Design and feasibility tests of flexible gripper for handling variable shape of food products

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Abstract: The application of automation for handling of non-rigid or semirigid food products are limited due to lack of appropriate gripper. Most of the robot grippers are not easily applicable due to food products are often delicate, easily marked or bruised, adhesive and slippery. In this paper, we present an innovative approach of a gripper for handling variable size, shape and weight of unpacked food products. The gripper operates using Bernoulli principle of generating a high-speed flow between the gripper plate and product surface thereby creating a vacuum which lifted the product was designed and built. Feasibility experiments were performed to demonstrate and obtain an overall understanding on the capability and limitations of the gripper.

Key–Words: Gripper, Food products, Flexible, Bernoulli, Handling

1 Introduction

Food and beverages manufacturing sector is one of the largest industry sectors in Europe. In the Data & Trends of the European Food and Drink 2008 [1] reported that it is a largest manufacturing sector with an annual turnover of €913 billions and employed a workforce of 4.3 million people. In the United Kingdom economy itself, food and drink industry turning around £3,570 billion a year, and employing close to 470,000 people [2]. Food industry is a key area for the application of the automation system [3]. As consequences of the need of increased quality control and improvement in repeatable production, many food manufacturers are now investing more heavily in the automated handling process.

The main aspect of our work is the development of reliable solution for grasping and manipulation of unpacked food products. Knowledge about physical and mechanical components of the gripper is derived from a study of available products on the market. In parallel, existing grippers and feasible mechanism solutions in the literature reviews described. Finally, particular attention must be given to design the gripper because food products deform significantly during handling and are easily bruised when they are in contact with hard and/or rough surface. The design of the gripper must also fulfil the hygienic requirements in the food industry. Details design, analysis and performance of the gripper plate have already presented in [4]. This paper focuses on the feasibility experiments in order to test the capability and limitation of the gripper on handling variable types of food.

2 Literature study on grippers in food industry

A gripper is an end-of-arm tooling used on robots for grasping, holding, lifting, moving and controlling of materials. Human hands have been the most common, versatile, effective and delicate form of material handling. However, for repetitive cycles, heavy loads and under extreme environments, grippers had to be developed to substitute for human hands. Robot-gripper systems are found to be effective for repetitive material handling functions in spite of their initial capital and ongoing maintenance expenses because of their reliability, endurance and productivity.

Reviews recent developments of robot grippers especially for food handling, it appears that at the time of initial application technology of robots, grippers specifically designed for dedicated tasks, and an not be revised for other forms, size and heavy load conditions. Later, with new technology of sensors, various flexible gripper designs proposed to overcome these weaknesses. However, their quality is cost prohibitive as well as maintenance issues and limitations for some materials and applications.

A number of grippers have been developed specifically for handling food products such as a gripper system developed by Khodabandehloo [5] for the task of orientating chicken portion on trays. A pneumatic rubber gripper has been used to give a degree of compliance as well as a safe and hygienic power supply for the food environment. A research group at Silsoe [6] has developed a gripper for handling sticky objects. A two-fingered jaw gripper with a moveable polyester film attached to its surfaces is used. The polyester film can be wound after releasing each object, ensuring that a clean piece of the strip is used for the next operation. Another gripper has been developed to handle sticky object, which is fresh sheets of lasagna. Moreno-Masey et al. [7] investigated the possibility of automating the manufacture of lasagna ready meals and developed a method based on the rolling action common in making pastry. By rolling a sheet of lasagna onto a roller and then gradually unrolling it above a product it was shown that the sheet could be positioned accurately and with little damage.

