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Design of an Automated Handling System for Limp, Flexible Sheet Lasagna Pasta

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Abstract—**The manipulation of flexible and limp sheet materials is a common requirement in many industrial manufacturing processes, however automation of even simple tasks involving these difficult to handle materials tends to be particularly problematic. The industrial manufacture of lasagne ready meals is one example of a process that has been almost completely automated except for the handling of the flexible lasagna pasta, which remains a highly repetitive and labour intensive manual task.**

In this paper a robotic end-effector is developed to enable the automatic handling of lasagna pasta sheets. The design of the end-effector is described and its performance evaluated through testing using a robot arm. The concept was further developed into a low cost fixed automation machine suitable for industrial use. The pneumatic pick and place type machine was able to pick a pasta sheet from a moving conveyor and place it into a plastic tray with a cycle time of less than 4 seconds.

I. INTRODUCTION

THE convenience food market has seen rapid growth in recent years. Current consumer trends reflect the increasing popularity of microwavable ready meals that can be quickly and easily prepared. The industrial manufacture of ready meals is a high volume process, which has relatively low profit margins due to the complexity of the product and high levels of competition between supermarket chains. As the demand for convenience foods continues to rise, manufacturers are looking for ways to increase their production capacity whilst at the same time reducing production costs.

Italian cuisine based ready meals form an important category within the many different types of ready meals available. The lasagne ready meal is particularly popular and made by placing alternating layers of meat sauce and lasagna pasta into a plastic tray. The industrial assembly of lasagna ready meals has been almost completely automated except for the handling of the pre-cooked lasagna pasta, which must be carried out manually by several operators per shift on the production line. Automation of the pasta pick and place operation would be desirable in order to reduce production costs, however the slippery yet adhesive and flexible nature of the lasagna pasta makes it a very difficult material to handle automatically.

The automatic handling of flexible or limp sheet materials has been the focus of numerous research programmes over the past twenty years with the majority of the work concentrating on applications in the textile industry [1]. A number of gripping devices have been developed to address the problem of how to pick up a single piece of fabric from a stack and transfer it to another location. Although the majority of these grippers were designed specifically for the manipulation of textiles, some of the concepts developed for the automated handling of flexible sheet materials may be of use in the design of end-effectors for the food industry. The grippers use various methods for picking up and releasing the fabric, which include the use of pins [2], pinching mechanisms [3]-[6], vacuum [7], Bernoulli effect [8], electrostatics [9], adhesives [2], [10], [11] and freezing [12]. The relative advantages and disadvantages of each gripping method are discussed in detail by Taylor [13], [14]. Their possible applications for the handling of non-rigid food products are evaluated by Chua, Ilschner and Caldwell [15].

This paper presents the development of an automated machine for the handling of flexible sheet lasagna pasta in the industrial manufacture of lasagne ready meals. Hygienic design considerations for grippers to be used in the manipulation of foods are discussed and a concept design for a lasagna pasta gripper is developed into a working prototype. In section III the gripper design is evaluated and optimised through testing using a robotic arm. Section IV details further testing and development of the gripper into a low cost pick and place system suitable for use in industry.

II. DESIGN OF A ROBOTIC LASAGNA PASTA GRIPPER

A. Hygienic Design Considerations

Machinery and equipment to be used for the direct handling and processing of food should be designed following a series of basic principles [16] that will result in good hygienic standards in production. Sanitary design principles are implemented in all aspects of a food manufacturing installation including building and machinery design and layout, equipment installation, maintenance and cleaning procedures. In the design of a piece of equipment which is to be in direct contact with the food being manufactured the sanitary design principles can be very restrictive, significantly limiting the number of possible configurations for a new design. However the result is often

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a very robust, simple design with few moving parts. Sanitary considerations relevant to the design of the gripper include:

Materials - The preferred material for the fabrication of equipment in sanitary applications is stainless steel. For food contact parts either 304 or 316 grade stainless steel is used.

Surface finish - Parts that are to come into contact with food should be polished to a sanitary grade finish of between 0.5 and 0.8 μmRa (average roughness) to ensure a smooth, crevice free surface so that small particles of food and bacteria do not become lodged in surface irregularities and become a potential source of microbial contamination.

Visibility for inspection and accessibility for cleaning - All food contact surfaces and immediately adjacent structures should be readily visible for inspection and accessible for manual cleaning. Designs should allow for easy dismantling of components to enable routine cleaning to be carried out as quickly and effectively as possible.

