AUTOMATED HANDLING AND FEEDING TECHNIQUES FOR SKEWERING OPERATIONS

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Research

HIGHLIGHTS

- An automated system connects skewering operations for unattended kebab production.
- Separating and aligning meat cubes, vegetable slices, and shrimp (C-shape).
- Multi-machine mode for producing meat and vegetables, and shrimp and vegetable kebabs.

ABSTRACT. *Barbecue kebab skewers typically consist of various meat choices, including chicken, lamb, pork, or seafood, and vegetables such as onion and pepper. Traditionally, manual kebab-making is a time-consuming and labor-intensive process, which is considered to be replaced by semi-auto and full-auto skewering machines. Currently, semi-auto skewering machines still require two main manual preparation processes: align the small meat and vegetable pieces into lines for skewering operations; superpose the large pieces of meat and vegetables, then do skewering and cutting operations. Fully automated skewering machines also have two different strategies. The first one is to use rotating scrappers and cups with a respective depth to ensure only one item can be loaded into each cup. All the cups are arranged into sequential cup rows and cup lines for skewering operations. However, the cups are frequently left empty because the rotating scrapper design often blocks any items falling into cups. Thus, some processing facilities still need extra labor to manually fill these empty cups. Another solution is the pick-and-place method by using robot arms and real-time image processing equipment, which cannot process irregular food pieces, such as shrimps (C-shape). In this paper, a novel fully automated handling and feeding system has been developed to prepare and connect the skewering operations to establish unattended kebab production lines. The performances of singulation, handling, and feeding operations have been investigated with different parameter settings and food items. Besides, the presented machine system is the first realization of unattended kebab production lines to process shrimps (C-shape), and the first design of using horizontal skewering operation to produce meat and vegetable kebabs (cube+ square piece) and shrimp and vegetable kebabs (C-shape+ square piece). This study will be beneficial for developing more effective next-generation skewering technologies and better value-added meat and seafood products.*

Keywords. *Automated skewering, Computer vision, Food sorting automation, Kebab skewer, Robotic food preparation, Singulation.*

As a kind of value-added food product, kebabs consist of cubed meat (Shish kebab) or ground meat (Koobideh kebab), typically including lamb, beef, pork, chicken, fish, and shrimp, sometimes with vegetables and various other accompaniments according to the specific recipe (Kraig and Sen, 2013). For Shish kebab, the traditional kebab-making process demands significant manual operations to place, align, and skewer meat and vegetable items, which is labor-intensive and time-consuming and may cause risk of injury and hygiene problems (Oi, 2004). As the demand for kebab products has grown, particularly in commercial settings such as restaurants and catering companies, there has been a need for achieving faster, cleaner, and more efficient production methods with less manual labor input.

To achieve better production quality and safety, simple manual devices were designed to put meat or seafood into separate holders for skewering operations (Roe, 2006). Without complicated mechanical equipment, these devices are good for efficiently and easily making kebabs at home or in the kitchen (Wigley Jr., 1986). Vegetables can also be added and skewered for health and nutritional consideration (Al-Raqadi, 2015). The advent of modular skewering devices allows users to customize the sequence and dimension of food items, offering a more personalized experience (Mollet, 2018). Besides, a further innovative design enables successively skewering and cutting large quantities of meat and vegetables (Mulchi and Lemberos, 2012). In terms of

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mass production for commercial purposes, semi-automated technologies have been explored with the integration of mechanical components that significantly reduce manual labor for continuous or batch skewering operations. Motors were used to drive the skewering motions to produce about six kebabs per cycle (Carmen and Sico, 1968). Continuous kebab production with automated skewering operations can be realized in conveyor-based systems (Walser, 2011; Yamanaka, 1974). Furthermore, advanced basket systems have been optimized by automating the skewer-and-cut process (Dolle, 1986), or adding temporary retention apparatus (Dolle, 1992). A multi-basket system can further improve the production efficiency since the preparation (stacking and placement of meat and vegetables), skewering, and cutting operations can be executed simultaneously in different stations (Emsens, 2000). Current kebab production lines have various insertion methods for skewering operations. Single or multiple skewer sticks can be directly inserted or guided into the food items by a motorized pusher (Chow, 1973), or rotating rollers (Walser, 2011). Sometimes bamboo and wood skewer sticks may be buckled or bent during the insertion process, resulting in inconsistent skewering quality. To address this issue, steel needles were applied to pre-pierce the food items and create channels for later inserting bamboo or wood skewer sticks consistently and smoothly (Emsens, 1989; Vitileia, 2015). Besides, guide tubes were designed as another solution to stabilize and guide the wood or bamboo sticks for skewering operations (Emsens, 1990, 1998).

Operations for handling, sorting, and separating items play pivotal roles in diverse industries. The genesis of traditional mechanical operations is often traced back to the point where items first contact the conveyor. Vibratory bowl feeders serve as a classic example, harnessing the power of vibrations to position individual parts on a conveyor (Boothroyd, 2005). Another approach to flexible part feeding employs three distinct conveyor belts (Causey et al., 1997). The system methodically elevates parts from a bulk hopper, ascertains the parts' orientations using contour imagery, and deploys a robotic arm for precise capture. Further innovation with turning functions engages with and reorients food items being transported, augmenting the efficiency and speed of subsequent processing stages (Bjarnason et al., 2022). Using adjustable barriers on the conveyor to direct items is a widely adopted design that is suitable for items with consistent sizes (Greve et al., 2023; Pothula et al., 2023). Sequential conveyors with different speeds expand the interspacing between items (Eilertsen, 2012) or selectively hold-and-release items (Isaacs et al., 2002). Rotary systems are designed to use centrifuge force to push the objects against the wall for sorting and separating (Layer, 1994). To separate and feed meat cubes and vegetable slices for skewering operations, fully automated kebab production lines have been only developed into two methods. The first one is to use rotating scrappers and cups with a respective depth to ensure only one item can be loaded into each cup (Völkl, 2017). All the cups are arranged into sequential cup rows and cup lines for skewering operations. But the cups are frequently left empty because the rotating scrapper design often blocks any items falling into cups. Thus, some processing facilities still need extra labor to manually fill these empty cups (MULTIVACGroup, 2024). Another solution is the pick-and-place method via robot arms and real-time image processing equipment (Mollet, 2020). However, as a common ingredient of kebab products, shrimps (C-shape) cannot be handled and fed by these two methods, because skewer sticks cannot be well aligned with shrimps for skewering operations.

