

Automated Handling, Assembly and Packaging of Highly Variable Compliant Food Products - Making a Sandwich

S. Davis, M.G. King, J.W. Casson, J.O.Gray and Darwin G Caldwell
Centre for Robotics and Automation, University of Salford
Manchester M5 4WT, UK

Abstract— This paper describes the design, construction and testing of an automated system for the assembly and packaging of triangular sandwiches. This process is currently highly labour intensive with little automated machinery available.

This paper analyses the current manual production techniques and develops a number of modular workstations which can be incorporated into an existing line in place of human operators. The machine developed completes the final assembly of the sandwich and then cuts and packages it into a plastic skillet (container) for dispatch. To test the overall performance of the system real plant trials were conducted with the machine in a sandwich production factory and the results of these trials are reported here.

I. INTRODUCTION

The food industry is the largest manufacturing sector in the EU, with an annual turnover in excess of €600 billion [1]. More than 2.5 million Europeans are employed in the food manufacturing industry and it also sustains further employment through farm production and distribution to the customer [1]. Consequently the industry has been identified as a major growth area for the application of automation systems with the aims of [1]:

- improving production efficiency
- enhancing hygiene standards
- improving working conditions
- increasing margins and profitability
- sustaining local employment in the face of global competition

Unfortunately from an engineering perspective and unlike more traditional manufacturing environments food products are natural, seasonal and regional and this places demands on automation unlike those in any other sector.

Currently automation and engineering practice in the food sector is highly variable ranging from completely manual operations to the most advanced automation technology. Although the range of automation styles is, in part, a reflection on investment policy in a low margin industry, in many instances the use of manual techniques is a deliberate policy. This is due to the flexibility provided by the human worker and the perceived in-abilities of current automation systems. This tendency to manual operation is particularly

acute when considering tasks involving the actual handling and manipulation of food products.

The majority of food products are non rigid. There is also significant variation in texture, colour, shape and sizes between product types as well as between examples of the same product. For this reason the handling characteristics of many foods cannot be reliably described by geometry based information (as in conventional engineering). In addition, the product geometry is often a function of time and the forces applied to it and this leads to unpredictable deformations during handling. Humans manage this variability with ease by combining dextrous handling capabilities (human hands) and behavioural models of the product accumulated with experience. The ingredients used in the production of triangular sandwiches are a good example of this.

A sandwich consists of two or more slices of bread enclosing one or more layers of meat or other fillings. The UK sandwich market, which is the largest in Europe, has been estimated to be currently worth €6bn a year with an annual growth rate of 7-8% [2].

This paper initially considers the current state of automated systems for sandwich production and their short comings. The current manual sandwich production processes are then analysed in section 3 to provide an initial starting point for the design of an automated system. Section 4 describes the design methodology used and Section 5 gives a detailed description of the design and function of the machine. Section 6 reports the results of operational trials before conclusions are presented.

II. BACKGROUND

While there are many variants on the layout of a sandwich there are certain common features that form a sound basis for the development of automation. Within the UK which has the largest factory produced sandwich industry in the EU, the vast majority of pre-packed sandwiches are formed from two slices of bread cut from a rectangular loaf. These are placed one on top of the other with some form of filling in between. The rectangular sandwich is then cut along one diagonal to form two triangular sandwiches which are then placed in a plastic or cardboard package called a skillet. There are a wide range of possible fillings, however, it is generally considered that the discrete component (i.e. no paste) sandwiches are the hardest to produce since there is nothing to bind the contents. Historically, the production of sandwiches has been exclusively manual with production

lines employing up to 40 people. With such a high labour content there have been various drives to automate, however, the only successful example has been developed for Uniq plc by Lieder [3]. This is an industrial robot based indexing system that covers the whole process from buttering through to packing using a jiggging system and is capable of handling paste fillings only.

In the system the individual ingredients which together form the finished sandwich, are indexed between workstations where different operations are carried out. This indexing increases cycle time, can cause spillage and requires a high cost drive system. The increased complexity also leads to higher maintenance and cleaning costs. The apparatus has limited flexibility and its ability to accommodate bread size variation is limited. In general the increased mechanical complexity requires higher safety guarding which in turn leads to higher space requirements.