B. Mechanism Design Considerations

As a first step in the design process, sheets of cooked wet lasagna pasta measuring 125 mm x 100 mm and similar to those used in ready meals were studied in order to determine their physical (handling) characteristics and how they would behave when being manipulated [17]. During these trials it was noted that the cooked wet pasta tended to adhere readily to a smooth surface. It was also noted that it was very easy to slide the pasta horizontally over the surface. Following these observations, a number of possible mechanisms were evaluated for the handling of the pasta sheets [17]. During the trials it became apparent that although pick up was indeed problematic the greater issue tended to form around consistent, repeatable and reliable release of the sheets. It was found that the easiest and most robust and reliable way to pick up the lasagna sheet was to lift one end and peel it off the surface. A concept mechanism was therefore developed which would produce the same peeling action. The sequence of motions required to pick up the pasta from a moving conveyor are illustrated in Fig. 1.

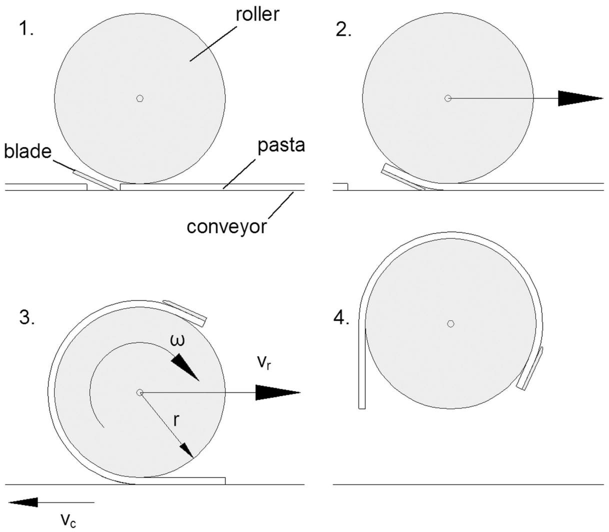


Fig. 1. Sequence of motions required to pick up a lasagna pasta sheet using the roller and blade gripper.

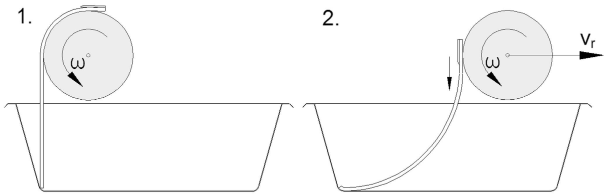


Fig. 2. Release of the lasagna pasta sheet from the gripper into the tray.

The pasta sheet is picked up by first lifting one edge of the pasta using a thin blade and then rolling the remainder of the pasta around a cylindrical roller. The blade (spatula) is first positioned in front of the pasta edge on the conveyor. The gripper then moves forwards so that the pasta slides onto the blade and due to the water present on the surface of the pasta, adheres to it. The roller now turns at angular velocity ω. Simultaneously the gripper moves forward at velocity $v_r = v_c - \omega r$ where v_c is the velocity of the conveyor and r the radius of the roller. The gripper lifts vertically away from the conveyor towards the end of the roll sequence, leaving a section of the pasta sheet hanging free. The pasta remains securely attached to the large surface area of the roller. To release the pasta, the pasta sheet is unrolled into the tray as shown in Fig. 2. The tray makes the release more difficult as the pasta must be released from a height. As the pasta is unrolled it now peels away from the roller. The pasta end is lowered to the bottom of the tray with the gripper stationary relative to the tray, which is on a moving conveyor. The gripper then continues to unroll as it moves forward at velocity v_r. Towards the end of the roll, the pasta drops away from the gripper due to its own weight. Although this is a free fall condition the process is highly repeatable and reliable.

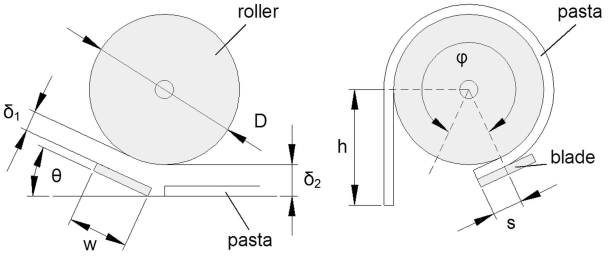


Fig. 3. Basic parameters for a roller and blade type gripper.

