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A hygienically designed force gripper for flexible handling of variable and easily damaged natural food products

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ABSTRACT

To overcome present difficulties in robotized food handling a force sensing robot gripper for flexible production is presented. A magnetic coupling is used to completely encapsulate the actuator mechanism, improving hygiene and enabling a future hose-down proof design. Product location, orientation and product type and width are extracted by a vision system to aid the gripping process. Knowing the product type the grip force is set individually for each product. In the paper data of achievable grip strength, positioning accuracy and gripping times for force controlled gripping are presented. Grip times of 410–530 ms for grip forces of 50–700 g respectively are realized. An initial microbiology study on a model system showed that an intermediate decontamination can be used to reduce the cross contamination of *Listeria innocua* (SIK215) significantly. The gripper is further shown to be able to handle an in-feed mixture of tomatoes, apples, carrots, broccoli and grapes without intermediate adjustments.

Industrial relevance: This paper covers the development and evaluation of a hygienically designed universal robot food gripper. The gripper enables an increased use of robots in the food industry and makes very flexible production with minimal changeover times possible.

1. Introduction

Previously, robots in the food manufacturing industry have been used mostly in packaging. However, today robots are slowly entering the open product applications (Brumson, 2008; Christensen, Dillmann, Hägele, Kazi, & Norefors, 2009). This requires much tougher demands on the equipment, not least hygiene requirements. If robots could be used in all parts of the production it would be possible to increase productivity, increase consistency and quality and reduce the risk of product contamination and product cross contamination (Wallin, 1997). The risk of repetitive motion injuries can also often be avoided by replacing human labour with robots for monotonous tasks (Christensen et al., 2009). As natural products are highly variable a key to be able to use robots for open food product handling is to be able to grip them effectively and without damage. Today it is furthermore important to be able to rapidly change the production to meet the changes in customer preferences (Jennergren, 2004). If a universal gripper could be developed that was able to handle not only the variation within one type of products but also many different types, it would further increase the use and flexibility of the robot stations e.g. to meet consumer demands in higher variation in ready-to-eat (RTE) meals.

Today a dedicated gripper can be developed for almost any product. This is nevertheless an expensive solution with very low flexibility. A universal gripper would enable the use of a robot station for a range of food production/assembly applications e.g. picking tomatoes for 2 h and, with zero changeover time, change to handling carrots and grapes. An automated intermediate cleaning step could be used to reduce the risk of contamination and cross contamination. However, this in turn implicates that the gripper in addition must be suited to withstand the rough wash downs faced in the food industry.

By increasing hygiene in product handling the risk of product contamination is reduced. It is not only wet products (suitable for microorganism growth) such as meat, fish, dairy products that can be contaminated. Many cases of low moisture content product such as chocolate, nuts, etc. have been causes of e.g. salmonella by cross contamination where the bacteria is transferred from contaminated equipment surfaces (Podolak, Enache, & Stone, 2009). Fresh products

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can be contaminated e.g. directly from manure used as fertiliser to vegetables, and these can in turn contaminate equipment. If a contaminating source is present the rate of cross contamination can depend on e.g. surface material, contact frequency, surface roughness, if the surface is dry or wet and on the product and contaminant themselves (Smith, 2007; Midelet & Carpentier, 2002; Rodrígues, Autio, & McLandsborough, 2007). It is important to try to reduce the amount of microbial pathogens to produce safe foods. The effect on the consumer differs. Some microorganisms have low infection doses such as verotoxigenic *Escherichia coli* (VTEC) that can be infectious with as little as 100 colony forming units (CFU), which is considered a very low dose, and others such as salmonella that have an infection dose of approximately 1 million CFU (Szanto et al., 2007). Production of RTE meals also increases the hygienic demands on the manufacturer as RTE products are often only heated to serving temperature, not cooked which would destroy present microbial contaminants, by the consumer or even consumed cold without further heat treatment. As a consequence of this the products are very sensitive to contamination after the final heat treatment step (Rosengren & Lindblad, 2003). It is therefore important to avoid contamination or cross contamination of microorganisms during all production steps to produce safe foods.

Potentially robots can improve production hygiene, compared to humans that have a tendency to cough, shed e.g. hair, skin fragments and saliva. Many food manufacturers want to reduce the amount of manual labour where open foods are handled. This is of course both a practical and economical issue. As labour costs increase and legislation is making it more costly for the company if workers are injured (repetitive motion injuries) a robot alternative becomes more attractive (Brumson, 2008). Robots are considered to be able to maintain a high quality and throughput 24 h a day without the need for breaks, toilet facilities, parking lots or a cafeteria. However, humans are extremely flexible and dextrous and are difficult to replace with robots.

