Chapter 7

Automatic Detection of Egg Shell Cracks

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7.1 Introduction

Eggs are natural objects that possess very complex surfaces, namely their shells, characterized by such features as pinholes, “starry nights”, cage marks or thin shells, stretch marks, strains or discolouration, as well as internal flaws such as blood in the yolks, etc. At present the candling of eggs for these features is done by two means:

[1] Manual, which is

- labour intensive, and may cause some mechanical intrusion;
- reliable, if the eggs are of good quality; i.e. detection rates greater than 90% with false positives less than 1%;
- flawed by high false positives if eggs of poor quality.

[2] Mechanical, which is

- effective but intrusive;
- prone to failure after very little usage; this method requires maintenance and may be unreliable if eggs of very poor quality.

This problem has been considered in some detail and at considerable cost ($1.5 million) over the last three years. The method of looking for cracks is based upon the Batelle patent (U.S. patent 4,161,366) with modifications introduced by Weichman *et. al* 1997 (U.S. patent 5,615,777). The principle of this method is to scan the surface of the egg with a laser which will produce a significant amount of diffuse light, known as egg glow, due to multiple internal scattering when the laser beam penetrates the surface of the egg. In practice this method has been used with some success, yielding a crack detection rate of greater than 60% with a false positive rate of less than 3%. However it still does not meet industry standards which require a crack detection rate greater than 80% with a false positive rate less than 1%.

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The problem for the study group was to find a reliable, non-intrusive means of detecting cracks in eggs. Intensity data from eggs were collected by Vision Smart for the group to analyse. Given the short time period of the workshop, the group focused on three main questions:

[1] Is there a feature of the intensity data which detects, and discriminates between, pinholes, cage marks, and cracks

[2] Are there ways to improve the current data collection process so that the answer to question (1) would be yes.

[3] Alternatively, are there other data collection methods which should be tried?

An attempt to answer question one is in Section 7.2; we found that there was some promise of a positive answer, but many problems arose. Based on our analysis of the data, we give some answers to question two in Section 7.3. Sections 7.3 and 7.4 give some answers to question three.

7.2 Data Analysis

In order to determine distinguishing features of cracks vs. other markings such as cage marks and starry nights, we analyzed intensity data provided for one dozen eggs. This data was collected by shining a laser on the egg, rotating the egg on end, and measuring the intensity as a function of position during this rotation. This gives one dimensional data at a given distance from the end of the egg, which we refer to as a "slice". The data on each slice contained measurements over 4 revolutions of the egg. This measurement was repeated on 27 different slices of each egg, which covered approximately two-thirds to three-quarters of the egg away from its ends.

An example of this data is shown in Figure 7.2. Since an egg has a different cross-sectional radius depending on the distance from the end, and an egg can wobble as it is being scanned, a black stripe was placed on each egg to aid in locating position on the egg in the data analysis. As can be seen from the data in Figure 7.2, there are four places where the intensity drops to 0, which indicates the location of the black stripe. Also, one can see spikes in the data at 4 places, corresponding to increases in intensity due to either a crack, cage mark, or pin hole. We analyzed this data to see if it allows us to distinguish between these features.

From our candling observations we noted that cracks were, in general, composed of one or more narrow linear segments. Therefore we would expect cracks to show up on several consecutive slices at adjacent positions. We would also expect to see such a feature on each of the four revolutions. Therefore knowing the position in the data is necessary for determining whether there is a crack, and we needed to eliminate deviations due to cross-sectional diameter variation and wobble. We found that a linear transformation, a shift and scaling of position, was sufficient for lining up data from the different slices, using the black stripes. We also found that the deviations due to diameter variation and wobble were about 3% on average (see Figure 7.2), and therefore concluded that these variations were not causing significant errors in the data.