The dimensions of the gripper are largely defined by the size of the pasta sheet being handled. The basic parameters for a roller and blade type gripper are shown in Fig. 3, where D is the roller diameter, φ the roll angle, w the blade width, s is the blade width outside the roll angle, θ is the blade angle, δ_1 is the gap between the roller and the blade, δ_2 the gap between the roller and the conveyor and h is the length of pasta left hanging from the roller. The diameter of the gripper roller is directly related to the length of the pasta sheet L to be handled and is given by (1) where φ and θ are specified in degrees.

$$D = \frac{360(L - s - h)}{\pi(\varphi + \theta - 90)} \tag{1}$$

The gap between the roller and the blade δ_1, the gap between the roller and the conveyor δ_2 and the blade angle θ are directly related to one another. The relationship between these three variables is given by (2) where t is the blade thickness.

$$\left(\frac{D}{2} + \delta_1 + \frac{t}{2}\right)\cos\theta + \left(w - s - \frac{t}{2}\right)\sin\theta + \frac{t}{2} = \frac{D}{2} + \delta_2 \tag{2}$$

This relationship is important because the gripper must make physical contact with the conveyor surface in order to be able to pick up the pasta sheet. The values of δ_1 and δ_2 will be dictated by the thickness of the pasta being handled and any clearances that may be required between the gripper and the pasta. Once δ_1 and δ_2 are known, the value of θ required to make contact with the conveyor can be calculated from (2). The coordinates of the theoretical point of contact can now also be determined in relation to a robot tool centre point.

The roll angle φ is determined by the actuator used to rotate the roller. In the food industry pneumatic actuators are generally preferred as they are relatively cheap, but particularly because they are able to cope with the frequent wash downs required during cleaning. Small rotary vane actuators are available with roll angles up to 270°. The blade width w should be large enough to lift and support the pasta edge during rolling. Significant adhesion occurs between the pasta and the surface of the blade due to the water film present on the surface of the pasta. For the 125 mm x 100 mm lasagna sheet it was found that the adhesion forces generated are sufficiently strong as to allow useful lifting of the pasta edge using a 14 mm wide blade without the need for any additional gripping forces to be applied [17]. Adjustment of the value of s allows some variation of the blade angle θ for a given combination of δ_1 and δ_2. A value of s = 9 mm was used. The length of pasta left hanging from the roller h is required in order to be able to unroll the pasta successfully. When unrolling the pasta tends to peel away from the roller easily, however it is the weight of this length of pasta that initiates the peeling action. A value of $h = D/2$ was used. The length of the roller was made equal to the width of the pasta sheet.

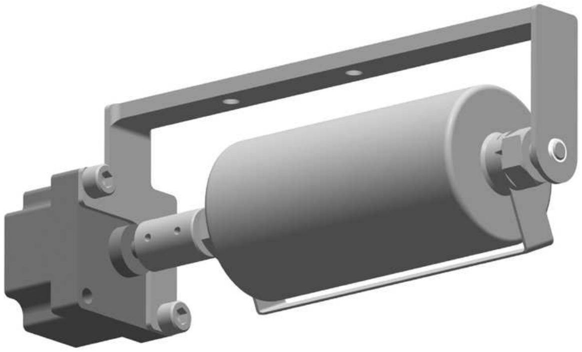


Fig. 4. 3D CAD model of the lasagna pasta gripper.

The roller and blade concept design was further developed into a proposed mechanical configuration for the gripper as illustrated in Fig. 4. The gripper is designed to be easy to clean and meet sanitary requirements for use in an industrial food manufacturing environment. The roller, blade and supporting bracket are constructed from stainless steel and polished to a sanitary grade finish. The total number of parts for the gripper is kept to a minimum. All parts are visible for inspection and the open design makes most parts accessible for manual cleaning without disassembly. The blade can be removed for cleaning by loosening two nuts that hold it in place and can be quickly reassembled without the need for readjustment. A plain polyacetal bushing supports one end of the roller. The roller is directly driven using a Bosch Rexroth RAN8 rotary vane pneumatic actuator. All parts are designed so that they can be manufactured using conventional machining techniques and standard material sizes are used where possible to reduce cost.