A fully automated sandwich making system has be developed by Davis et al. [8] based on a simpler dedicated yet more flexible concept. The automated system consisted of a continuously running corded conveyor which transports the bread slices and sandwich assemblies between workstations. Each process in constructing the sandwich starting from ingredient placement to the packing of sandwich has been handled entirely by the sandwich machine. Erzincanli [9] has been working on another method of handling nonrigid products by using a radial flow principle to lift up the object. The end-effector operates on the principle of generating a high-speed fluid flow between the nozzle(s) and product surface, thereby creating a vacuum which levitates the product. The clearance gap of the nozzles must be very small in comparison to the diameter of the central tube for an attraction force to be generated. The high outflow rates from the nozzle mean that this method is not suited to handle of delicate products that would be destroyed by the air flow. Using the same principle, Davis and his colleagues [10] have developed a gripper to handle delicate sliced fruit and vegetable products. The device operates on the Bernoulli principle whereby airflow over the surface of an object generates a lift. The gripper allows objects to be lifted with minimal contact thereby reducing the chances of damaging or contaminating the object. The gripper plate fitted with a number of ribs arranged in a spoke like manner, in order to overcome the object to stick to the surface of the gripper making it difficult to release. A deflector is included as part of the gripper to overcome object damage by the centre of the airflow. They have tested the gripper by placement of slices of tomatoes and cucumber on to sandwiches.

3 Flexible gripper for handling food products

After reviewing on different gripper types, designs and capabilities in the literature review, a flexible gripper based on Bernoulli principle and its aided with fingers proposed in this paper. The flexible gripper with fingers incorporated with Bernoulli effect has a wider potential market in handling other things such as egg, portions of chicken, fruit, fish, dough, and therefore, it could also be extended to handle products other than food. This technique has a major advantage over the old gripper [10] because it is capable of handling not only flat-shaped food products, but also able to lift and hold round, irregular shaped products. It is also necessary for the gripper used for food application to be simple and capable of hygienic use.

The flexible gripper developed in this project would see improvements in the efficiency of the device by reducing the airflow and possibility supply pressure in order to reduce the operating costs. Since the compressed air used in this gripper has direct contact with food, the purity level for that air is in equivalent to ISO 8573.1 Class 2.2.1 [11]. To achieve this high quality compressed air, cost is the main concern to the food industry. As a result fingers will be in cooperation with the gripper design in order to reduce the amount of air flow being used in handling the food.

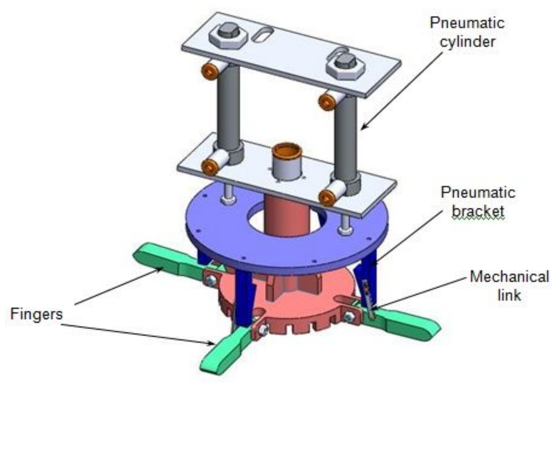

Figure 1: A CAD design of the gripper

The gripper operates on Bernoulli principle whereby airflow over the surface of an object generates a lift. After the object is lifted by Bernoulli effect, then the air flow will be switched off and the object is supported by the fingers to be transferred to another point. This will reduce the amount of airflow used to handle the object. The guides will be introduced and fitted on the surface of the plate gripper in order to minimize the object's to contact with the surface of the gripper thereby reducing the chances of damaging or contaminating the object. A 3D CAD has been developed in SolidWorks environment, by considering the size of the fingers and gripper plate in the kinematic model. Figure 1 shows the CAD design of the gripper system. It has been decided to use commercial aluminium alloy for manufacturing the fingers and other parts since it is low-cost and lightweight.