The complexity of a sandwich can vary enormously and this has a significant effect on the intricacy of the assembly task. Observation showed that fillings consisting of many individual pieces of dry ingredient were the most difficult to handle without the filling falling out. As a result the filling chosen to be used in this project was chicken salad. This contains many individual chicken pieces and discrete components such as sliced tomatoes and cucumbers and lettuce leaf making it particularly difficult to handle. An automated system capable of processing this sandwich is likely to be able to handle simpler fillings with ease.

III. MANUAL SANDWICH ASSEMBLY

When designing automation for food assembly tasks it is often useful to study how the production is accomplished manually, although direct duplication of human operations is unlikely to lead to the ultimate automated solution. For this reason operation of a “Chicken Salad” sandwich production line was analysed using photographic and video techniques and ergonomic data.

Figure 1 shows diagrammatically a sequence of individual operations in the formation and packaging of the sandwich. This process consists of five individual operations:

- i). **Ingredient Placement** – Individual ingredients including butter, chicken pieces, a whole lettuce leaf, sliced cucumber and sliced tomato are placed onto a single square slice of bread.
- ii). **Topping** – A second buttered slice of bread is placed on the top of the first slice and compacted, completing the sandwich. The pressure applied during the topping is the only mechanism that serves to retain the integrity of the sandwich when handled.
- iii). **Cutting** – The sandwich is positioned and cut once diagonally to form two triangular sandwiches. This cutting is fully automated. During the cutting it is specified (by the retailer) that the diagonal cut must present the two halves with less than 3mm variation in size. It should be noted that daily variation in the size of slices of bread arriving from the bakery may be up to 15mm in height.

- iv). **Clapping** – For packing, one of the triangular sandwich sections emerging from the cutter is lifted and placed on the top of the second triangle. In this process the sandwich is rolled from its horizontal position through the vertical and then placed horizontally on the first slice. At this point only careful use of the operator’s fingers prevents the contents from falling out.

- v). **Packing** – The two stacked triangular sandwiches are placed into a plastic container (skillet).

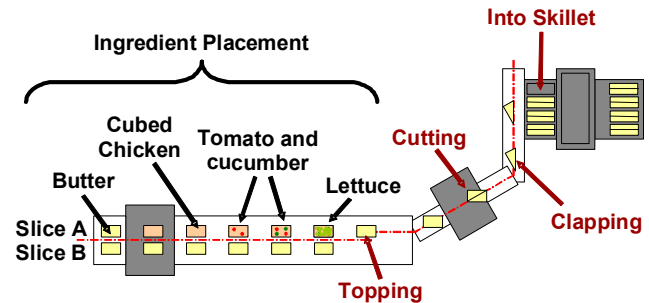


Figure 1 – Chicken Salad Sandwich Production

IV. DESIGN METHODOLOGY

This project used a robot based approach during the design phase which allowed processes to be extensively tested before construction of a dedicated automation prototype.

This robotic prototyping allowed complex kinematic and dynamic (motion, velocity and acceleration) profiles to be verified rapidly, at minimal cost and with actual food products [6-7]. As a result, alternative handling mechanisms could be assessed by developing robot end effectors rather than having to completely redesign prototype machines. Ultimately this approach leads to superior final designs since there is less financial drive to accept the first, but possibly not the best successful design. Having tested and proved the kinematic, dynamic and handling operations there is subsequently much more likelihood of success first time and a resultant reduction in cost and time to implementation.

This approach also allowed mechanisms much less complex than a robot to be identified in a similar manner to the work of Akella et al [8].

V. AUTOMATED SYSTEM

The machine developed aimed to automate the final four operations in the production process outlined in the previous section. Automatic placement of many ingredients can be achieved with commercial depositors and where such systems do not exist (as is the case for tomato and cucumber slices) separate projects have addressed these issues [6]-[7].

The automated system developed in this project consists of a continuously running corded conveyor which transports the bread slices and sandwich assemblies between workstations. This conveyor is separated into two lanes with each lane handling half of the sandwich assembly. Each of the workstations is modular and stand-alone (PLC, electrical

control cabinet and pneumatic service unit). During machine operation pairs of bread slices are input to the machine with one slice being placed in each lane. Retailer demand requires that successive slices from the same loaf must be mated to produce an aesthetically pleasing final sandwich.

