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GRIBBOT – Robotic 3D vision-guided harvesting of chicken fillets

Ekrem Misimi [a,*], Elling Ruud Øye [a], Aleksander Eilertsen [a], John Reidar Mathiassen [a], Olav Berg Åsebø [b], Tone Gjerstad [b], Jan Buljo [b], Øystein Skotheim [c]

[a] SINTEF Fisheries and Aquaculture, NO-7465 Trondheim, Norway
[b] SINTEF Raufoss Manufacturing, NO-7465 Trondheim, Norway
[c] SINTEF ICT Optical Measurement Systems and Data Analysis, NO-0314 Oslo, Norway

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ABSTRACT

In Norway, the final stage of front half chicken harvesting is still a manual operation due to a lack of automated systems that are suitably flexible with regard to production efficiency and raw material utilisation. This paper presents the 'GRIBBOT' – a novel 3D vision-guided robotic concept for front half chicken harvesting. It functions using a compliant multifunctional gripper tool that grasps and holds the fillet, scrapes the carcass, and releases the fillet using a downward pulling motion. The gripper has two main components; a beak and a supporting plate. The beak scrapes the fillet down the rib cage of the carcass following a path determined by the anatomical boundary between the meat and the bone of the rib cage. The supporting plate is actuated pneumatically in order to hold the fillet. A computer vision algorithm was developed to process images from an RGB-D camera (Kinect v2) and locate the grasping point in 3D as the initial contact point of the gripper with the chicken carcass for harvesting operation. Calibration of camera and robot was performed so that the grasping point was defined using 3D coordinates within the robot's base coordinate frame and tool centre point. A feed-forward *Look-and-Move* control algorithm was used to control the robot arm and generate the motion trajectories, based on the 3D coordinates of the grasping point as calculated from the computer vision algorithm. The results of an experimental proof-of-concept demonstration showed that GRIBBOT was successful both in scraping the carcass, grasping chicken fillets automatically and in completing the front half fillet harvesting process. It demonstrated a potential for the flexible robotic automation of the chicken fillet harvesting operation. Its commercial application, with further development, can result in automated fillet harvesting, while future research may also lead to optimal raw material utilisation. GRIBBOT shows that there is potential to automate even the most challenging processing operations currently carried out manually by human operators.

1. Introduction

The poultry processing industry is enjoying worldwide growth in spite of operating on small margins. Processors have faced challenges both in terms of the continued growth of the poultry market and increasing demands from retailers for new and higher quality products. One way of meeting these challenges has been to automate processing operations with the aim of achieving consistently high quality and reducing production costs. In comparison with the fish and some other processing industries, poultry processing is highly automated with the exception of certain challenging operations that are still carried out manually due to the absence of technologies that can compete with the effectiveness of human operators.

Yield is crucial to most producers in the poultry processing industry (Itoh et al., 2009), but existing commercial systems continue to suffer from low product yield compared to established manual operations. A typical operation in poultry processing is the front half deboning of chicken breasts to produce fillets. Automation has been extremely difficult due to the complexity of the operation and the degree of dexterity required. Commercially available deboning systems (Zhou et al., 2007) consist of fixed mechanical technologies that are unable to cope with the wide variations in the sizes and shapes of birds, which consequently renders them unable to optimise raw material yield and utilisation.

In Norway, poultry processing is a massive industry with a production volume of 63,762 metric tonnes and total revenues of

* Corresponding author. Tel.: +47 982 22 467.
E-mail address: ekrem.misimi@sintef.no (E. Misimi).

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NOK 5 billion (approx. USD 1 billion) (Flesland and Hansen, 2015). Global annual production is estimated to be 92.7 million tonnes, generating revenues of USD 132 billion. The USA is the industry leader with an annual production of 17.04 million tonnes and revenues of USD 24 billion (FAO, 2012). The industry is dissatisfied with current commercial automated chicken harvesting technologies because, despite of the advantages of these machines, they still cannot compete with the skill, flexibility and adaptability of human operators. Chicken fillets represent the highest-earning product from the entire bird and there is a pressing need from the processing industry to introduce an automated front half fillet harvesting technology that can adapt to anatomical variation, while at the same time optimising raw material utilisation. Norway, in particular, is a specific country given very high labours costs compared to other countries. For industry, a strong incentive for automation of harvesting operation is to make the processing plants more competitive and profitable. Recruitment of qualified labour force is also seen as one of the major challenges in food processing sector. Automation is, therefore, often seen as a measure that can contribute to compensate for the shortage of qualified labour force (Paluchowski et al., 2015).

Traditionally, the harvesting of chicken fillets is based primarily on two methods:

(a) Manual harvesting of fillets from the carcass preceded by a cutting operation using a knife or similar cutting tool.
(b) A fixed machine-based operation using a knife or similar cutting tool combined with a mechanical system designed to release the fillets from the carcass.