1.1. Grippers

Many different approaches have been used when designing grippers intended to be able to handle a variety of product shapes. Lien and Gjerstad (2008) presented a cryo gripper that freezes the product to the gripper surface. This allows handling of various products. However, it would cause unacceptable freeze damage in many food products. Hirose and Umetani suggested a bicycle chain-like design with pulleys and string that grips the products by wrapping itself around the product applying a uniform pressure on every link (Hirose & Umetani, 1977). Non-contact Bernoulli grippers have been presented for flat products (Davis, Gray, & Caldwell, 2008; Erzincanli & Sharp, 1997) and for 3D products (Pettersson et al., 2010). Perovskii demonstrated how the hardening effect generated by applying vacuum on a pouch of particles could be used to enclose and grip products of any shape (Perovskii, 1980). Pettersson, Davis, Gray, Dodd and Ohlsson (2010) presented a similar approach, utilizing the phase shifting characteristics of a magnetorheological fluid attached to two parallel gripper arms.

Various parallel arm grippers for food products have also been suggested in research projects. Friedrich, Lim, and Nicholls (2000) presented a sensor gripping system that provided grip force, product weight and slip information for flexible and variable products to enable minimal force for gripping. Naghdy and Esmaili (1996) developed an online algorithm to measure grip force and fruit ripeness from the variations in armature current at product contact. With compliant inflatable rubber pockets as grip surfaces Choi and Koc (2006) demonstrated controlled pick and place handling of as varied products as eggs (50 g), steel hemispheres (5 kg) and wax cylinders. However, one substantial problem with parallel arm grippers is the difficulty involved in sealing the mechanism and making them washable. Pneumatic devices are often low in cost and simpler to make wash down proof. Stone and Brett (1995) describe an inexpensive finger gripper design based on pneumatic rubber bellows. Pneumatic grippers are, however, more difficult to use if a fast force regulation without overshoot is needed.

Most of these approaches are promising and demonstrate a high degree of flexibility. A two fingered parallel arm approach seems promising for universal handling of delicate and variable products. However, the grippers presented are not, in their current design, suitable for use in food production. The grippers are often not designed to be hygienic and the grip times are often quite long.

The aim of this paper is to present the development of a universal gripper with short grip times able to handle different products and their inherent natural variations in size, shape, frailness and texture. Such a gripper would enable a unique flexibility in e.g. RTE meal production. A new actuator encapsulation has been investigated and an initial study has also been performed on the effectiveness of an intermediate decontamination step. With a vision system, products are localized and identified, removing the need of mechanical aligners and allowing extraction of product parameters to facilitate and speed up the gripping. In the paper data of grip times, grip strength, positioning accuracy and decontamination effect are presented.

In the next chapter gripper design and the experimental setup used are presented. Section 3 describes the methods used for evaluation. In Section 4 the results are discussed and conclusions and future work are presented in Section 5.

2. Gripper design and experimental setup

2.1. Designing a force gripper

Various actuators and mechanisms can be used to generate a gripper arm closing motion. In this project a stepper motor has been used removing the need for a position encoder and allowing for open loop control. Stepper motors are a low cost and robust solution. Pneumatic actuators were rejected as fine and fast force control is problematic. There are unlimited mechanisms available to produce the closing motion of two gripper arms such as scissors closing, beak closing or linear motion (Lundström, 1973). For relatively low grip forces, small gripper size and large arm strokes the linear actuator is found to be the most suitable. Firstly, grip force will be independent of opening and, secondly, the gripper arms will be moving in a plane. Other mechanisms generally induce a curved closing motion of the gripper arms making gripper positioning dependent on product size (Li & Zarrugh, 1983). A belt and lead screw mechanism translates motor rotation to a linear motion, allowing a large stroke in a small space. One gripper arm is connected to the linear mechanism and the other gripper arm to the aluminium gripper frame, producing a parallel arm gripper. The use of only one moving arm simplifies the design and lowers the cost. However, this was shown to lead to some unexpected consequences as shown in Section 5.4.

Two strain gauge sensors placed on the stationary gripper arm base are connected to a ½ Wheatstone bridge amplifier circuit to measure the grip force. A 10 bit A/D sampling of the force is implemented with an Atmel AVR atmega16, 8 bit, microcontroller. In the prototype the grip force is limited to 800 g and the resolution is approximately ± 4 g due to signal noise. Strain gauge sensors are a low cost, robust and well tested technique. To increase the contact area a 3 mm thick compliant foam covered with a vinyl rubber material is used as a grip contact surface.

The microcontroller also handles the serial communication between the robot station and the gripper, motor motion and also keeps track of the gripper arm position. A linear motion motor control and PD force controller algorithm have been implemented in the microcontroller. Motion and gripping commands are initiated from the robot station but autonomously performed by the microcontroller.