A. Topping Station

The mechanism developed to perform the topping task is shown in Figure 2. A slice of bread, with the buttered side facing up, travels along the upper conveyor. This slice must be inverted and placed buttered side downwards on the top of the filling contained on a second slice located on the lower conveyor.

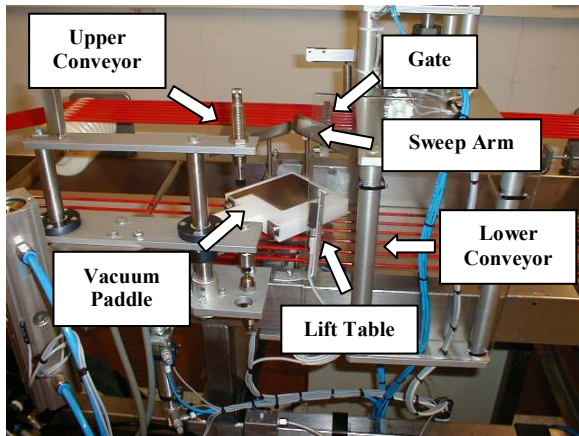


Figure 2 - Topping Workstation

There are particular handling concerns that relate to the lifting of the porous bread slice and the possibility of damage to the bread (marking of the surface due to dragging across the belts and drying due to the air flow). The mechanism developed consisted of a flat vacuum paddle with a shallow slotted channel in its surface. The channel was positioned so that when a slice of bread was placed on the paddle its edges covered this channel. When a vacuum is generated in the channel the paddle grasps the slice of bread securely by its outer edges in spite of the porous nature of the bread.

The topping process begins with the vacuum paddle in its raised position so that its upper surface is at the same height as the upper conveyor. A buttered slice of bread on the upper conveyor travels “square on” to the conveyor until it makes contact with the gate. At this point the gate prevents any further motion. A photoelectric sensor detects the presence of the slice and triggers the motion of the sweep arm which transfers the top laterally placing it on the upper surface of the vacuum paddle.

At the same time the bottom slice of bread containing the filling travels along the lower conveyor until it makes contact with a “V” shaped locating and centring gate protruding between the conveyor cords. A second photoelectric sensor detects this slice of bread and activates the lift table. This rises from below the conveyor lifting the bread clear and thus preventing further motion.

The vacuum paddle is then activated and applies a vacuum to hold the upper slice of bread to it. The gripper rotates through 180° and lowers the now inverted top slice into place on the filling on the lower slice. The paddle applies a small evenly distributed vertical force to the sandwich to compress it before releasing the slice and returning to its raised position. The lift table and lower gate are then retracted allowing the topped sandwich to continue along the conveyor to the next workstation.

In order to minimise the cycle time and therefore maximise system throughput the vacuum paddle has ports on both faces to eliminate the need to reset the paddle (by reversing it 180°) before topping the next sandwich. With this operation a cycle time of under 1 sec is achieved, permitting operation substantially faster than the 45 sandwiches per minute achieved by manual operation.

B. Optimum Cut Station

When the two triangular sandwiches are placed into a plastic skillet (a thermoformed triangular container) if they have not been cut accurately from corner to corner the resultant sandwich can appear untidy. Whilst this in no way affects the taste or structure of the sandwich it can potentially reduce customer appeal and may lead to rejection by the retailer. Retailers retain the right to reject a whole day’s production for inaccurate diagonal cuts. It is therefore critical that the cut be performed diagonally from corner to corner with a very high degree of accuracy. Achieving this given the substantial variations in bread slice size that can occur daily is not a trivial task.

To achieve this accurate diagonal cut, the full sandwich, comprising top and bottom slices and filling is aligned so that a true diagonal cut can be achieved. The sandwich is transported along the lower conveyor and passes beneath a vision recognition system that registers the profile and size of the sandwich. From this profile the true diagonal cut line is calculated and transferred to a downstream aligning mechanism.