This study reports the development of a novel system for handling and feeding meat, seafood, and vegetable items to prepare the skewering operations. The proposed research is innovative because we depart from the status quo to develop a new technique by utilizing an automation scheme in place of manual work and filling in the blanks of the automation design for upstream processing of kebab productions. The typical handling and feeding process is demonstrated step by step with detailed pictures. The current design's processing capacity and production efficiency are evaluated with different parameter settings and food items. Finally, the continuous production of meat and vegetable kebabs and shrimp and vegetable kebabs is demonstrated with multi-machine combination and horizontal skewering operation. The presented machine system is the first realization of unattended kebab production lines to process irregular food pieces, such as shrimps (C-shape), and the first design of using horizontal skewering operation to produce meat and vegetable kebabs (cube+ square piece) and shrimp and vegetable kebabs (C-shape+ square piece). It can freely integrate with most of the skewering machines, which will have the tremendous potential to benefit the U.S. meat and seafood processor by minimizing labor dependence and costs.

Materials and Methods

System Design Basis

The handling and feeding system is schematically illustrated in figure 1. The main actions of the system are: (1) to separate food items (singulation), (2) to arrange food items into appropriate spots (handling), and (3) to feed food items into sequential cup rows for skewering operations (feeding). Three PVC flat belt conveyors are used as three working sections: the initial singulation section, the further singulation section, and the handling and feeding section.

Initial Singulation

In the initial singulation section (fig. 2), a self-made rotating paddle wheel is installed on the first conveyor to create a single layer of meat cubes or vegetable slices (no stacking on top of each other). The rotation direction is reversed to the conveyor moving direction to push down the stacked

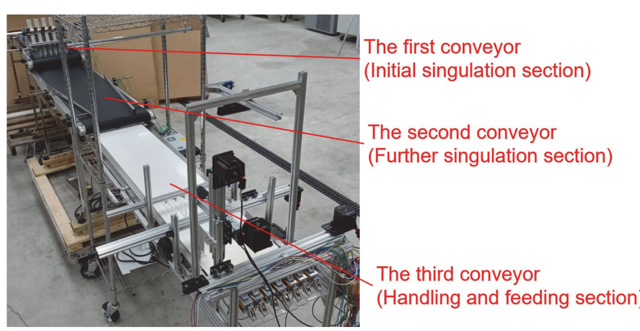

Figure 1. The experimental setup for the whole preparation system.

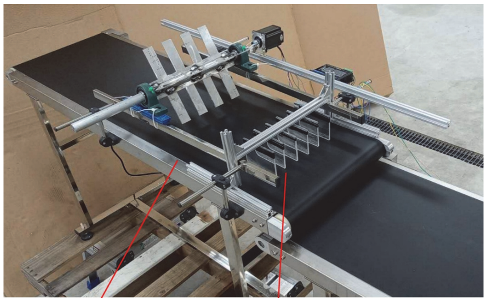

Figure 2. The first conveyor (Initial singulation section).

food items. Because the chicken and beef are usually cut into 2.54 cm cubes for skewering (Elsner et al., 1998; Lepper-Blilie et al., 2014), the distance between the paddle blade tips and conveyor belt is a little bigger than the thickness of one food item (3 cm for meat cubes or 0.3 cm for vegetable slices) to prevent stacking. As an example, a batch of chicken cubes is dropped at the beginning of the first conveyor, as shown in figure 3a. After creating a single layer of chicken cubes and splitting them into seven lines (fig. 3b), the second conveyor further separates the chicken cubes at a faster speed. The lane width is 3.5 cm, and the width of paddle wheel blades and gaps between each blade is 3 cm.

Further Singulation

The second conveyor is installed right after the first one. With a faster speed, the second conveyor can space the seven lines of cubes or slices as further singulation operation (Eilertsen, 2012). Due to the limited handling and feeding speed in the third section (conveyor), the first conveyor fully stops and the second conveyor slows down to match the third conveyor's speed when the frontmost chicken cubes move to the end of the second conveyor (fig. 4). At that time, the batch of chicken cubes would form into smaller batches (the total amount of chicken cubes on the second conveyor) by the high-speed conveyor (second conveyor) and are then sent to

(a)

(b)

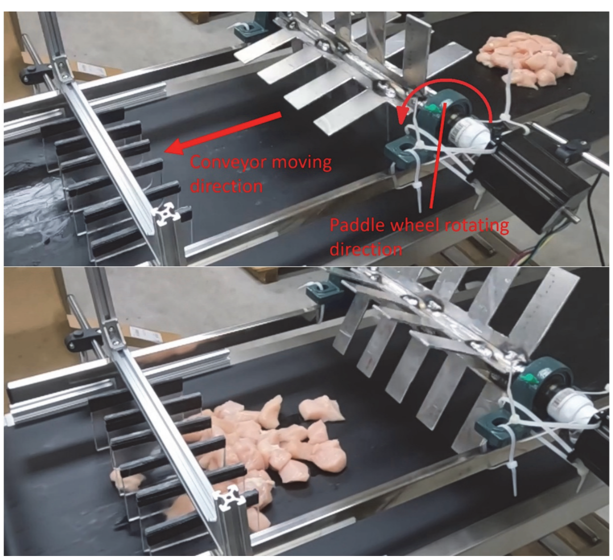

Figure 3. Initial singulation operation in the first conveyor (a) a batch of chicken cubes (30 pieces) is dumped at the beginning of the first conveyor; (b) the rotating paddle wheel creates a single layer of chicken cubes, then the seven-lane track splits them into seven lines.

the third conveyor. Once this sub-batch has been completely sent to the third conveyor (downstream), the first conveyor restarts moving, and the second conveyor speeds up again to do a singulation operation for the next sub-batch of chicken cubes coming from the first conveyor (upstream). Therefore, the second conveyor has been switching the roles between the separator (high speed to separate the chicken cubes from the first conveyor (upstream)) and the feeder (low speed to send the separated chicken cubes to the third conveyor (downstream)) in the system.