Based on some preliminary observations from candling the eggs and considering the data, we used a simple scheme based on windowing and thresholding to pick out significant features in the data. For example, large spikes in the intensity are generally narrow, and are usually followed by a drop below the mean. (This is the phenomenon of "ringing", due to the circuit response in the measuring device, as seen in Figure 7.2. Indeed, this ringing was a clue to use that the recorded data we were analyzing had been clipped to 256 levels by the software.) Then, if there was a significant variation in intensity, above a certain threshold, in a narrow window of the data, we would mark that location with a 1. Otherwise we would mark it with 0. That is, the data from each slice was converted to a string of 1's and 0's, 1's indicating the location of a significant variation in intensity. If there is a crack in the egg, then one would expect that this marking would yield a series of 1's on consecutive slices at adjacent positions, indicating the increased intensity of light on the crack.

We used this procedure on several of the sample eggs which had significant features. In particular we show the results for five eggs: one with a crack, one with a strong cage mark, one with a weak cage mark, one with a starry night, and one with almost no markings. The windowing/thresholding

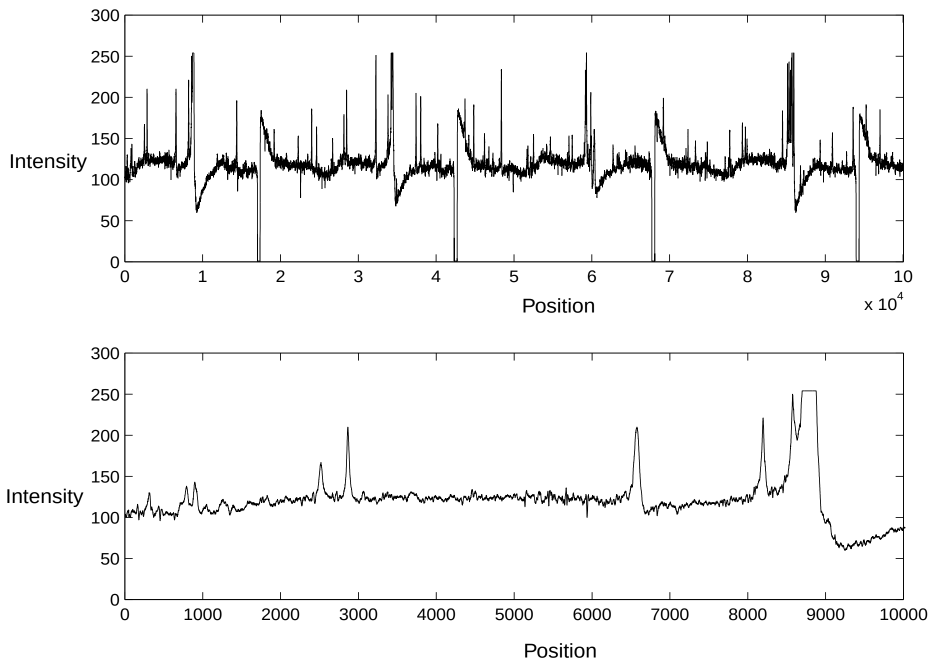

Figure 7.1: Intensity data collected for slice 11 of Egg13. The top figure shows the data collected for 4 revolutions of the egg, on slice 11. The drops in intensity indicate the location of the black stripe placed on the egg. The bottom figure zooms in on this data during the first rotation. Note that the data has been clipped at 256, so that the full height of the intensity spike is not captured. Note also the drop in intensity following the spike, caused by instrument response to rapid changes in intensity.

