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Photonic Imaging with Optical Coherence Tomography for Quality Monitoring in the Poultry Industry: a Preliminary Study

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ABSTRACT

A photonic imaging method that gives the possibility to measure egg quality was applied. Since the method is non-contact and non-destructive we believe that this photonic imaging method may be successfully integrated in the automated inspection systems in the poultry industry. The method involves scanning an invisible infrared light beam over the eggshell, allowing to detect possible cracks and reveal information about the structure of the eggshell. The high resolution, high quality measurements obtained through optical coherence tomography (OCT) make it feasible to be utilized as part of an automated inspection system. In this paper we present an OCT scan image of the egg tip and reconstructed volumetric images of the eggshell surface. The method enables the detection of small cracks on eggs and reveals the detailed inner structures of the cracks.

INTRODUCTION

In every industry sector, it is crucial to detect problems related to the product and to measure its quality. The poultry industry is no exception. In the poultry industry, one needs to make sure that the egg quality lies within a specific range. And for an egg to be of good quality it is important that the eggshell is intact and of high quality. (Solomon, 1997). If the eggshell is not intact and has, for example, cracks on its surface, the egg presents low quality in general. Such an egg is prone to damage, dehydration, and microbial infection. The more frequently these problems occur, the higher embryonic mortality rates are observed (Yoho *et al*., 2008).

Eggshell quality can be assessed by a number of different methods. Egg weight, eggshell weight, eggshell percentage, eggshell thickness, and eggshell weight per unit of surface area are typical methods employed in the poultry industry (Jones, 2006).

Some new approaches to determine egg quality involve signal-processing methods. Mertens *et al*. (2006) measured the stiffness and damping ratio of the eggshells to determine egg quality. By measuring resonant frequency, it is possible to measure eggshell strength without destroying the eggs (De Ketelaere *et al*., 2004). Another study applied acoustic resonance frequency analysis to assess eggshell quality (Dunn *et al*. (2005).

According to Carnarius *et al*. (1996), intact eggs are stronger than cracked eggs. It was determined that all relevant egg-quality parameters, such as eggshell weight, percent eggshell, eggshell thickness, specific gravity, and eggshell weight per unit surface area were all much greater than in intact eggs than in cracked eggs. (Thompson *et al*.,1986). Therefore, it is important to detect cracks on eggshells when determining the quality of eggs. Measuring eggshell stiffness modulus enables detecting cracks with no need of breaking the eggs, thereby providing a nondestructive method to infer egg quality (Lin *et al.*, 1993).

The aim of this research article is to show that employing a photonic imaging modality that uses an infrared light beam for optical coherent measurements enables detecting cracks on eggshells non-destructively. In the next section we will explain the non-contact and non-destructive measurement principle.

MATERIALS AND METHODS

The field of photonics utilizes light to accomplish various technical tasks ranging from communication to, for example, material processing and imaging. In imaging, the use of photons allows obtaining images in a non-contact and non-destructive manner. Optical coherence tomography (OCT) is one such photonic imaging method. The first OCT image was an image of the retina and was taken in the early 1990's (Huang *et al*., 1991). OCT proved to be a reliable and versatile imaging method and has been applied especially in medical sciences. Because OCT is a non-contact non-destructive method, it proved to be useful to take sensitive measurements of the structures of the human eye (Fercher, 1986). However, OCT imaging is certainly not limited to medicine and has been applied in many different areas, such as material science (Meemon *et al.,* 2013), art conservation (Liang *et al.,* 2005), archeology (Liang *et al.,* 2008) and agriculture (Meglinski *et al.,* 2010). In a recent paper, OCT allowed to non-destructively measure layered polymeric GRIN material (Meemon *et al.,* 2013).

In this paper, we extended the application of OCT to poultry, and demonstrate the use of OCT to determine egg quality, particularly to detect cracks on eggshells.

OCT working principle resembles ultrasound imaging. However, instead of using sound waves, OCT makes use of light wave reflections in the imaging process. An OCT system shoots photons contained in a beam of light on a surface and then constructs the images based on the time-delay information contained in the reflected waves that come from different depths inside the sample. Hence, an OCT system generates a high precision depth-profile. The typical resolution levels achieved with OCT exceeds those obtained by ultrasound imaging. Time-domain OCT and frequency-domain OCT have measurement resolutions of 5-10 μm. On the other hand, a 10 MHz ultrasound measurement device has a resolution close to 150 μm. OCT provides more than 10-fold resolution enhancement over ultrasound sensors. It is clear that the high-resolution quality of OCT may prove to be useful when imaging minute structures such as cracks on surfaces (Bashkansky, 1997).