Handling and Feeding

In the handling and feeding section (fig. 5) (the third conveyor), another seven-lane track is installed to re-ensure that all the cubes or slices are distributed into seven lines. One push plate is attached to a single-axis linear actuator (Openbuilds, Zephyrhills, FL) to remove any left unseparated food items as a final singulation check. Another push plate is attached to a three-axis V-slot linear actuator (Openbuilds, Zephyrhills, FL) for handling and feeding operations (arrange food items into appropriate spots, and feed food items into sequential cup rows for skewering operations). A low-cost webcam (TECKNET, Liverpool, UK) is mounted on the top of the third conveyor to monitor and locate the meat cubes or vegetable slices. Seven electromagnetic solenoids with seven sliding plates are installed horizontally at the end of the third conveyor to feed meat cubes or vegetable slices into sequential cup rows for skewering operations. Fresh raw chicken, green pepper, and raw shrimp were obtained from a local retail grocery store and kept at 4°C for use within 72 h. Chicken and pepper were cut into 2.5 × 2.5 × 2.5 cm cubes and 2.5 × 2.5 cm slices, respectively (Elsner et al., 1998). The width of seven lanes and seven sliding plates is 3.5 cm for fitting the food item size.

The third conveyor and two push plates are controlled by the machine vision system. OpenCV is used for image acquisition and object detection based on HSV (Hue, Saturation, and Value) color space. Contours of every distinct object within the field of view are sketched to calculate the projected area and locate the real-time position on the conveyor belt for the first push plate's selection operations and the second push plate's handling and feeding operations. A specific projected area value is defined for identifying the oversized targets that multiple cubes or slices stick together (cannot be normally handled or fed to the skewering process). If the objects are identified as oversized, the first push plate will be actuated to push the objects out of the conveyor. Another specific projected area value is defined for identifying the single objects to be moved by the second push plate (laterally move objects to other lanes and/or longitudinally move objects forward to fill the empty spots). The third conveyor is programmed to be moved intermittently (1.5 cm/s), which means the cubes or slices will be moved forward around half of their own length every second. The single objects' vertices being detected inside the handling section indicate that the cubes or slices are ready to be handled and fed to the skewering process (fig. 5). Some real-time image analysis illustrations for detecting the oversize items are shown in figure 6.

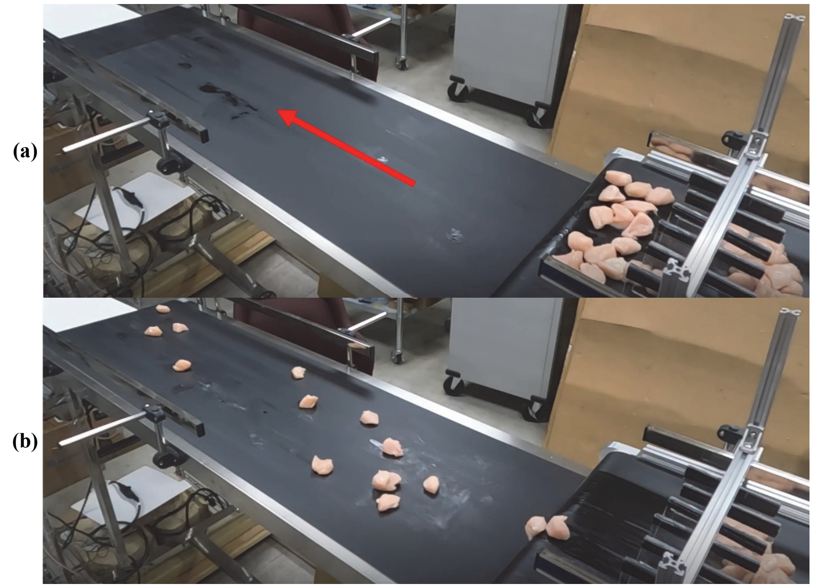

Figure 4. Further singulation operation in the second conveyor: (a) seven lines of chicken cubes are sent to the second conveyor; (b) the first conveyor fully stops, and the second conveyor slows down the speed as the same as the third conveyor's speed when the frontmost chicken cube moves to the end of the second conveyor.

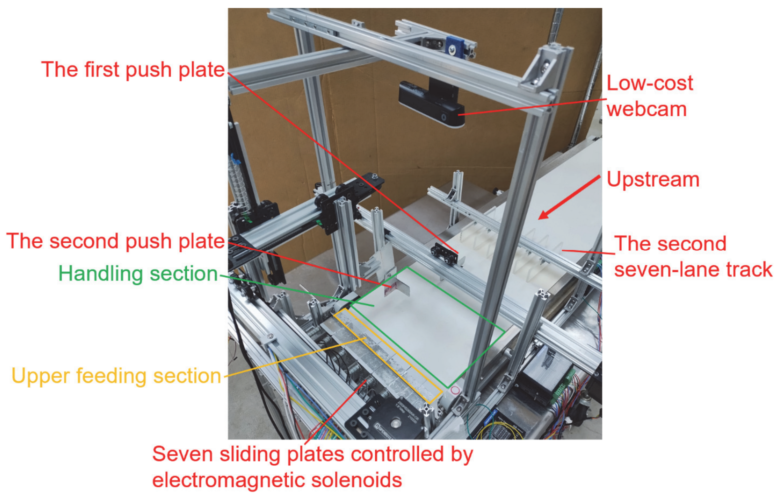

Figure 5. Handling and feeding sections located at the end of the third conveyor.

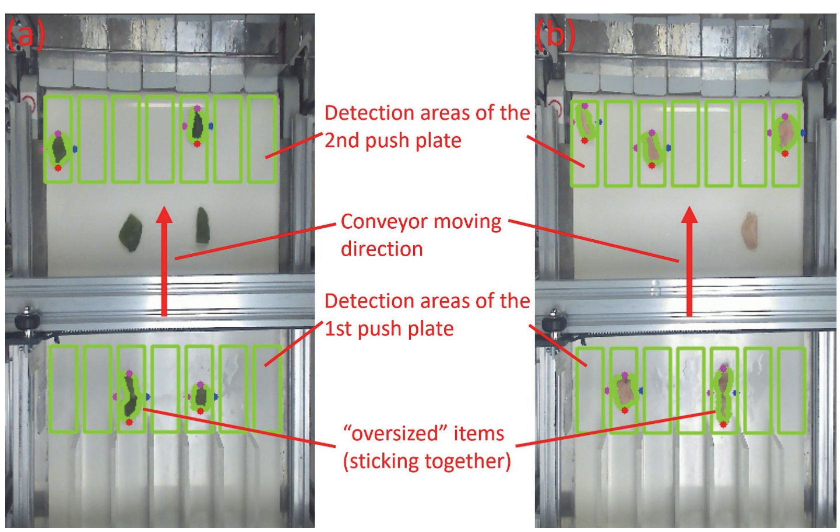

Figure 6. Detection images from the low-cost webcam (a) green pepper slices; (b) chicken cubes.