III. ROBOTIC HANDLING OF LASAGNA PASTA

In order to quickly assess the handling performance of the lasagna gripper design, a robotic arm was used to test a prototype gripper using real pasta sheets. This allowed the design to be evaluated and the gripper parameters to be experimentally optimised prior to investing in the manufacture of a full sanitary specification gripper. A CRS Plus A460 robot was equipped with a simplified version of the lasagna pasta gripper, which consisted of a length of tube with an attached blade as shown in Fig. 5.

The sequence of linear motions and rotations of the roller required to pick up the pasta sheet and place it correctly into a tray was established and the robot programmed to carry out these motions. It was found that picking up the pasta using the gripper was relatively straightforward and very high success rates were achieved. Releasing the pasta correctly into the tray proved to be a little more difficult, however by modifying the programmed motions of the gripper and adjusting specific gripper parameters it was possible to position the pasta consistently in the bottom of the tray. Part of the sequence used to handle the pasta sheets is illustrated in Fig. 6. It was observed that the parameters δ_1, δ_2 and the amount of pasta that slides onto the blade before rolling begins affect the amount of adhesive grip on the pasta sheet during the initial stages of pick up and the final stages of release. These three factors in particular were found to have the greatest influence on gripper performance.

The pasta tends to adhere to the blade due to the water present on its surface and the adhesive force is proportional to the surface area of pasta in contact with the blade. The motion of the gripper was adjusted to vary the amount of pasta allowed to slide onto the blade before the start of the roll so as to increase or decrease the amount of grip on the pasta sheet. Good results for both pick up and release were achieved when the pasta was in contact with the full width of the blade. The effect of increasing δ_1 was to reduce grip during pasta release so that the pasta tended to fall away from the gripper more easily. Increasing the value of δ_2 affected pick up and tended to make the pasta slip off the blade at the start of the roll. The maximum value of δ_2 after which the pasta could no longer be picked up was around 5 mm. The results suggest that a large value of δ_1 and a small value of δ_2 are required for optimum gripper performance. Consistently good results were obtained for both pick up and release of the pasta by setting δ_1 to 4 mm and δ_2 to 3 mm. Changing the values of δ_1 and δ_2 alters the blade angle θ as calculated from (2) and requires an adjustment of the initial orientation of the roller.

When picking up a pasta sheet it was necessary to lift the gripper away from the surface of the table towards the end of the roll. This ensured that the length of pasta h would be left hanging from the roller. It was found that lifting the gripper vertically by 10 mm during the final 90 degrees of rotation was sufficient to prevent this length of pasta from sticking to the roller. The final positioning of the pasta sheet depends also on the length of pasta that is initially unrolled into the tray. Once the end of the pasta has made contact with the bottom of the tray it adheres to it providing an anchor point for correct placement.

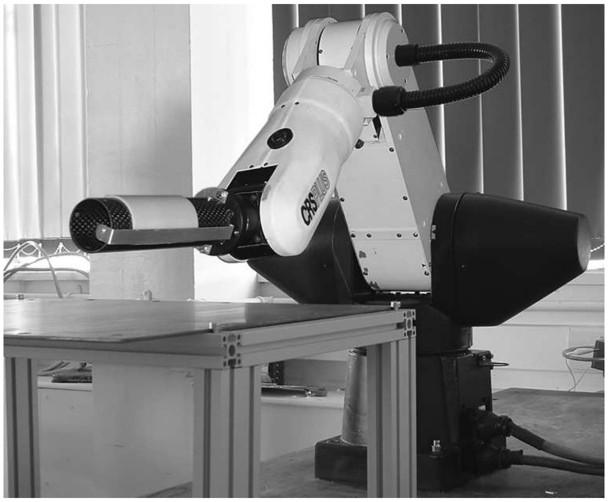


Fig. 5. CRS Plus A460 robot with prototype gripper picking up a lasagna pasta sheet from a table.

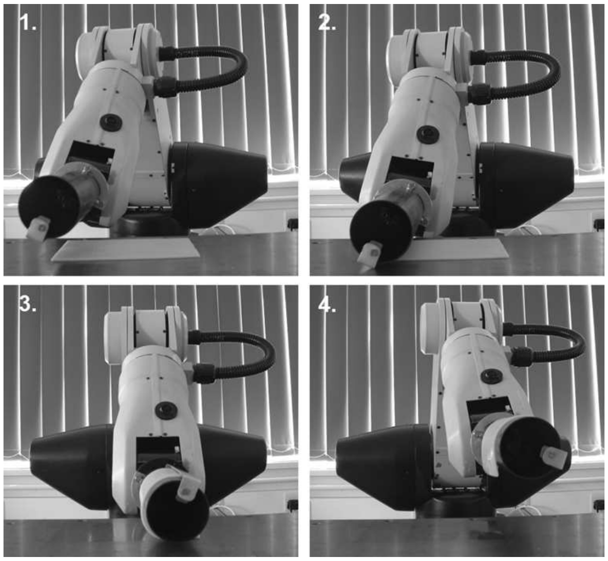


Fig. 6. Sequence of motions in the robotic handling of a lasagna pasta sheet.