4 Experiments and Results

4.1 Experiment Setup

A pick and place type machine equipped with the gripper has been built. The machine was designed suitable for use in industry using a number of pneumatic actuators. The machine has three degree of freedom, a first degree of freedom is a horizontal translation along the z axis. The second degree of freedom about z axis is provided by the finger actuators of the flexible gripper and the third is the vertical movement along the z axis. The flexible gripper machine was bolted directly onto the food conveyor belt by a simple mounting frame made from commercial available structural aluminium extrusion. The mounting frame allowed adjustment of the position of the machine in x, y and z directions relative to the food conveyor belt. In food industrial application a welded stainless steel frame would be preferable as it would be easier to clean.
The flexible gripper for handling food products system was equipped with a photoelectric sensor. A Pepper+Fuchs F22 diffuse-reflective sensor was used to detect the approaching food on the food conveyor belt. The sensor was placed to one side of the conveyor belt at an angle to position it directly above the product. A program has been written using the Siemens STEP 7 - Micro/Win software in order to control the gripper system by coordinating the timing and motion sequences of the actuators. The STEP7 - Micro/Win programming package provides a user-friendly environment to develop, edit and monitor the logic needed to control an application.The experimental setup of flexible gripper for handling food products machine is shown in Figure 2.

4.2 Range of Samples

The size, shape, weight and surface structure of food are the most important characteristics from the point of view of gripping and invariably have to be con-

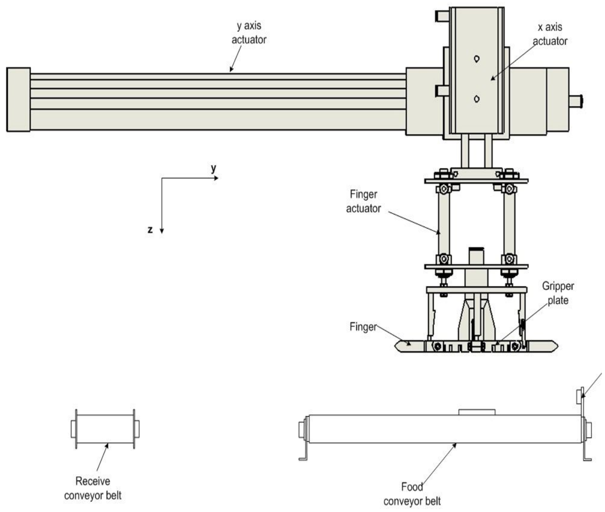

Figure 2: Experiment setup for pick and place food

sidered when testing gripper's capability in handling food products. A classification system for robotic food handling carried by Erzincanli and Sharp [12] helps in selecting range of samples of food to be tested on the gripper. It is very important to know the geometrical profiles and characteristics of each sample of food before being tested on the gripper. Another characteristics, for instance, compliance, bruise–ability and fragility need to be considered because food products with those characteristic will encrypt gripper for handling it.

4.2.1 Size

The diameter of the gripper plate is 64 mm, however it not means food with the size of 64 mm can be handled by the gripper. This is because that when all fingers in a closed position, the gripper plate diameter is become smaller, which is about 50 mm as shown in Figure 3. Foods that have a large diameter, as big as 50 mm height and should have less height of only 2mm. Nevertheless, food with a small diameter as small as 15 mm can have a greater height is 17 mm tall. Figure 4 shown the relationship between diameter and height of the food that the gripper was capable of handling. If we have food samples will be tested on the gripper, we can measure the diameter and height of the food sample, if it is in the range such as in Figure 4, the sample can be tested on the gripper.