In the third conveyor, after passing through the seven-lane track, the first push plate (controlled by the single-axis linear actuator) performs back-and-forth linear motion to push the “oversized” chicken cubes (sticking together, which cannot be normally handled by the next push plate) out of the conveyor (fig. 7a). These chicken cubes can be collected to a certain amount (equal to the batch size) and then sent back to the first conveyor for restarting the process as a new batch. Finally, the second push plate (controlled by the three-axis V-slot linear actuator) moves the chicken cubes to the top surfaces of the sliding plates, which are defined as seven empty spots (figs. 7b-c). The seven electromagnetic solenoids can be actuated to pull the seven sliding plates if these seven empty spots are filled up, which means that there are seven chicken cubes sitting on the top surfaces of the sliding plates (fig. 7d). Thus, seven chicken cubes drop into a line of cups (fig. 7e), which sequential cup rows can freely integrate with most vertical and horizontal skewering operations (Vitileia, 2015; Völkl, 2017).

At the end of the third conveyor, we define three subsections (fig. 8a): handling section (Zone A), upper feeding section (Zone B), and lower feeding section (Zone C, cup rows for skewering operation). According to the machine vision measurement, the basic operation rule of the second push plate is to keep using the coming ones to fill the empty spots, then to fill the sequential cup rows line by line for the downstream skewering process. One example of handling and feeding meat cubes is shown in figure 8. At the beginning, four meat cubes are detected in Zone A. The second push plate is actuated to move them forward to fill four empty spots (figs. 8b-c). Although conveyor rolling can keep moving them toward the feeding sections, meat cubes or vegetable slices may be stuck by the gap between the conveyor and sliding plates. In figures 8d-e, six more meat cubes are moved into Zone A. The two frontmost cubes can be directly pushed to fill two empty spots, and the last empty spot will be filled by the nearest cube (like figs. 7b-c). After this line of cubes is fed into the cups below (Zone C) and sent out for the skewering process, the rest three will be directly moved to fill the next seven empty spots (figs. 8f-g). With the moving conveyor, five new meat cubes appear in Zone A. One of them can be directly moved to fill one spot. Then the push plate will one by one fill the rest three spots, starting from the right side (figs. 8h-i). Therefore, the operation procedures of the entire system are summarized in figure 9.

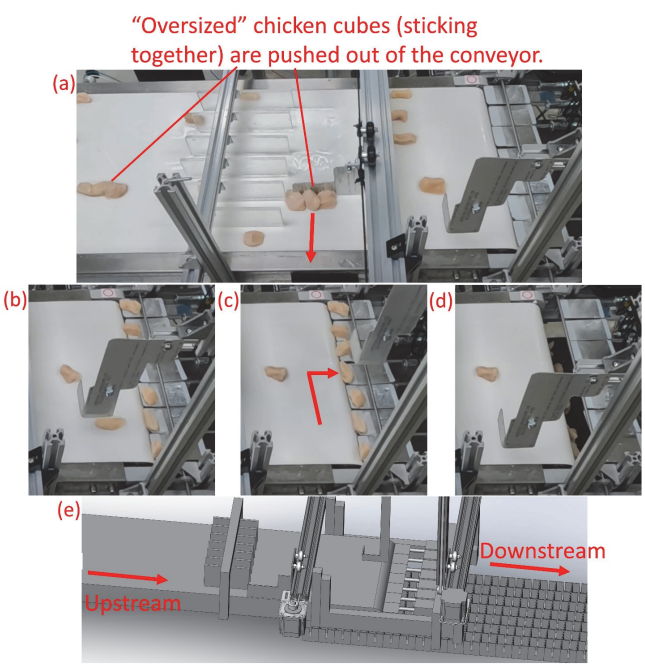

Figure 7. The typical handling and feeding process in the third conveyor (a) “oversized” chicken cubes (sticking together) are pushed out of the conveyor; (b) the second push plate keeps moving the coming chicken cubes to fill the empty spots; (c) seven empty spots (top surfaces of horizontal sliding plates) are filled up; (d) seven chicken cubes drop into a line of cups for skewering operations; (e) from upstream (after singulation before handling and feeding) to downstream (after feeding into sequential cup rows).

Experiments

Singulation Tests

The singulation tests were set to evaluate the capacity of the first two conveyors’ setup. The first conveyor’s speed was fixed at 89.5 mm/s (30 RPM). Four speed levels (119.3 mm/s (40 RPM), 149.2 mm/s (50 RPM), 179 mm/s (60 RPM), and 208.8 mm/s (70 RPM)) were experimented on in the second conveyor, in which objects were spaced and separated due to the faster speed. Four food options were tested and evaluated for their singulation performance: 2.5 × 2.5 × 2.5 cm uncooked chicken cubes, 2.5 × 2.5 × 2.5 cm cooked chicken cubes (boiled for 20 minutes), 2.5 × 2.5 cm green pepper slices, and small size raw shrimps (70–90 pieces per one-pound bag). Every food option with a distinct conveyor speed setting was executed with five replications. In figure 10, the 2^{nd}, 4^{th}, and 6^{th} lanes were closed for shrimp singulation test because shrimp (C-shapes) may be stuck on the wall of the lanes. As the working concept presented in figures 3 and 9, a big batch of food items was dumped on the first conveyor to prevent items being stacked vertically. The food items were then sent to the second conveyor. The batch size indicates the number of items dumped from the container to the conveyor belt (fig. 11). For investigating the singulation performance, if the batch size is too small (less than 100 pieces), one singulation cycle (fig. 4b) can process the whole batch, which has the same results for different food options (100% separated). Consequently, we used a large batch size (280 pieces) to ensure the singulation percentage is always less than 100%. Thus, the difference between the sub-batch sizes can be clearly compared and summarized. When the speed difference between two conveyors creates a sub-batch of food items (fig. 4b), the amounts of food items (a sub-batch including both separated and unseparated items) in the second conveyor were counted and compared as the singulation performance. Since the speed difference of two conveyors cannot 100% separate all the items, the items’ projected area values were detected and calculated (fig. 6) to determine the unseparated amount as another singulation evaluation index.