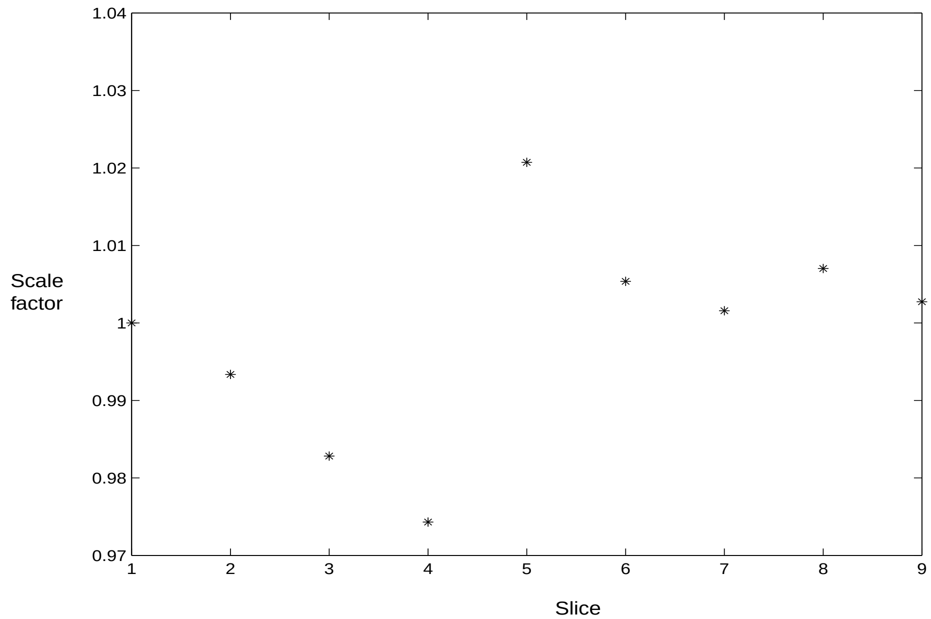

Figure 7.2: Scale factors used to line up data from 9 slices of Egg13. (Slice used as reference value has factor 1, which is the first factor shown.) Note that the scale factors vary on the order of 3%. We found this to be true for the other eggs as well.

scheme applied to the laser data resulted in the following plots, where dark spots indicate the 1's, and the white spaces indicate the 0's (see Figure 7.2). We used approximately the same thresholds and window size for each set of data, with the exception of the last plot (Egg 15), where the threshold was reduced to enhance the picture. The data is repeated 3 times in the horizontal direction, indicating 3 revolutions on the egg. The fourth revolution is not shown, since some parts of this data were not used after the data was lined up using the linear transformation for comparing position.

Summary of the plots:
Egg 13: This egg has a crack, which shows up as a linear sequence of dark spots at the same position on each slice, and it appears on each of the three revolutions. Note that there are also some other isolated spots of intensity variation, due to variations in the readings and the egg shell thickness.
Egg 16: This egg has a strong cage mark, which also shows up on each of the three revolutions as a linear sequence of dark spots at adjacent positions on neighboring slices. Therefore we would have some difficulty in distinguishing this cage mark from a crack, as in Egg 13. We make some comments on distinguishing cage marks, which are generally wider than cracks, in Section 7.3.
Egg 9: This egg has a weak cage mark, which appears on each of the revolutions for not more than 2 or 3 of the slices. Since these markings are isolated from the other variations, which are also isolated from each other, this mark does not have the linear nature of a crack and thus can be distinguished from the crack as in Egg 13.
Egg 6: This egg has a starry night, which is a speckled pattern of spots which show increased light intensity. Since these spots are so close together, it would be difficult to find a crack from this data if there was one. We note again that this data was clipped, so we can not comment on the possibility of finding a crack with unclipped data.
Egg 15: This egg had very few markings, and a significantly lower threshold was used to indicate that there was some variation in intensity. Note that the variations do not compose any linear feature on all three revolutions of the egg, so that we would conclude correctly that there is no crack.