The vision system is used to analyse the uncut assembled sandwich prior to entering the optimum cut station. The system uses software sensors to calculate the optimum diagonal between the leading and trailing corners of the sandwich.

Information from the vision system is processed and used to control a stepper drive at the optimum cut station to rotate the sandwich (about a defined leading corner) by the required amount to align the sandwich accurately.

The vision system also identifies a badly assembled or an over/under sized sandwich. This information can be used to operate a reject station to allow the sandwich to be manually reworked.

At this alignment station the point of the leading corner of

the sandwich is once again located in a “V” shaped gate that raises and lowers through the strands of the conveyor cords, as shown in Figure 3. When located in the “V” gate an IR sensor detects the presence of the sandwich and signals the alignment lift table to rise between the conveyor, below the slice, and lift it clear of the conveyor. The “V” gate is then lowered and using the profile data from the vision system the alignment lift table is rotated to align the true diagonal of the sandwich with the axis of travel of the conveyor. The table then lowers the sandwich back onto the conveyor allowing it to progress to the cutting machine. Diagonal cut alignment though this workstation is better than 0.1° giving a cut quality well in excess of the retailer demands.

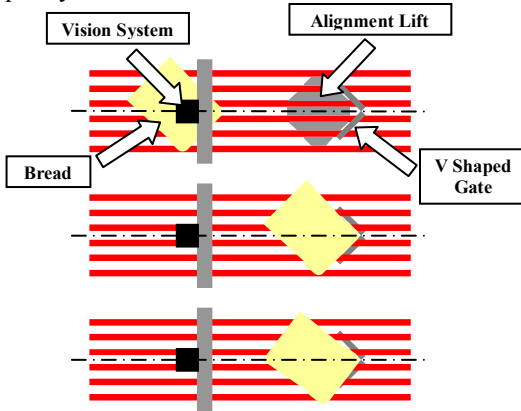


Figure 3 - Aligning Mechanism

Sandwich cutting can be carried out using any of the existing established mechanised methods such as water jet cutting band saws or an ultrasonic knife.

C. Sandwich Clapping

After cutting, the two triangular sandwiches must be placed one on top of the other. This process is known as clapping. Observation of human operators performing clapping reveals that the most common method is to invert one of the triangular sandwiches and then place it on the top of the second sandwich. During this process the operator firmly clamps the sandwich to prevent filling from falling out. Although the risk of losing the filling is increased during this process it forms the standard mechanism as the operators finger dexterity can retain the filling and it places a low stress on the limbs. However, this process is a good example of an instance where replicating human actions does not lead to the optimal automated solution.

To achieve clapping human operators first clamp the sandwich to hold the contents in place and then invert it. The automated solution developed does away with the need to clamp and invert the sandwich thus simplifying the operation.

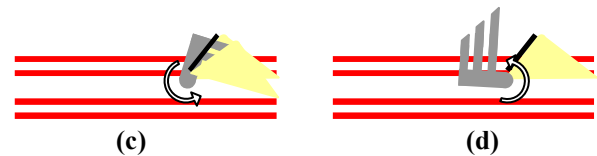
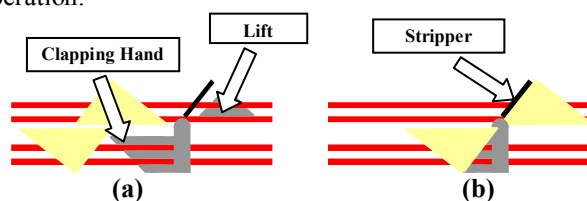


Figure 4 – Clapping Station

In automated clapping, the two triangular sandwiches are transported from the cutter to the clapping station on two conveyors with the diagonal cut face travelling along the axis of transfer, Figure 4. These conveyors are a slightly different heights.

One sandwich half travels along the lower conveyor whilst the second is elevated by the upper conveyor to a height slightly above the upper surface of the first sandwich. As the first sandwich travels along the conveyor it triggers a photoelectric sensor which actuates a lift table to accurately locate the first half sandwich.