Handling and Feeding Tests

The handling and feeding tests were designed to assess the production efficiency and capacity of the third conveyor (fig. 5). 2.5 × 2.5 × 2.5 cm cooked chicken cubes (boiled for 20 minutes) were used with seven batch sizes (21, 63, 105,

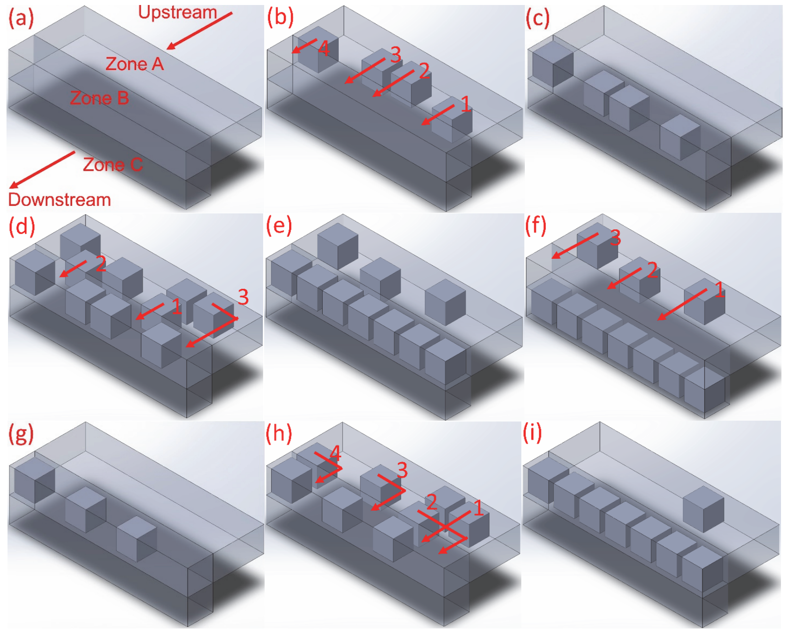

Figure 8. Example of handling and feeding meat cubes to explain the operation rule of handling and feeding (a) three subsections: Zone A (handling section), Zone B (upper feeding section), and Zone C (lower feeding section); (b-c) four meat cubes are detected in Zone A and the second push plate is actuated to move them forward to fill four empty spots; (d-e) six more meat cubes are moved into Zone A, and three of them are selected to fill the last three empty spots; (f-g) after this line of cubes being fed into below cups and sent to skewering process, the rest three are directly moved to fill next seven empty spots; (h-i) five new meat cubes are moved into Zone A, and four of them are used to fill the rest four empty spots.

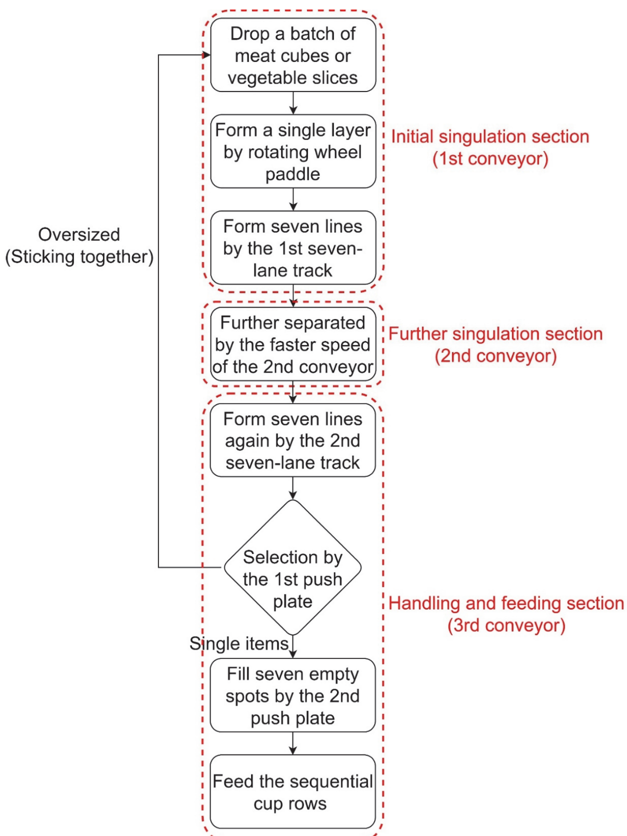

Figure 9. The typical production procedures.

147, 189, 231, and 273 pieces). Because each line has seven cups, these chicken cubes were fed into different numbers of cup rows (3, 9, 15, 21, 27, 33, and 39 lines). There are two kinds of handling and feeding operations: direct operations (feeding only: moving the chicken cubes to feed the corresponding empty spots, like figures 8b and 8f) and indirect operations (handling and feeding: moving the chicken cubes from other lanes to feed the empty spots, like the 2nd, 3rd, and 4th cubes in figure 8h). The total numbers of direct and indirect operations were compared with different batch sizes to evaluate the operation time (more indirect operations lead to longer operation time). Every batch size setting was executed with five replications.

Results and Discussion

Singulation Performance

Figure 12 indicates how the conveyors' speed difference and different food options (different shapes, stiffness, and friction conditions) affect the singulation performance. The sub-batch size is the total amount of chicken cubes (including both separated and unseparated items) on the second conveyor in one singulation cycle. For an unseparated amount, N pieces of items sticking or stacking together are counted as N unseparated items. The sub-batch size of food items is inversely related to the second conveyor's speeds because the frontmost items move to the end of the second conveyor faster. A shorter time period allows a smaller number of items to be dropped from the first conveyor to the second conveyor. In each sub-batch, the unseparated amount also reduces as the second conveyor's speed increases, because the faster speed leads to a higher chance to create space between each item. Due to the lower friction, cooked chicken cubes and pepper slices have excellent singulation performance. With 208.8 mm/s (70 RPM) speed of the second conveyor, the sub-batch sizes of cooked chicken cubes and pepper slices are 30 pieces and 26.8 pieces, respectively, and only 3.8 and 2 unseparated

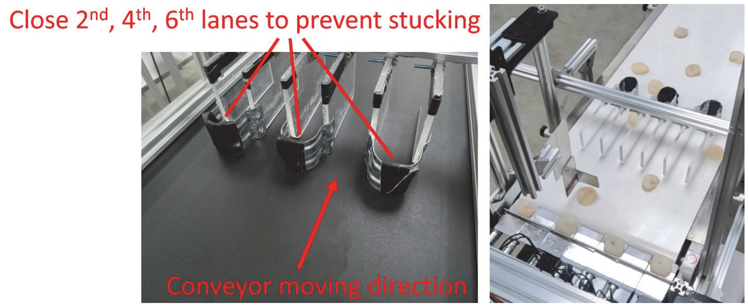

Figure 10. To prevent the shrimps from getting stuck on the wall of the lanes, three caps were installed in two seven-lane tracks to close the 2nd, 4th, and 6th lanes.