It was necessary to reuse the pasta pieces during testing. A consequence of this was that the cooked pasta tended to dry out very quickly becoming less slippery and increasingly sticky, which made releasing the pasta difficult. The pasta had to be sprayed with water to keep the amount of surface moisture approximately constant. In an industrial production environment the pasta would be continuously produced and each pasta sheet would have the same characteristics when it arrived at the gripper. If pasta characteristics remain constant, the gripper can be expected to perform consistently with every pasta sheet.

IV. DESIGN OF AN AUTOMATED MACHINE FOR PASTA HANDLING

The robotic trials demonstrated that the proposed gripper design could be used successfully to automate the pick and place operation required for the handling of lasagna pasta sheets. The placing of the pasta sheets into trays involves handling only one product in a high volume process and is perhaps better suited to a fixed automation solution rather than the use of a programmable robot. In order to assess the performance of the proposed gripper design under conditions similar to those in a real industrial application, a low cost fixed automation machine was designed and built using pneumatic actuators. The pick and place type machine is shown in Fig. 7 and also in the accompanying video. It is able to pick pasta sheets from a moving conveyor and deposit them into trays travelling on a parallel conveyor.

Analysis of the motions required for the task revealed that only four degrees of freedom are necessary to carry out the pick and place operation. The machine has two degrees of freedom consisting of a horizontal translation along the y axis and a vertical translation along the z axis. A third rotational degree of freedom about the y axis (pitch) is provided by the rotary actuator on the lasagna pasta gripper. The fourth degree of freedom results from the motion of the pasta as it is transported on a conveyor along the x axis. It was determined that the rolling and unrolling of the pasta could be carried out in one continuous uninterrupted roll at constant angular velocity. This meant that closed-loop positional and velocity control of the gripper were not required. A programmable logic controller was used to coordinate the movements of the actuators to reproduce the sequence of motions previously executed by the robot arm. Conventional directional valves were used to drive the pneumatic actuators and the instroke and outstroke speeds of each actuator were set using exhaust flow control valves. The required actuator speeds are determined by the velocities of the pasta and tray conveyors. The conveyor velocities were both set to 135 mm/s, which is a value similar to that used in industry. The lasagna pasta handling machine was equipped with two photoelectric sensors. The first detected the approaching lasagna pasta sheets on the pasta conveyor and triggered the pick and place cycle. The second was placed on the tray conveyor and was used to position the trays ready for the pasta to be lowered into them. Part of the pick and place sequence is illustrated in Fig. 8. The actuator motions had to be correctly timed for successful operation. Adjustments to the timing were made directly in the programmable logic controller program. The machine was capable of continuous fully automatic operation with a pick and place cycle time of just under 3.6 seconds.

Fig. 7. Automated machine for lasagna pasta handling during trials.

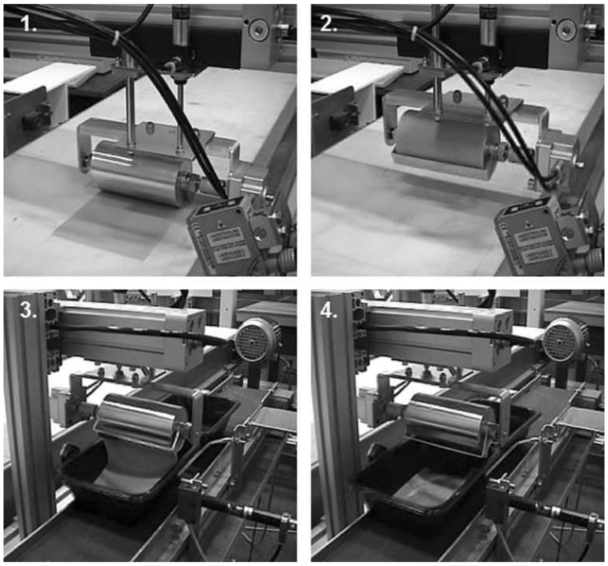
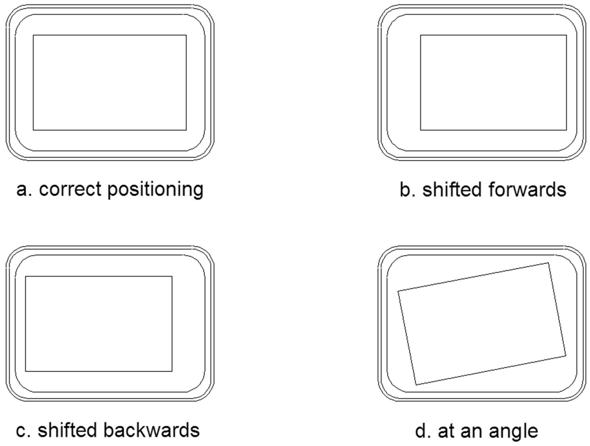