A second photoelectric sensor detects the presence of the 2nd half sandwich on the upper conveyor and activates the clapping hand. This hand is supported from above but is specially shaped to allow it to pass between the conveyor cords and locate below them. On detecting the sandwich the hand rises, lifting the sandwich from the conveyor before rotating through 180° to locate it above the lower conveyor. As the hand rotates a stationary stripper plate comes into contact with the leading edge of the rotating sandwich half when it is correctly located over the lower slice. This causes the hand to slide beneath the sandwich, allowing the upper sandwich half to be placed accurately on the lower slice. The lift table on the lower belt is then lowered allowing the clapped sandwich to move to the final packing station. To minimise cycle time two independently controlled rotary hands were used as this allows the second hand to clap a sandwich whilst the first is returning to its initial position. Clapping speeds of over 60 sandwiches per minute are possible with the upper limit set by the rotational speed at which the filling contents starts to disintegrate.

D. Skillet Packing

Skillet packing is the operation of placing the two-stacked sandwich halves into a thermoformed triangular skillet. The mechanism developed to achieve this can be seen in Figure 5.

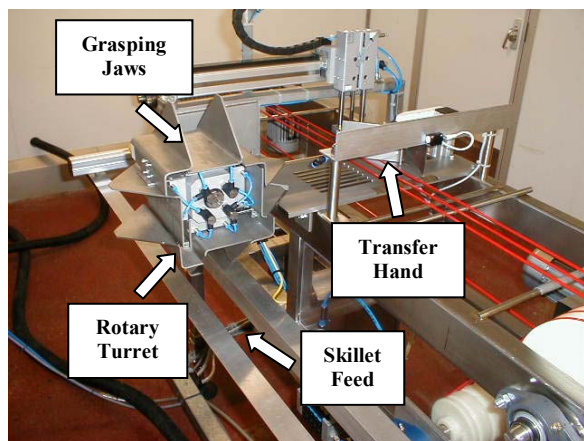


Figure 5 - Skillet Packing Station

The conveyor belting transfers the stacked halves of the sandwich with the diagonal cut face travelling along the axis of transfer. A sensor identifies the arrival of the sandwich stack and activates a "V" shaped transfer hand. The hand pushes the stack laterally off the conveyor and into the four station rotary turret. Each of the turrets stations contain two jaws. The transfer hand positions the stack on the lower jaw and then the jaws are actuated and grasp the sandwich stack. The transfer mechanism is reset and the turret rotated 90° above a waiting skillet. The sandwich stack is then released and drops into place in the open-ended skillet below.

E. Machine Operation

The complete sandwich machine can be seen in Figure 6. An industry standard programmable logic controller (PLC) is used to control the basic functions of the process. All sensors, variable speed drives, stepper drives, vision system and pneumatic control valves are connected to and controlled by this PLC.



Figure 6 - Complete Machine

A touchscreen Human Machine Interface (HMI) is used to operate the machine and to give the operator feedback about the operating state of the machine i.e. running/stopped alarms etc. The HMI also has an engineer mode that allows qualified personnel to change conveyor speeds and also to

perform basic sequencing checks. The HMI is connected to the PLC via a serial link.

The conveyors are driven by four conveyor motors. Variable speed drives (VSD) are used to control the speed of the four conveyor motors. The VSD's are controlled by the PLC via the HMI.

Stepper drives are used where controlled movement of the sandwiches is required. A stepper drive is used at the optimum cut station to precisely align the sandwich before the sandwich is cut. The clapping station uses three stepper drives to place the two halves of the cut sandwich precisely on top of each other prior to being packed. The packing station uses a stepper drive to rotate the assembled sandwich through precisely 90° before being dropped into the awaiting skillet. All the stepper drives are controlled by the PLC. All the sensors are connected to the PLC.

VI. PRODUCTION TRIALS

To establish the validity of each principle a series of trials were conducted within a sandwich production factory. The aim of the trials was to critically analyse each process and establish whether these principles worked with real products and in a true factory environment. The trials lasted 10 weeks and involved tests on over 250,000 sandwiches. All trial information was logged on a daily basis, and the main results are summarised in the next section. The tests were conducted by suitably trained line staff.