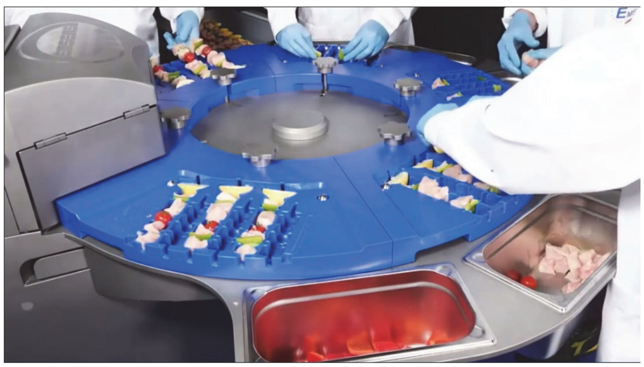

Figure 11. In the manual preparation process for skewering operations, meat cubes and vegetable slices are taken from containers (CM Machine Services Ltd., 2023). In our design, one whole container of the food items is dumped into the production line as one batch.

pieces (87.3% and 92.5% singulation percentage). Moreover, although the rotating paddle wheel creates single layers of the items, slices (thinner and lower) are easier to restack together than cubes (thicker and higher) when they pass through the first seven-lane track. Then the stacked pepper slices drop to the second conveyer, which achieves higher sub-batch sizes and unseparated amounts than the cooked chicken cubes. For example, at 119.3 mm/s (40 RPM) speed, the second conveyor produces 91.8 pieces of sub-batch size for pepper slices (including 30.2 unseparated pieces), but 61 pieces of sub-batch size for cooked chicken cubes (including 16.8 unseparated pieces). Besides, uncooked chicken cubes are easier to stack together (much sticker) then sent to the singulation process (produce higher sub-batch sizes and unseparated amounts). Finally, despite only four lanes, shrimp have the second highest sub-batch sizes. Shrimps are thinner and lower than the two kinds of chicken cubes, but thicker and higher than pepper

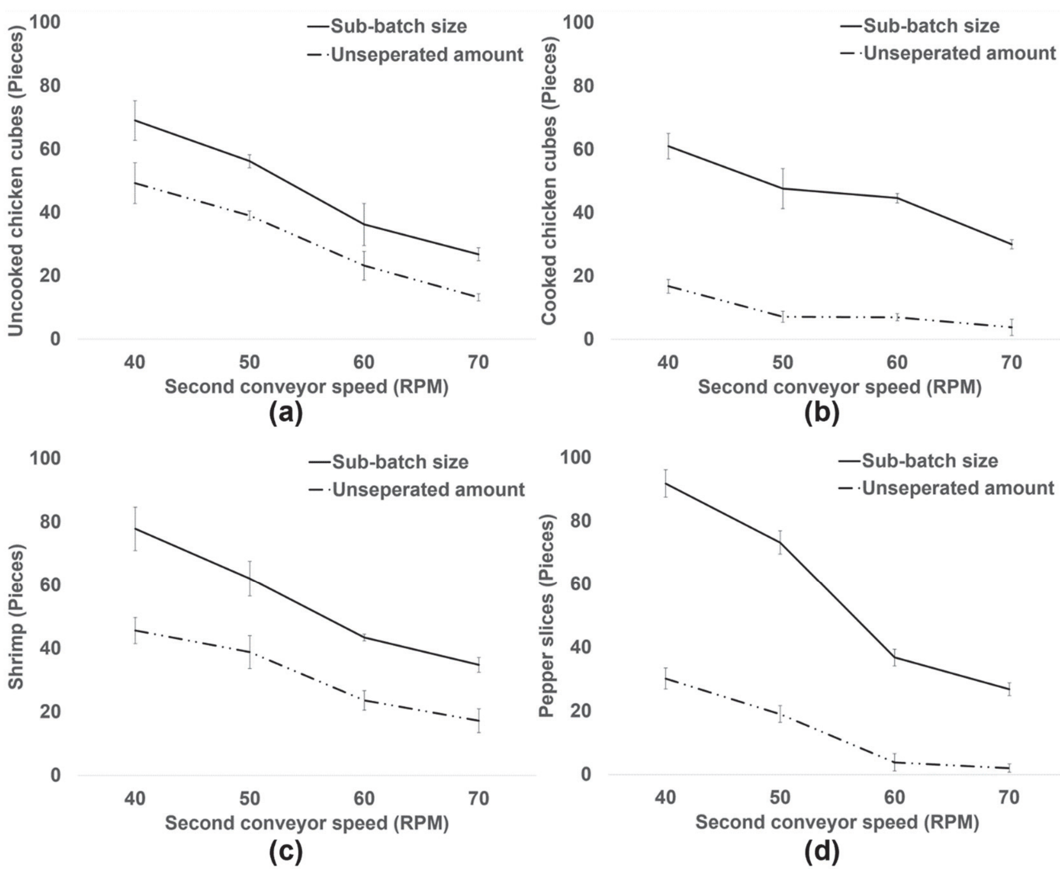

Figure 12. Singulation performances (a) uncooked chicken cubes; (b) cooked chicken cubes; (c) shrimps; (d) pepper slices.

slices. So, shrimps are easier restacked than chicken cubes. Then dropping to the second conveyor together creates the higher amount in the same time period (higher sub-batch size). With 119.3–208.8 mm/s (40–70 RPM) speed settings, the second conveyor led to 34.8–77.8 pieces sub-batch sizes for shrimp, but 30–61 pieces sub-batch sizes for cooked chicken cubes, and 26.8–69 pieces sub-batch sizes for uncooked chicken cubes. However, compared with pepper slices, higher friction makes stacked shrimps more difficult to be separated in the second conveyor, resulting in a higher unseparated amount. Especially with 208.8 mm/s (70 RPM) speed, the second conveyor led to only 2 pieces of unseparated pepper slices, but 17.2 pieces of unseparated shrimps. Due to the conveyors' limited speed range (30–70 RPM) and high-friction conveyor belts, we cannot further improve the singulation performance of uncooked chicken cubes and shrimps in this study. We will try other food-grade conveyors with a wider speed range and different conveyor belts (like plastic chains) in future work.