Many poultry processors employ the manual approach today. Human operators use their visual, tactile and kinesthetic senses, as well as their learning abilities and cognitive skills, to make accurate calculations of the effort required to perform the chicken fillet harvesting operation.

The main challenge facing the development of an efficient automated harvesting technology for chicken fillets is to design and build in adaptability to the variations in the size, shape and orientation of the fillets attached to the carcass. These variations require precise identification of the grasping point and adaptive harvesting by means of an effective *grasp, scrape and release* procedure. As in other food processing sectors (Balaban et al., in press), the poultry processing industry is looking for flexible automated solutions that can both automate manual operations but also improve raw material utilisation.

Robotic automation has been employed in the meat, chicken and seafood industries worldwide, and has included the development of specific gripper tools (Buckingham et al., 2001; Itoh et al., 2009; Bondø et al., 2011; Caldwell, 2012; Purnell, 2013, 2006; McMurray, 2013; Buljo and Gjerstad, 2013; Hinrichsen, 2010). For example, robots have enabled increased speeds of meat processing operations, but have so far been unable to adapt to anatomical variations (Barbut, 2014). Guire et al. (2010) studied the feasibility of robot-based applications using vision or force control for cutting beef carcasses and the harvesting of pork hams. Firstly, they examined the expertise of human operators and studied their manual dexterity during the cutting operation. Subsequently, they tried to replicate this process using an industrial robot. The authors concluded that the main challenge lies in building-in adaptation to the high variability in the size of beef carcasses. As regards chicken, Zhou et al. (2007) reported a study designed to automate front half deboning to produce high-quality chicken fillets. The authors initially studied the structure of the chicken shoulder joint as a starting point for the specification of cutting locations and trajectories, and proposed a 2-DoF (Degrees of Freedom) cutting mechanism. In Zhou et al. (2009), the authors subsequently focused on the kinematics of this cutting mechanism and the accuracy of the actual cutting point location. Hu et al. (2012) describe ongoing work in the intelligent automation of bird deboning and conceptualised the operation in three parts; (1) a characterisation of non-uniform bird anatomy using statistics and image processing, (2) the derivation of a nominal cutting path using image features correlated with internal anatomical structures and robot kinematics, and (3) the making of corrections for deviations from the nominal cutting path. The authors concluded that while preliminary results showed that the deboning operation was effective, the cutting robot should be upgraded to incorporate more degrees-of-freedom in order to enable greater versatility in performing the various cuts required for complete bird deboning.

One of the key reasons why the use of robotics for automated food handling and processing operations remains a challenge is the difficulty in replicating the complex manual dexterity of skilled human operators. Consequently, one of the most challenging aspects of implementing robotic automation is the selection and design of the appropriate gripper and cutting tools used to manipulate the raw material. Seliger et al. (2007) and, more recently, Fantoni et al. (2014), have described the most commonly applied physical principles for the gripping of non-rigid objects. However, one thing remains clear: there is currently still no universal gripper system for manipulating food raw materials, and the most common approach remains to tailor an optimal system on a case-by-case basis. Pettersson et al. (2011) described a gripper system based on the two-finger principle with emphasis on the hygienic design of the driving mechanism and the force control of fingers against the surface of the food object. Lien and Gjerstad (2008) described a gripper based on the freeze-plate principle, whereby a Peltier element is used rapidly to freeze a gripper plate, thus enabling it to grip the object. By changing the direct current direction, the plate is then re-heated and the object released from the gripper. Gjerstad et al. (2006) designed a compact needle gripper that employed curved needles which penetrated the muscle tissue. This gripper is characterised by excellent grip and clamping force, and was tested on salmon, white and other fish, beef and pork meat with promising results. Sam and Nefti (2010) demonstrated a flexible gripper designed to manipulate a variety of food products based on a combination of the Bernoulli-principle and finger concept. It was tested for the handling of strawberries with promising results. Alric et al. (2014) presented a robotic meat cutting system based on vision and the use of a knife held by one 6-DoF ADEPT Viper robot. A four-fingered gripper was attached to a second ADEPT robot which held the meat being cut. Hu et al. (2012) employed a knife equipped with a force sensor and attached to a 2-DoF robot arm for deboning chicken carcasses.

Our focus in this paper is to present the research resulting in the "GRIBBOT", a novel concept for the robotic harvesting of chicken fillets guided by 3D vision. The name is taken from "*gribb*", the Norwegian term for vulture. The paper includes a proof-of-concept demonstration of a compliant gripper that grasps the fillet, scrapes the carcass, and finally releases the fillet from the carcass. GRIBBOT is a completely novel concept for the robotic automated harvesting of front half chicken fillets. Commercial automation of this operation will not only increase production capacity and profitability in the poultry industry, but may also enable increased utilisation of the raw material at an early stage in production process. The results of this proof-of-concept exercise demonstrate that GRIBBOT has huge potential in terms of the robotic automation of chicken fillet harvesting, and similarly of other challenging food processing operations currently performed manually by human operators. GRIBBOT, with the current configuration, can harvest only one front half fillet at a time.