4.2.2 Shape

Shape can be defined as overall shape in terms of the basic geometric elements. Food products are produced naturally, therefore, the shape of the products

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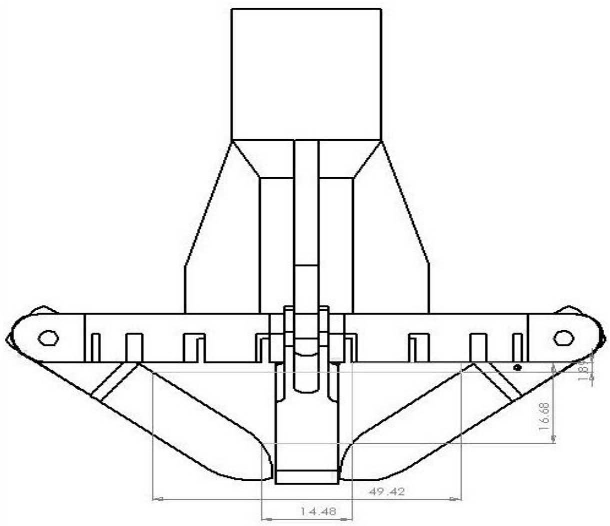

Figure 3: Range of sample that the gripper is able to handle

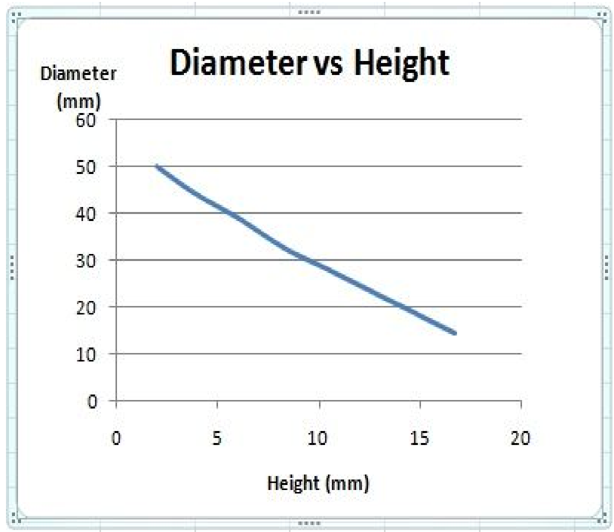

Figure 4: Relationship between the sample diameter and height of sample

cannot be precisely controlled. It is difficult and almost impossible to find any two apples with exactly the same shape even when they are the same type of apple. Their shapes differ slightly from each other. Various food with different shapes have been experiments by the gripper. Slices of cucumbers, tomato and potatoes have been tested under flat type of food. Grapes, strawberries and raspberries have been categories as round type of food. Variable shapes of food such as marshmallow, jelly gums and sweets also being tested by the gripper.

4.2.3 Weight

A specific weight of food varies depending on the type of food. For instance, a marshmallow could be a similar size with a baby potato, but there is a significant weight difference between them. In order to determine the range of weight of food that the gripper is capable of handle, a number of experiments have been carried out. The range of weight of food that can be lifted by the gripper is highly dependent on the shape of food itself. The range of weight of food is bigger, if the food is a flat type of food. However, if the shape of food is a variable or a round type, the range becomes smaller.

4.2.4 Surface structure

In food products, it is difficult to find a surface that is similar to mechanical parts surface. Each food product has a different surface structure, this comes comes from their nature and it cannot be controlled. Some fruits have smooth surface such as grapes, plums and blackberries, however others like raspberries, have rough surface structure. A number of experiments have been carried out to test food with different surface structure ranging from smooth to rough. It can be seen that the gripper has difficulty lifting up food with smooth surface structure compare with rough surface. Food surface with bread crumb such as fish fingers and chicken nuggets were easily lifted up by the gripper.

4.3 Variable shapes of food

Various tests at different levels were performed to verify the feasibility of the flexible gripper. First, in order to demonstrate that it could handle a variety of food shapes, food with different shapes was picked, moved and placed without any handling problems such as slippage, dropping, or breakage. For instance, around two dozens of strawberries and raspberries with different sizes, weights and shapes were picked and placed repeatedly without dropping and damaging as depicted in Figure 5. The same experiments have been repeated to handle different types of food so that a flat and an irregular type of food.