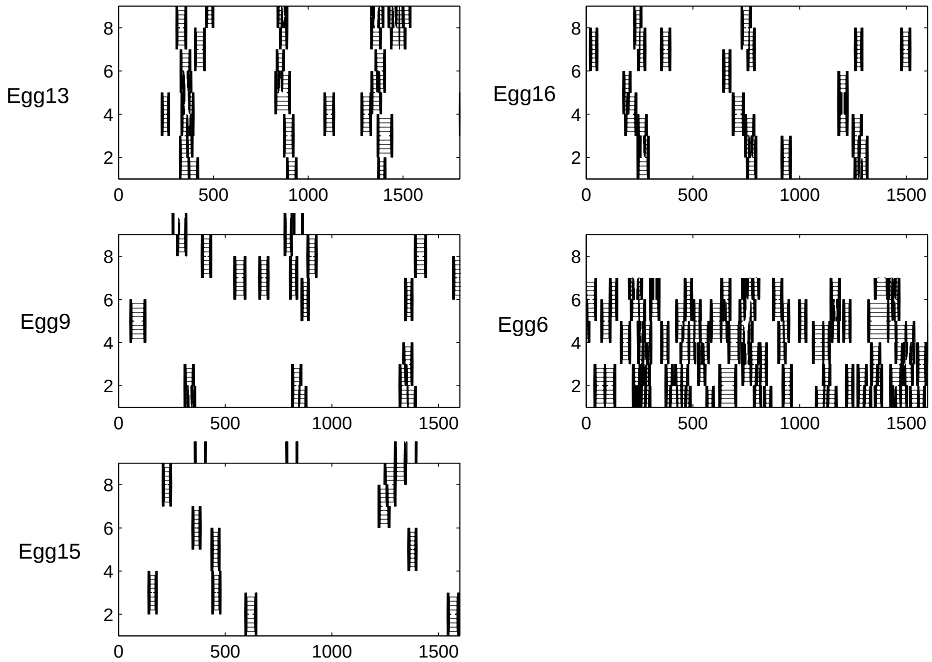

Figure 7.3: Each of these plots is a color coding of the laser data, as a function of position on the circumference (horizontal direction), and slice (vertical direction). The dark areas indicate where there was increased intensity variation.

7.3 Suggested approaches

We discussed a number of alternative investigations to pursue should the present plan prove unfruitful. We've restricted our discussion primarily to approaches which are minor variations on the original proposal.

7.3.1 Beam width

The data collected by VisionSmart used a 100 micron beam width. Since one is measuring intensity of the light penetrating the egg, an ideal situation would be to have the diameter of the laser beam smaller than that of a crack. This way, when the crack rolls past the laser, there would be a point when all the light from the beam would penetrate the shell; one could expect from this a significant increase in the intensity. Moreover, when the crack rolls past a narrower laser beam, the intensity would drop very quickly, much more quickly than when the beam passes through a cage mark, which is wider than a crack. In conversation with Dr. Lyder, it was mentioned that the average width of a crack is about 10 microns. So a beam size of 10 microns (smaller if possible) may help distinguish cracks from cage marks.

7.3.2 Registration

A minority opinion held by some members of our group is that the problem of *registration*, converting the one dimensional data to two dimensional information by aligning the slices of data, is very challenging. As discussed in Section 7.2, the slice diameter varies from the previous by about 3% due to egg wobble and cross-sectional variation in egg diameter. Note also that although we speak of *slices* as though the egg were sliced uniformly, the actual trajectory of the laser along the egg wobbles since the egg wobbles. The reader might think of wrapping a thread around an egg; although one might hope to keep the spacing even, sometimes the threads will overlap and sometimes there will be wide gaps.

If features are reasonably clear, this problem of determining where the laser beam is on the egg may not be insurmountable. However, features are typically unclear. On an egg such as starry night, the features are quite blurry, making registration virtually impossible.

We propose two possible approaches to deal with the problem of registration:

[1] Avoid the problem of registration altogether by diagnosing cracks in one-dimensional data. With a 10 micron beam, this may work well enough. A *possible* crack found within the same region of several consecutive slices may be sufficient to determine that it is a *probable* crack without precise registration.

[2] Hold the egg steady while moving the laser beam. The position of the beam can be more precisely measured than the rotational position of the egg, making registration much easier.