With the same batch size, a higher sub-batch size can reduce the number of singulation operations to help improve the production efficiency. Additionally, a lower unseparated amount is preferred because unseparated items need to be sent back to the first conveyor for restarting the process as a new batch (fig. 7a). In figure 12b, although 119.3 mm/s (40 RPM) produces the biggest sub-batch size in the second conveyor, it also leads to a higher unseparated amount. Due to the low friction with the PVC conveyor belt, the appropriate conveyors' speed difference (leading to a relatively bigger sub-batch size and a lower unseparated amount) for the singulation of cooked chicken cubes and pepper slices is 59.7 mm/s (20 RPM) (89.5 mm/s (30 RPM) on the first conveyor and 149.2 mm/s (50 RPM) on the second conveyor) under the current experimental production scale. Thus, in handling and feeding tests, 149.2 mm/s (50 RPM) was applied to the second conveyor for the singulation operation.

Handling and Feeding Performance

Figure 13 shows the operational capacity investigation of the experimental design settings. For batch sizes 21, 63, and 105, more chicken cubes need more direct and indirect operations. However, the number of indirect operations of batch sizes 147 and 189 doesn't increase as the batch size becomes larger. Because after passing through the rotating paddle wheel, a small batch cannot fully cover the width of the conveyor belt (fig. 14a), which means that the most left and right empty spots at the end of the third conveyor always need to be filled by moving items from the middle lanes. All seven lanes can be fully covered until the batch size increases to 105 (fig. 14b). Then higher batch sizes only enlarge the middle rectangle-shaped zone (red bounding boxes in figs. 14b-c) to increase the number of direct operations. Because instead of indirect operations, all seven lanes have more items to be directly moved to feed the corresponding empty spots. However, although the cooked chicken cubes have very low friction, with the limited dimensions of conveyor belts, further increasing the batch size (231 and 273) makes more cubes closer or in contact with each other. Then the first push plate in the third conveyor removes more cubes (fig. 7a) and creates more random indirect operations because the empty spots related to

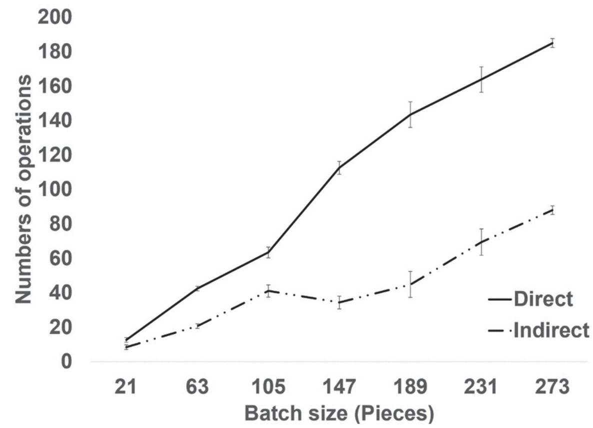

Figure 13. Numbers of operations for handling and feeding cooked chicken cubes (direct operations: feeding only, moving the chicken cubes to feed the corresponding empty spots, like figs. 8b and 8f; indirect operations: handling and feeding, moving the chicken cubes from other lanes to feed the empty spots, like the 2nd, 3rd, and 4th cubes in fig. 8h).

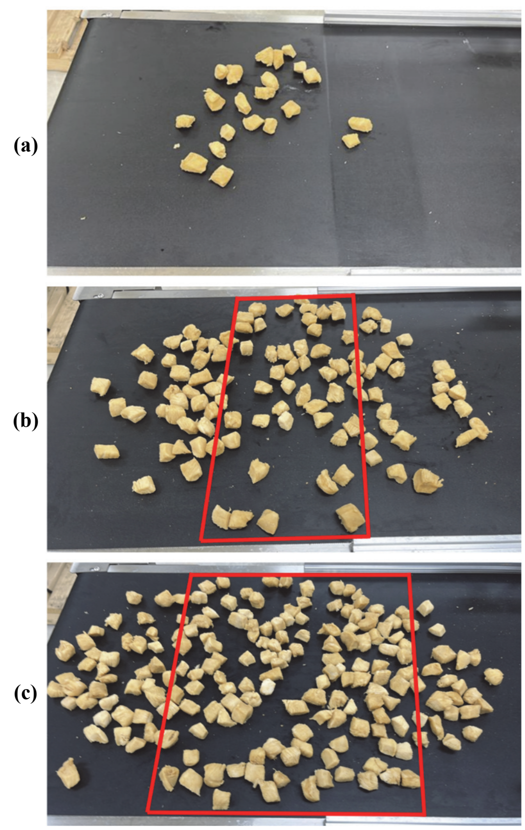

Figure 14. Distribution of cooked chicken cubes after passing through the rotating paddle wheel (before further singulation (fig. 4)) (a) 21 pieces; (b) 105 pieces; (c) 189 pieces.

those removed cubes have to be filled by moving other cubes from other lanes. Therefore, the batch sizes between 105 and 189 fit well with the operational capacity range of the current equipment configurations.