4.3.1 Flat shape of food

Sliced cucumber, tomatoes and cookies have been used to test the ability gripper for lifting food in the form of flat shape of food. Table 1 shows the range in terms of diameter and weight that the gripper is capable of handling. The gripper could handle up to almost 60 grams of tomato with diameters of 50 mm.

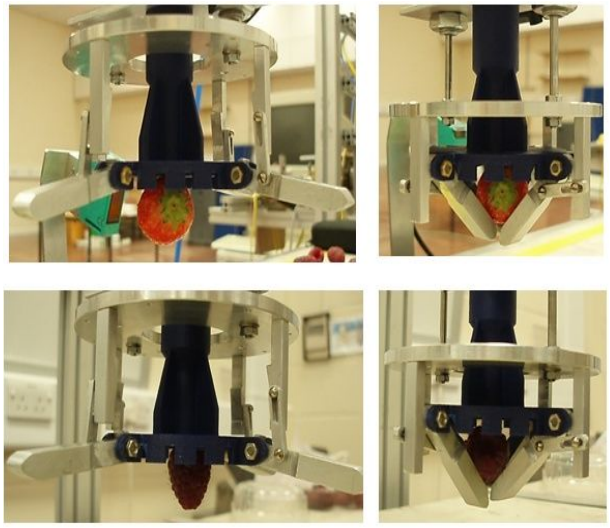

Figure 5: The gripper handling strawberry and raspberry

Table 1: Different weights and sizes of flat shape of food

Food type	Diameter (mm)	Weight (g)
Cucumber	44.0	33.0
	43.0	28.0
	44.2	17.0
	38.4	7.0
Cookies	58.12	18.0
	32.4	5.0
	20.0	2.0
Tomato	49.2	59.0
	57.4	21.0
	41.2	18
	23.1	8

4.3.2 Round shape of food

In order to evaluate the real gripping capabilities a series of tests was made on families of food of similar shape but different dimensions such as strawberries, raspberries and grapes, whose weight, dimensions and surface characteristics were known. Table 2 shows the range of round type food that the gripper could handle. We can see the range of weight have been reduced drastically compare with the flat type of food.

4.3.3 Irregular shape of food

Jelly gums, marshmallows and chicken nuggets have been to test the ability of the gripper for handling variable type of food. These types of food are called processed food, therefore they have standard weight with fancy, irregular shapes. Table 3 tabulated the experimental results of the irregular shape of food have been tested with the gripper. Figure 6 shows the gripper was handling variable shape of jelly gums.

Table 2: Different weights and sizes of round shape of food

Food type	Size (mm)	Weight (g)
Strawberry	26x29x25	8.0
	23x25x23	6.0
	24x21x19	5.0
	23x21x15	4.0
	15x22x19	3.0
Raspberry	19x24x21	5.0
	16x21x20	4.0
	15x20x17	3.0
	14x19x16	2.0
Grape	26x16x16	7.0
	25x14x14	6.0
	24x13x13	5.0
	23x13x13	5.0

Table 3: Different weights and sizes of irregular shape of food

Food type	Size (mm)	Weight (g)
Jelly gum	35x25x20	7.0
	38x23x20	7.0
	24x24x19	7.0
	30x22x20	7.0
	26x23x19	7.0
Marshmallow	20x220x15	5.0
	21x15x16	4.0
	20x20x10	3.0
	24x15x10	2.0
Chicken nugget	35x25x6	22
	34x26x6	22
	36x24x6	22
	34x24x6	22

4.4 Lifting force with different contact surface area

Further experiments were carried out to investigate the capability of the gripper. First, the nozzle head was brought down near the object via a specified clearance gap using a vertical movement mechanism. The gripper plate was positioned at the centre of the object to be lifted. Then, through regulating the valve, the air