We employed a spectral domain optical coherence tomography (OCT) imaging with a resolution of approximately 7 μm (Sabuncu, 2014). Hence, our system enables high precision measurement of the eggshell surface and its structure. The diagram of our system is shown in Figure 1. The system sends invisible infrared optical waves onto the egg surface. The photons are generated at the broadband light source by a super-luminescent diode with central wavelength at 930 nm. Then, the interference patterns created by the waves reflected from the egg (placed in sample arm) are

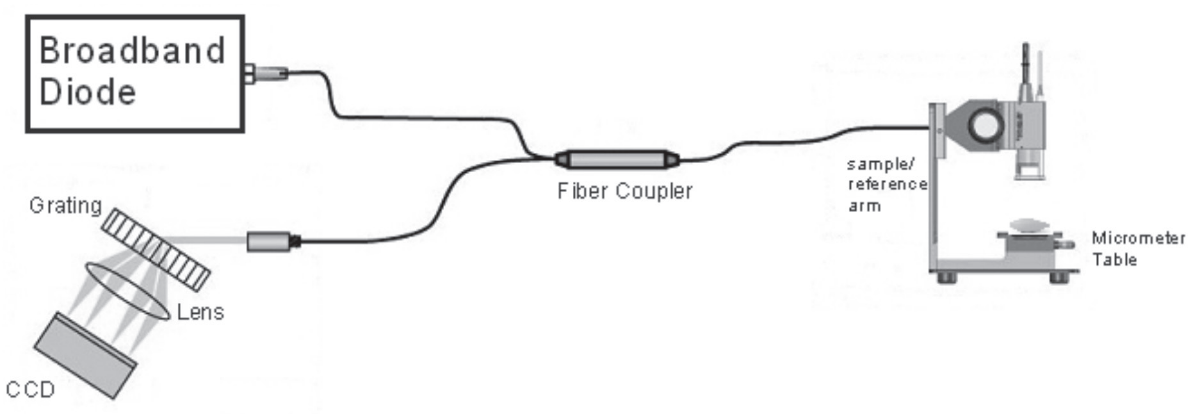

Figure 1 – The spectral domain OCT setup. The broadband light source is a super-luminescent diode with central wavelength 930 nm and bandwidth 100 nm. FC represents a fiber coupler that combines the light waves reflected off the sample and reference arms. The interference signal is then separated to its frequency components through an optical grating and sent to a CCD.

recorded and simultaneously separated into different frequency components in a charge-coupled device (CCD). An optical grating is used for the separation of the spectral components of the signals. Since different frequencies correspond to signals coming from different depths of the sample tissue, this measurement provides in-depth information about the egg.

The application of a Fourier Transform to the received signal provides the A-scan of the evaluated sample. This is optically obtaining using the grating, which splits the signal into its spectral components. Combining sequential A-scan images created along a transversal plane of the sample results in B-scan images. For further reading on the theory underlying how OCT images are formed, refer to the review article by Joseph M. Schmitt (Schmitt, 1999).

When the test object (in our case, the egg) is placed in the sample arm in order to obtain the OCT images, one needs to make sure that the light coming from the OCT source is focused on the egg. The procedure to achieve this with the egg is as follows. First, it is necessary to fix the length of the arm by monitoring the signal reflected off the eggshell air interface. Tuning the length of the arm until a sharp image is seen on the CCD camera enables a coarse adjustment. Then, fine-tuning is obtained by optimizing the OCT spectrum on the B-scan.

The technical specifications of our OCT system were as follows:

The light source had a bandwidth of around 100 nm centered at a wavelength of 930 nm. The A-scan line rate was 1.2 kHz and B-scan frame rate was at 512 lines/frame. The depth and lateral resolutions were 7 μm and 8 μm, respectively. Imaging depth was around 1.7 mm, with a Signal-to-Noise Ratio (SNR) of 83 dB.

RESULTS

This section presents the main results obtained by optical coherence tomography imaging. We show the images that enabled detecting very fine cracks on the egg surface. We also present 3-D volumetric scans of the eggshell that reveal information about the crack structure. Figure 2 shows a scan of the egg tip. In this image, the infrared beam is directed towards the egg tip from the top, scanning the egg tip. As the infrared beam propagates through air, the image obtained is black because no reflections are obtained. Consequently, the upper section of this section, which is black, corresponds to air, whereas the white line corresponds to the section where the infrared beam is reflected on the egg, resulting in the profile of the egg tip. In this particular scan, one can clearly see that the portion of the evaluated egg is intact and free from cracks. These images also show eggshell thickness, as well as the variations in thickness. These are valuable data to determine eggshell uniformity and, according to a recent study of Sun *et al*. (2012), can be used to quantify egg quality (Sun *et al.* (2012).

Figure 2 – OCT scan of the egg tip. This is a typical OCT scan where the beam arrives from the top section. The white regions correspond to reflections hence giving the eggshell profile.

