

# Detection of hatching and table egg defects using hyperspectral imaging

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A hyperspectral imaging system was developed to detect problem hatching eggs (non-fertile or dead embryos) prior to or during early incubation and to detect table eggs with blood spots and cracked shells. All eggs were imaged using a hyperspectral camera system (wavelengths detected from 400-900nm) and a tungsten-halogen backlight. Hatching and table eggs with and without defects were imaged then broken out for confirmation of defects. Overall, the hyperspectral imaging system appears capable of detecting developing hatching eggs by Day 3 of incubation at a 91% rate for white shell eggs, and an 83% rate for brown shell eggs. Blood spots in table eggs can readily be detected with at least a 90% accuracy rate. Cracked shells are difficult for the hyperspectral system to detect under typical conditions. Hyperspectral imaging is capable of detecting hatching egg development during early incubation and blood spots in table eggs, but does not readily detect cracked shells.

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## Introduction

Technologies have been developed as non-destructive methods for determining egg quality. Machine vision and other techniques have been developed and tested to address a range of egg problems as reviewed by De Ketelaere, *et al.* (2004). Systems developed include blood spot and bloody white detection in intact eggs by various methods where the spectrum of light transmitted through the egg was analyzed. (Brant *et al.*, 1953; Gielen *et al.*, 1979; Patel *et al.*, 1996; Schouenberg, 2003). Spectral analysis of transmitted light has also been used with various detection devices to attempt to determine fertility or early development in hatching eggs (Das and Evans, 1992a; Das and Evans, 1992b; Bamelis *et al.*, 2002; Liu *et al.*, 2004). Bamelis *et al.* (2002) also employed an acoustic resonance analysis method for embryo detection. Other systems have been developed to detect infertile, dead, or contaminated hatching eggs during transfer at 18 days to minimize cross-contamination during vaccination (Chalker, 2003). Three current areas of research in our laboratory that incorporates hyperspectral imaging for the study of egg quality include: 1) determination of fertility and early embryo development of hatching eggs; 2) detecting blood spots inside table eggs; and, 3) detecting shell cracks.

Poultry hatcheries continue to set and hatch large numbers of eggs while attempting to lower costs of equipment and labor. However, a percentage of eggs set will not hatch, and during incubation several of these eggs may contaminate the hatching cabinet with bacteria or molds. Infertile egg rates range from 1% to 18% depending on a number of factors such as bird type or flock age, which results in commercial hatcheries incubating approximately one billion eggs per year that are infertile. Hatcheries tend to load incubators to maximum capacity to increase utility efficiency, which may drop hatchability by 0.5% to 2% due to decreased ventilation and higher temperatures in the racks (French, 1997). Thermometer readings in the incubator also have been observed to read lower than actual temperatures,

which easily leads to overheating in the racks (Mauldin and Buhr, 1995). Currently, about 5% of eggs are candled after 10 days of incubation and “clear” eggs from this group are removed and counted to determine flock fertility. All of the infertile eggs included in the 95% of eggs not candled at that time remain in the incubator for the duration. These remaining infertile eggs are likely to harbor and grow pathogenic bacteria or molds, contributing to cross-contamination when these eggs build up pressure during decomposition and “explode” in the incubator.

More than 90 billion table eggs are produced each year in the U.S.A.; although blood spots appear in less than 1%, many millions of eggs contain blood spots. Manual or computer-assisted candling machines are used to remove these eggs prior to packaging and distribution to the consumer. Blood spots may be due to a variety of factors (genetics, caging, range feeding, and seasonality) as reviewed by Lerner and Taylor (1947), and also may be caused by stress (Campo and Gill, 1998). Brant *et al.* (1953) used a spectrophotometer to determine that a 575 nm wavelength was crucial to detecting blood inside intact table eggs. A simple vision system was paired with a neural network to detect blood spots in eggs (Patel *et al.*, 1996) although results did not exceed 91% accuracy. Detection accuracy was improved somewhat with a color vision system and additional neural network training (Patel *et al.*, 1998).

External egg defects may include stained, cracked or checked shells. Vision imaging has been used to detect dirt on stains on brown shell eggs (Mertens *et al.*, 2005). Cracked egg shells may pose more of a threat due to a possible increase in human *Salmonella* outbreaks from egg contents contaminated with pathogens that enter through cracks in the shell (Todd, 1996). Crack detection using imaging has been conducted by a number of researchers using slightly different methods; however, the accuracy of detection ranged from 88% to 96% (Elster and Goodrum, 1991; Goodrum and Elster, 1992; Han and Feng, 1994; Worley and Goodrum, 1995; and Patel *et al.*, 1998). Because of the difficulty of detecting cracks with vision imaging, especially small cracks and checks, acoustical testing is usually employed (Cho *et al.*, 2000; De Ketelaere *et al.*, 2000) and has been incorporated into most commercial egg processing systems.

Because of the large number of hatching and table eggs produced each year, and their potential impact on food safety, it is important to develop an accurate and fast system for detecting egg defects. Therefore the purpose of these experiments was to determine the feasibility of a hyperspectral imaging system to detect infertile or non-developing hatching eggs, blood spots in table eggs, and cracked egg shells.

## **Materials and Methods**

### **Imaging System Components.**

The imaging system consisted of a 12 bit digital camera with silicon CCD detector connected to a spectrograph and lens assembly. The camera was attached to a computer with software capable of capturing a hypercube image. Each pixel in the image contained spectra from approximately 400 to 900 nm. Eggs presented to the system were placed on a flat surface with a 29 mm diameter cutout; a tungsten-halogen (150 watt) light mounted below the surface provided a candling effect.