Fig. 8. Sequence of motions in the automated handling of a lasagna pasta sheet.

Testing of the machine was carried out to measure its performance and determine the success rates that could be achieved. The machine was put through approximately 300 pick and place cycles under test conditions using cooked lasagna pasta. For the purpose of the tests a pick and place operation was considered to be successful if the machine placed the pasta sheet in the centre of the tray with a permitted horizontal positioning error of 10 mm in any direction. This typically is the accuracy with which a human operator places the pasta inside the tray in industry and a pasta sheet positioned within these limits was considered to be acceptable for lasagne production. The results obtained were as follows: 96% of the pasta sheets were picked up from the conveyor and rolled onto the gripper successfully. 68% of the pasta sheets picked up were placed inside the tray and within the specified positioning limits. 31% of the pasta sheets picked up were successfully placed inside the tray but



a. correct positioning

b. shifted forwards

c. shifted backwards

d. at an angle

Fig. 9. Correct positioning of the pasta in the tray and most common positioning errors.

outside the specified positioning limits. The most common positioning errors are illustrated in Fig. 9. Accurate positioning of the pasta was made more difficult by the shape of the lasagne ready meal trays. It was observed that when the pasta was lowered into the tray only the corners of the pasta sheet would make initial contact with the tray's sloping sides, providing a poor anchor point for pasta placement. A pasta sheet positioned outside the specified limits would usually be shifted either forwards or backwards in the tray. These positioning errors were attributed to the poor initial contact between the pasta and the sloping tray sides and to variations in the amount of water present on the surface of the pasta as a consequence of the need to reuse the pasta pieces during testing. Relatively wet pasta tended to slip on the sides of the tray and was positioned further forwards while dryer pasta tended to stick more readily to the tray sides causing it to be positioned further back. Pasta that had dried out slightly also had a tendency to stick to the blade after being unrolled. Whenever this happened the pasta sheet would be pulled to one side as the gripper returned to its starting position resulting in the pasta being placed in the tray at an angle. In the few cases where the pasta sheet was not picked up successfully it was observed that excess water had been present on the surface the pasta. It is likely that the occurrence of the most commonly observed positioning errors would be greatly reduced if the shape of the tray were modified so that the pasta sheet made initial contact with a flat surface when being lowered into the tray, providing a much better anchor point for positioning. Observations suggest that with further development the machine would perform sufficiently well for reliable use in industry.

V. CONCLUSION

The automated lasagna pasta handling machine potentially offers a low cost solution for the automatic assembly of lasagne ready meals. The machine could be easily installed onto existing semi-automatic lasagne assembly lines with minimal investment or modification to the line. The lasagna pasta gripper is designed to meet sanitary requirements for food processing equipment and it is estimated that a sanitary grade lasagna pasta handling machine could be produced for around £2,000. The next stage of development would involve extensive testing of the machine on an industrial lasagne assembly line. The machine is expected to perform more consistently when handling continuously produced pasta sheets in a real production environment. The main challenge for future development will be the integration of several machines working together on the same production line. With minor improvements to the design it should be possible to reduce the pick and place cycle time to just under 3 seconds. Nine machines would then be required to fully automate a line producing one lasagne ready meal per second. The same output is currently achieved on industrial semi-automatic lines using three or four operators per shift to handle the lasagna pasta. It may also be possible to modify the lasagna pasta gripper for use in similar applications involving the handling of other limp, flexible sheet materials.

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