Considering that an essential component of egg quality is the detection of eggshell cracks, we present below the results of OCT egg crack measurements.

Figure 3 shows an OCT 3-D volumetric image of a location on the egg surface where a crack can be seen. The OCT image provides high-resolution details of the crack structure. The crack width and depth and its whole profile can be seen in this OCT image. The image can also be rotated and shown from above (Figure 3b).

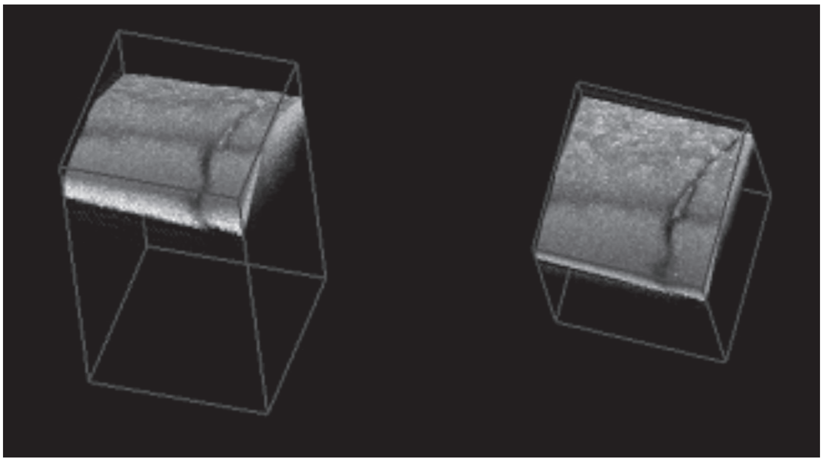

Figure 3 – Volumetric 3D OCT scans taken on the egg surface. Here one can see a crack structure on the egg. The image is rotated to look at the crack from the top.

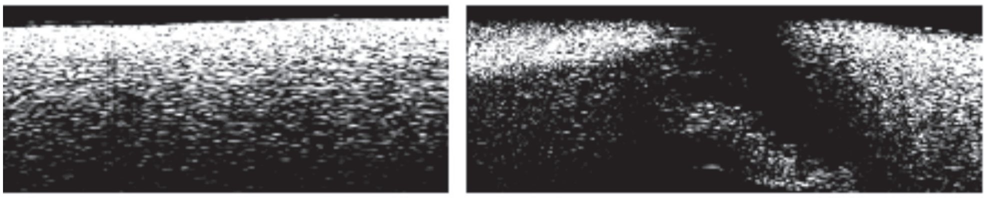

Figure 4 – B-scan OCT images. These are typical B-scans on the egg surface. In the left figure image wee see an intact eggshell and on the right we see clearly see a crack sturcture in the egg. The difference between an intact egg OCT image and cracked egg OCT image is obvious.

We also present the B-scan images showing the cracks in Figure 4, which clearly show the differences between an intact and a cracked eggshell. The analyzed cracks ares 30-40 µm wide. These cracks are visible because of the high resolution (of approximately 8µm) images obtained by the OCT system.

The OCT program enables the direct measurement of any desired distance on the OCT image. Hence, OCT imaging allows for the accurate characterization of the crack structures. Crack depth, length, and width are easily measured by the OCT method.

Since only low-power photons are used in this method, the measurement is not only non-contact, but also non-destructive. This is verified by carefully taking OCT scans after initial OCT measurements. These OCT measurements are identical to the first OCT measurement, clearly showing that the egg structure and crack remain undisturbed by the OCT scan.

DISCUSSION AND CONCLUSIONS

In this article, we investigated the possibility of using photonic imaging with optical coherence tomography to monitor egg quality. We used OCT images to detect eggshell cracks. The OCT method gives us a possibility to determine if the eggshells are intact or not. We also used volumetric OCT imaging to obtain 3D structures of the cracks. To the best of our knowledge, this was the first time OCT was applied to detect and to measure 3D structures of cracks on egg surfaces. Because OCT is a high-resolution imaging modality, it allows detecting fine crack structures. Considering that OCT allows measuring eggshell profile and detecting eggshell cracks, it may be used to evaluate egg quality. In addition, due to its non-contact and non-destructive nature, we believe that OCT could, at least in principle, be used for quality inspection in the poultry industry.

The method could also be used for evaluating the eggs of endangered species. For instance, an extensive research study on the effects of pollutants and environmental contamination that cause thinning of eggshells of falcons was recently published (Castilla *et al.*, 2010). Therefore, OCT could be used to quantify the hazardous effects of certain chemical wastes and pollutants on egg quality in a variety of species. The OCT photonic imaging modality can be a useful measurement tool for the poultry science.

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