Discussion and Demonstration for Skewering Operations

The results indicate that the proposed machine can handle and feed food items with cube, slice, and C shapes for skewering operations. But in the current design methodology,

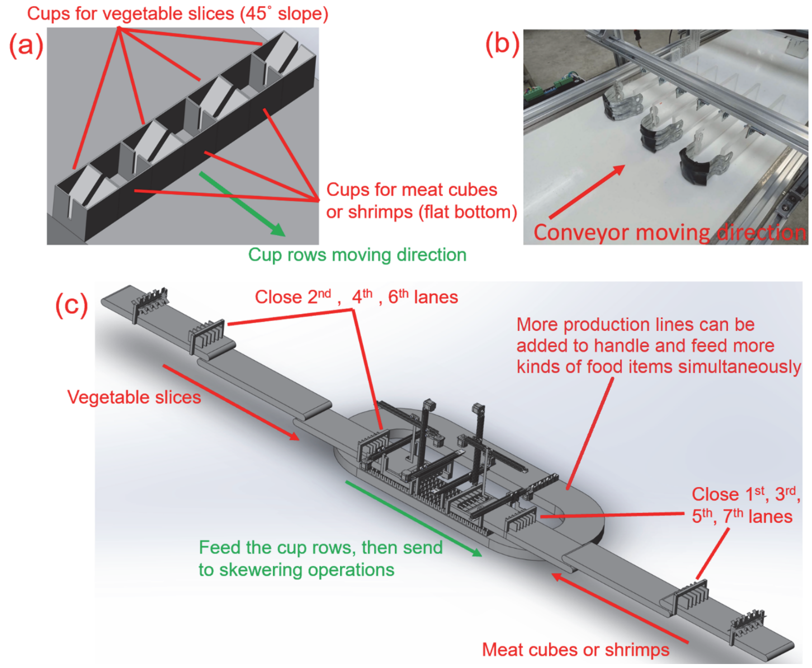

Figure 15. Multi handling and feeding production mode, including (a) cup rows for skewering slices, cubes, and C-shapes; (b) caps to close specified lanes; and (c) two production lines for handling and feeding different food items simultaneously.

one machine can only handle one food option at a time, which means that meat and vegetables cannot be dropped into one machine system simultaneously. To further demonstrate the commercial potential and improve the kebab production flexibility, a multi handling and feeding production mode is to be developed as shown in figure 15. A regular cup with a flat bottom for meat cubes or shrimp, and a novel cup with a 45˚ slope inside for vegetable slices can be designed and assembled as cup rows for horizontal skewering operations (fig. 15a). Thus, two production lines with the same handling and feeding operations can be combined to produce meat and vegetable kebabs or shrimp and vegetable kebabs (fig. 15b). The two production lines close the 1st, 3rd, 5th, 7th, and 2nd, 4th, and 6th lanes, respectively, to feed meat cubes, shrimp, and vegetable slices into specified cups (fig. 15c). Furthermore, more production lines for handling and feeding other food items can be freely added to produce advanced kebabs, which means that more than two kinds of food items can be handled and fed into different cups in the same row simultaneously, then sent to skewering operations. A horizontal skewering operation example with four 3D printed cup prototypes is presented in figure 16. Cup rows are first passed through the first machine for feeding vegetable slices, then moved forward to the second machine for feeding shrimps (fig. 16b). Thus, a seven-lane track on conveyors and seven cups for each line can produce kabob products, including three pieces of meat cubes/shrimps and four pieces of vegetable slices for each kabob skewer. Then, during the skewering operations, vegetable slices are pushed against the cup side wall and punctured by the skewer stick. After being

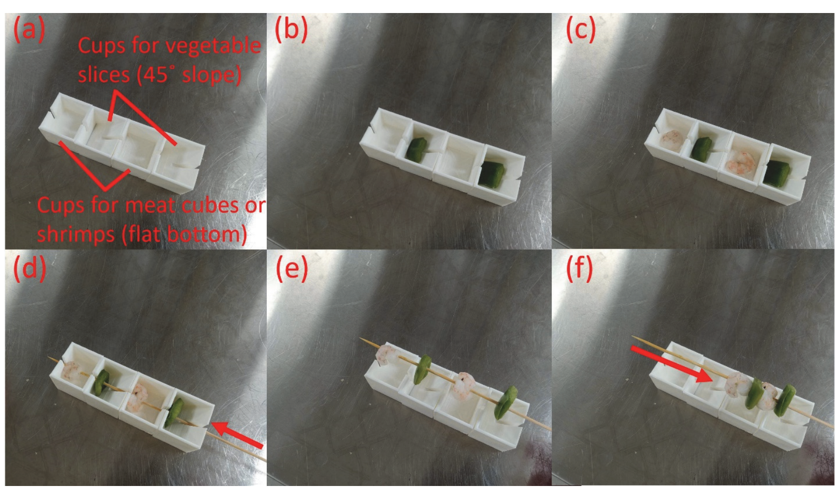

Figure 16. Horizontal skewering operation example for producing shrimp and vegetable kebabs (a) 3D printed cup prototypes for skewering slices, cubes, and C-shapes; (b) vegetable slices are fed into the cups with 45˚ slope; (c) shrimp are fed into the cups with flat bottom; (d) horizontal skewering operation (vegetable slices are pushed against the cup side wall and punctured by the skewer stick); (e-f) take out and press-tight the kebab for packing or other further processing operations.

taken out of the cups, shrimp and vegetable slices are press-tightened by a horizontal pressing motion.

Conclusion

In conclusion, a novel proof-of-concept machine system was developed to separate, handle, and feed meat cubes, shrimps, and vegetable slices for skewering operations. The working concept and the typical handling and feeding process are described and evaluated with real experiments for unattended continuous production. Experimental results provide design guidelines for future scale-up production (batch size, conveyor speed difference, food options, etc.). A multi-machine production mode shows the applicability of producing meat and vegetable kebabs and shrimp and vegetable kebabs. However, the present system faces some challenges. The current machine prototype was developed with consideration of engineering design, and some of the parts like conveyors, paddle wheel, and push plates, are not food-grade. Additionally, this study focuses on investigating the engineering feasibility without further improving the production speed and throughput. Future work will increase the handling and feeding speed by adapting other detection methods (like lidar sensing and thin film pressure sensing) and improving the operation process (like adding more push plates to feed several food items into empty spots simultaneously) with the consideration of food safety. Other parameters, like number of lanes, rotation speed, and shape geometry of the paddle wheel, will be analyzed to develop detailed design criteria. Besides, compared with suction cups (one-by-one pick-and-place), vacuum suction hoses will be applied to take out the oversized cubes more precisely (without affecting other normal separated meat cubes), and the oversized cubes will be sucked and sent back through the hoses as part of the recollection process. Moreover, advanced automated kebab production will be realized through integrating this handling and feeding process with other upstream and downstream processing steps, such as meat dicing and packaging processes.

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