7.3.3 Hairline cracks

Some hairline cracks are not visible by the untrained naked eye. This suggests that a direct image processing approach may be inadequate for observing these cracks. It may be necessary to apply some pressure to the egg to temporarily widen the cracks. To minimize risk to the equipment and to the egg, we propose that pressure be applied either through bursts of air (avoiding touching the eggs altogether) or with soft spring cushioned walls (the cushioning avoids the need for precise calibration of the motors which move the walls).

If applying pressure to the egg is feasible, then an image-differencing approach (taking an image of the egg before and after pressure is applied) should prove more fruitful than the laser-beam approach.

7.3.4 Vary beam wavelength

If we restrict ourselves to laser beam approaches, there has still been little investigation done concerning which wavelengths are best. We recommend trying several different wavelengths to determine if some wavelengths penetrate better than others.

7.3.5 Imaging techniques

Given the recent improvements in digital imaging and processing power, imaging techniques which were much too slow and cumbersome a decade ago may in fact be fruitful. Digital cameras with high resolution ($1248 \times 1024 \times 12$ bits) are currently able to output images at upwards of 30 frames per second. Actual algorithms for detecting cracks might range from thresholding to fractal or wavelet analysis.

7.4 Literature Review

A literature search, using the on-line databases available at the University of Calgary and the University of Saskatchewan, was performed in order to determine whether any of the questions which arose during our discussions had previously been addressed. Some papers were found which partially address some of the alternate approaches we have suggested; a brief review of these papers is given here.

One alternate approach to the laser experiment is to use an approach which attempts to more closely simulate the backlighting and human eye image analysis of existing egg candling systems. Two papers [1],[2] discuss image analysis of eggs based on approaches of this kind.

In the first paper, the objective of the study was to develop a global analysis procedure in the frequency domain for the detection of cracked egg shells. Direct images of backlit eggs were taken and the images were analyzed using two-dimensional Fourier transform analysis. A global analysis procedure was developed and using various inspection models they obtained an 88% success ratio.

They observed that while 88% is not good enough to replace a commercial egg candling system where manual candling can classify up to 98% of cracked eggs, their global analysis procedure showed better performance than the crack detection algorithm [3] which uses edge detection and contour finding methods. They also suggest that a frequency domain analysis coupled with a neural network may lead to an inspection system which would do better than their current frequency domain analysis approach.

In the second paper, the objective of the study was to develop an automated procedure for detecting egg freshness. An egg was backlit using a cold white light source. The yolk and air-sack of the egg then cast shadows on the opposite wall of the egg and a CCD camera was used to take a photograph of the illumination profile on this wall. The image obtained was pre-processed and then the data was passed to neural networks. They used both multilayer perceptron and modular multilayer perceptron neural network approaches. The work reported here is somewhat preliminary as they only tested 120 eggs, however, they report a 100% classification rate. The features relevant for detecting egg freshness are much less complex than those needed for detecting egg cracks so it is unclear whether the results of this work will be helpful for the egg crack problem.

Cork planks, used for making cork stoppers for example, exhibit a variety of features such as holes, cracks, and insects which have some similarity to the type of features found in egg shells. Several papers [4],[5] indicate that success has been obtained for classifying cork quality using image analysis techniques combined with a neural network approach.

Another alternate approach to the problem is to try to better understand whether the current industry standards are economically justified based on product and market research. Some of the issues relevant to this were discussed by A. Oosterwoud [6] in 1987. With regard to product research, he concludes that the most important factor controlling the proportion of cracked eggs was the type of cage in which the hens were kept. He also discusses consumer attitudes towards eggs. He notes that "It has been standard procedure in marketing technology to establish quality characteristics without asking consumers for their opinions." Although he seems mainly to be talking about internal qualities of the egg, one would suspect that the same is true for external qualities as well. He concludes that more research is needed with regard to consumer attitudes towards eggs.

7.5 References

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