the conveyor into the designated HOME position on the tray-receiving platform. The white pneumatic pusher arm is fully deployed, and the tray is now precisely nested within the bounds of the receiving platform, aligned for the next phase of ingredient dumping. The remaining trays on the conveyor remain securely in position, buffered by the integrated side rails to prevent any unintended shifting during the actuation.

At t = 20 seconds (Fig. 17), the system enters the ingredient dispensing phase, where the leading tray previously positioned in the HOME position is now actively undergoing the dumping operation. The rotating arm mechanism, which securely holds the tray, has tilted it over the target cooking vessel below. The tray is inclined at a sufficient angle to ensure that the contents are fully emptied into the pot, aided by gravity and the smooth, sloped surface of the stainless-steel tray. The adjacent trays on the sliding platform remain stationary and correctly aligned, waiting for their turn in the sequence. The dumping motion is performed with mechanical precision and fluidity, ensuring that the tray returns to its original horizontal orientation after the operation, thereby avoiding any misalignment during tray retraction.

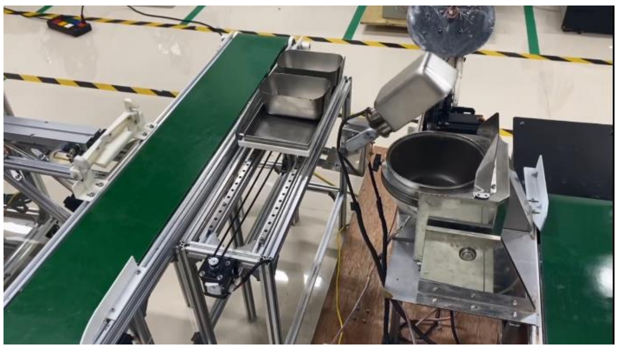


Fig. 17. Experimental of setup at t = 20s

At t = 33 seconds (Fig. 18), the system continues its automated cycle with the second tray now in the dumping phase. The dumping arm has engaged the next compartment, lifting and rotating it above the cooking vessel with a controlled tilt to release its contents. The first tray has already been returned to its position on the receiving platform, demonstrating the system's ability to handle sequential material delivery with minimal delay. The staged dumping operation enhances accuracy and flow control, preventing ingredient overlap or premature mixing. The remaining tray remains stationary and secured on the sliding support rails, waiting for its turn. The dumping trajectory, tray tilt angle, and alignment with the pot are consistent with the previous phase, confirming the repeatability and mechanical precision of the system's rotary actuator.

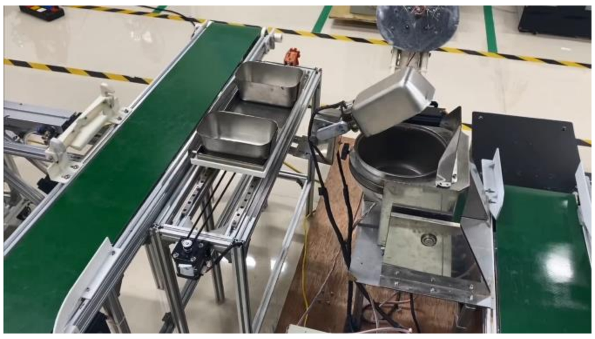


Fig. 18. Experimental of setup at t = 33s

At t = 46 seconds (Fig. 19), the system reaches the final stage of its multi-tray dumping sequence. The third tray has now been lifted and rotated into the dumping position, directly above the cooking pot. This marks the culmination of the automated cycle for this batch of trays. The first two trays are visibly returned and stacked securely on the tray platform, while the final tray is undergoing controlled inversion to release its remaining contents.

The tray tilting actuator maintains consistent rotational motion and alignment, ensuring that each tray empties without misplacement or spillage. The continued mechanical precision and synchronized actuation reflect the robustness of the system's design capable of operating cyclically and repetitively with minimal mechanical fatigue or misalignment. Table 1 presents a detailed timeline of the key events occurring during the automated tray feeding process. The sequence begins with the tray's arrival at the engagement zone (0.1s), confirming the responsiveness of the conveyor positioning system. Within a fraction of a second, the pneumatic actuator initiates motion (0.2s), and the tray is fully seated in the HOME position by 0.5s. This rapid positioning phase demonstrates the system's ability to perform initial alignment tasks in under one second, an important factor for high throughput applications. The dumping phase begins at 20 seconds, indicating a controlled delay that allows the system to verify positioning and initiate the rotational tilt mechanism. The subsequent events at 33 and 46 seconds correspond to the dumping of the second and third trays, respectively, highlighting the sequential operation of the system.

Fig. 19. Experimental of setup at t = 46s

The consistent time intervals between each dumping action reflect the system's stability and repeatability in performing repetitive mechanical tasks.

Table 1. Automated Tray Feeding Process Timeline

Time (s)	Event Description
0.1	Tray arrives at the pusher; system ready for engagement
0.2	Pneumatic pusher begins to move tray forward
0.5	Tray fully enters the HOME position (preparing for dumping)
20	1st tray is tilted and contents are dumped into the pot
33	2nd tray is tilted and dumping begins
46	3rd and final tray completes its dumping phase

3. Conclusion and future work

This study presents the successful design, fabrication, and testing of a modular tray feeding module intended for automated kitchen systems, particularly those operating in high-throughput industrial environments. The system integrates a conveyor mechanism, pneumatic actuators, a tray positioning platform, and a rotational dumping unit to automate the handling and transfer of meal trays. The complete process from tray delivery and ingredient dumping to tray return has been fully automated, demonstrating significant improvements in consistency, hygiene, and labor efficiency.

Simulation results, including structural and displacement analysis using finite element methods, confirm that the mechanical components operate safely under expected loading conditions. Experimental trials further validate the system's performance, with stable operation, precise tray alignment, and reliable tray transfer confirmed over repeated cycles. The system satisfies the design requirements for speed, repeatability, and food safety, and shows strong potential for real world deployment in industrial kitchens, canteens, and institutional food service facilities.

Future Work will focus on several key directions to enhance the current system:

- Vision Integration: Incorporating computer vision to identify tray orientation, detect anomalies, and improve engagement precision.
- Multi-tray Optimization: Developing parallel tray handling capability to further reduce cycle time and increase throughput.
- Closed-loop Control: Implementing sensor feedback for real-time position correction and fault detection.
- System Scalability: Adapting the module for integration with upstream and downstream kitchen automation systems, including robotic arms and dishwashers.
- Extended Durability Testing: Performing long-term operational testing under industrial conditions to evaluate component wear and maintenance schedules.

These enhancements aim to further improve the system's adaptability, reliability, and integration into broader smart kitchen infrastructures, contributing to the next generation of intelligent, automated food preparation systems.

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