A. Topping

The main problem experienced during the trials of the topping mechanism was a reduction in the grasping force generated by the vacuum paddle. This was caused by debris being sucked into the paddle and air lines and reducing the flow of air.

A pneumatic cylinder was used to raise the vacuum paddle however, lowering was achieved using the force of gravity. It was found that unless the mechanism was lubricated regularly the paddle could remain jammed in the raised position. This problem could easily be rectified by actively lowering the paddle using a double acting cylinder.

The specified machine throughput could not initially be achieved due to the time delay used to ensure the lower slice of bread was in place before topping. Reprogramming of the PLC resolved this problem allowing the intended throughput of 45 sandwiches per minute to be achieved.

B. Alignment

The only significant issue identified with the alignment station was occasional snagging of products on the vision system. This was caused by the variation in sandwich thickness caused by the distribution of the filling within it. This problem was overcome simply by raising the height of the camera and shielding above the conveyor.

C. Clapping

The design of the clapping mechanism was only suitable for handling sandwiches of a particular thickness. The range of sandwiches that could be processed could be greatly increased if this station was made adjustable. This could be achieved with relative ease and would involve the addition of adjusters on the clapping hand and stripper plate.

D. Packing

Whilst the packing station successfully loaded the clapped sandwiches into the plastic skillet the visual appearance of the resultant packaged sandwich was not consistently acceptable. This was caused by the sandwiches being dropped into the skillet. Whilst this is unlikely to cause problems for sandwiches with a paste like filling, the loose nature of the chicken salad filling means it moves during the release phase.

The reason that the mechanism produced loaded the sandwiches vertically was to be compatible with the sandwich manufacturers existing thermoformers. A much simpler way to fill the skillets would be to load the sandwich horizontally into skillets placed on their side. As a result of these trials there has been a reassessment of the thermoformer choice and this station will be redesigned in future work.

E. General

A number of other issues were raised during the trials which would increase reliability and aid cleaning and maintenance.

It was found that on occasion the sandwich moved relative to the conveyor instead of staying static on it. This was caused by the relatively small contact area between the corded belt and the sandwich. Unsupported sections of the product were able to sag between cords and the resultant force could cause motion of the entire sandwich. In extreme cases this could lead to the product falling from the conveyor completely. This problem could be minimised by the addition of more parallel cords, this would require the redesign of the lifting tables and clapping hands to accommodate the new cords, but would not fundamentally effect operation.

Water ingress into sensors and motors presented a number of problems which on occasion lead to failure. The operational environment of the machine contains high levels of moisture, from both cleaning and general operation. Despite consideration of this during the design phases of the project problems still occurred and the sensors and motor will need substituting with those of a higher IP rating in the future.

One final issue identified which would greatly increase the ease of component removal and reduce the time required for cleaning would be the inclusion of "quick release" mountings. Currently to clean the machine's components individual parts must be removed using screwdrivers and spanners. This obviously requires significant time and "quick-release" connections would reduce this. An

appropriately designed release mechanism could also remove the danger of fasteners being misplaced during cleaning.

VII. CONCLUSIONS

The objective of this research was to define and develop methods of automation for use in the sandwich assembly process. The specific functions involved, were; topping, optimum cutting alignment, clapping and packing of the sandwiches in skillets. The project defined these functions and designed and developed a proof of concept rig to demonstrate each of the functions. Whilst the sandwich considered here had a chicken salad filling the mechanisms can equally be used for most other common fillings.

Before the prototype machine was constructed each of the individual processes were tested using a robot. This allowed assessment of each task without the expense of building the full prototype. Also it allowed many solutions to be tested rapidly, often within days, enabling the optimal solution to be identified.

After testing using the robots a prototype was produced, this underwent significant industrial trials in a sandwich manufacturing factory. The results of these trials led to minor modifications to the system enabling it to achieve specified task reliably.

The benefits of the system developed to manufacturers are in terms of reduced costs, due to reduced labour requirements, and in improved product quality in the form of enhanced appearance of the sandwiches. The system offers additional benefits in terms of improved hygiene. The biggest source of potential contamination is from human operators and the system reduces the number of these. Benefits should also be observed in terms of lost time through staff turnover which is particularly high in the food sector.

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