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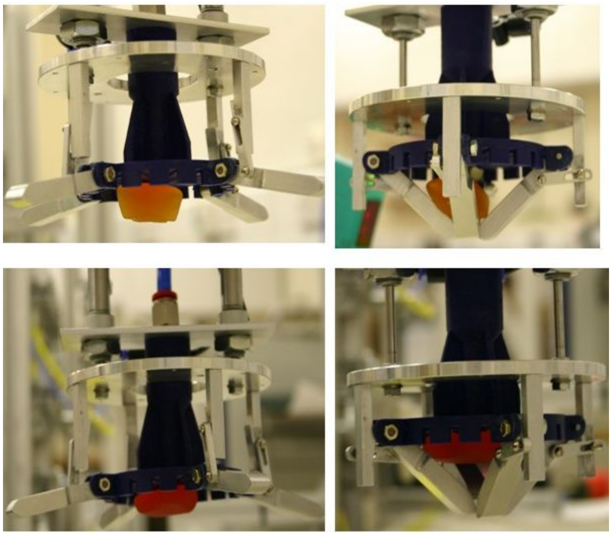

Figure 6: The gripper handling irregular shapes of jelly gums

supply was slowly increased. The minimum air flow rate at which the object was lifted was noted. The experiment was repeated for different diameter of the potatoes. The above procedure was repeated for different weights and air flow rate is continuously noted.

The same experiment and procedures then repeated to lift up a number of strawberries. These experiments were used to evaluate the performance of the gripper for different shape of food in further details. Contact surface area of strawberries is much different with sliced of cucumbers and potatoes. Strawberries have less contact area with the gripper plate compared with sliced of potatoes. As a result the gripper have higher lifting force and required less air flow rate to handle flat type of food compared with round or irregular type of foods. Figure 7 shows the result the variation of flow rate used to be lifted sliced of potatoes with two different diameters. Therefore, the more contact area of the object with gripper plate the less amounts of air used to lift up the object.

Contact area between the object and the gripper plate play an important role to determine the effectiveness of the gripper. The bigger the contact area, the easier for the gripper to lift up the object. However, for the variable shape of objects have less contact area with the gripper plate, so example strawberries with round shape even though the diameter of the strawberry is 10 cm, however the contact area is only 4 cm. As a result, a variable shape of the object with less contact area with the gripper plate needs higher air flow rate in order to be lifted up by the gripper.

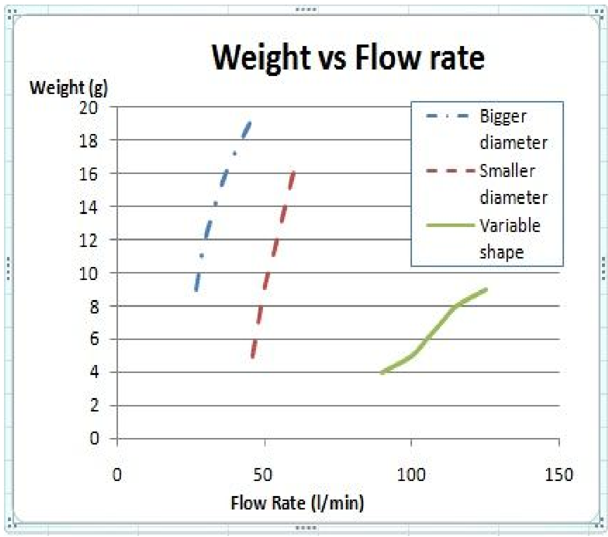

Figure 7: Weight vs Flow rate for different diameter of food

5 Conclusions

This paper presents a design and testing of a flexible gripper for handling food products. The gripper operates using the Bernoulli principle. A gripper aided with four fingers was designed and developed to handle variable sizes, shapes and weights of food. Food products with different sizes, shapes and weights have been tested on the gripper in order to verify the capability and to test the limitation of the gripper. Capability of the gripper was limited by the contact area of the gripper plate with the surface area of the food to be lifted up. The gripper was able to handle flat type of food with higher weight range, however for irregular shape of food the gripper need higher air flow rate and the range of weight of the food that the gripper capable to handle were reduced tremendously.

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