### **Hatching Egg Fertility and Development.**

The following experiment was reported by Smith *et al.* (2005): A commercial hatchery provided layer-type white shell eggs from Single-Comb White Leghorns (SCWL) for each of two trials utilizing 48 eggs each. Eggs were incubated at 37.5 C (99.5 F), 85% relative humidity, with hourly automatic turning. On Day 0 and at Days 1, 2, and 3 of incubation, 12 eggs were removed from the incubator, imaged, and broken out for visual confirmation of fertility or development. Images were taken with the egg lying horizontal to the camera. Twelve brown shell broiler-type eggs were obtained locally from broiler layers and incubated at settings as described above. On Day 0 twelve eggs were imaged, then the same 12 eggs were incubated for 1, 2, and 3 days; imaging was conducted on the same 12 eggs each subsequent day.

On Day 6 the eggs were visually assessed for embryo development. Images were taken with the egg standing vertical to the camera, with the air cell up.

SCWL white shell eggs were exposed for 30 ms and a ratio of transmission images at two wavelengths, 576 and 655 nm was used for analysis. The ratio was used to differentiate pixels from the entire image as positive or negative fertility or embryo development, using an algorithm to mask the negative pixels in the image interior and non-essential background exterior pixels. The same process was used for broiler chicken brown shell eggs, except they were exposed for 250 ms and wavelengths used were 576 nm, then a range of wavelengths (682 $\pm$ 13nm, varying across eggs). Using a range was necessary as the brown shell pigments resulted both in decreased light transmission and increased the amount of variability between individual eggs. The lower wavelength (576 nm) was chosen as it provided the maximum spectral difference between infertile and fertile eggs in layer-type eggs. The upper wavelength was chosen (655 nm for layer eggs, 682 nm plus or minus 13nm for broiler eggs) as it represented the maximum light transmission through the egg (peak signal to the detector).

#### **Blood Spot Detection.**

In a preliminary series of experiments, a total of 240 white-shell table eggs were obtained from a commercial processor. Eggs were imaged on their sides (horizontal to the camera) for an exposure time of 50 ms. A ratio of transmission images at two wavelengths, 577 and 565, were used to determine if pixels from the image were positive for blood. An algorithm was used to mask negative and other non-essential pixels.

#### **Cracked Shell Detection.**

A total of 30 eggs were obtained from a commercial egg processor in a preliminary experiment. These eggs contained cracked or checked shells as determined by the egg grader at the location. Eggs were imaged on their sides. A variety of exposure times were used to optimize the difference between normal shell spectra and crack spectra. For the same reason a variety of spectral and spatial analyses were used.

## **Results and Discussion**

### **Hatching Egg Fertility and Development.**

The hatching egg study originally reported by Smith *et al.* (2005) produced the following results (summarized in *Table 1*). The hyperspectral imaging system detected fertile and developing embryos from layer type white shell eggs at the following rate: on Days 0 and 1 only 1 of the 46 eggs confirmed as positive by breakout was detected; on Day 2 60% of the 20 eggs were detected; on Day 3 91% of eggs were detected (21 of 23). The hyperspectral imaging system inaccurately detected one of the 7 infertile eggs as fertile on Day 2. For broiler-type brown shell eggs, the hyperspectral imaging system detected 13 of 24 eggs as developing, and 14 of 24 on Day 2. On Day 3, 20 of 24 eggs (83%), were detected as developing. All 24 of the brown shell eggs were fertile, so false positive rates were not determined.

**Table 1. White shell layer-type eggs confirmed by breakout, number detected and accuracy of imaging system on Days 0-3 of incubation, and brown shell broiler-type eggs (summarized from Smith et al, 2005).**

<b>Egg type</b>	<b>Incubation Day</b>	<b># Eggs</b>	<b># Confirmed</b>	<b># Detected</b>	<b>% Detection</b>
Layer, white shell	0	24	23	1	4
	1	24	23	0	0
	2	24	20	12	60
	3	24	23	21	91
Broiler, brown shell	1	24	24	13	54
	2	24	24	14	58
	3	24	24	20	83

The 576 nm wavelength that was found to be an important indicator of development in this study was probably due to the close relationship between this wavelength and the 576±1 nm wavelength previous researchers have reported when eggs contain visible blood (Brant *et al.*, 1953; Das and Evans, 1992a). The configuration of the hyperspectral system is probably detecting the early formation of red blood cells, capillaries, and the blood ring structure associated with early embryo development. The difficulty in identifying a specific upper wavelength, and using a band instead for brown shell eggs was likely due to low light transmission through the egg. Previous researchers have reported a decrease in light transmission through brown shell eggs (Liu *et al.*, 2004; Shafey *et al.*, 2004). The use of multiple wavelength bands was also utilized by Liu *et al.* (2004), where 20-nm wide bandwidths were used with average transmittance calculated for the bandwidth. The wavelength range (668 to 695 nm) was used because each egg varied in transmittance, probably due to shell pigmentation variation. Hyperspectral imaging systems are capable of detecting embryo development during early incubation, but further research, including lighting, presentation, and data analysis will be required to improve accuracy.

#### **Blood Spot Detection.**

Blood spots in white shell table eggs were consistently detected at a greater than 90% accuracy rate. As noted above, one of the wavelengths used (577) was similar to previously reported research where visible blood (probably hemoglobin) was detected (Brant *et al.*, 1953; Das and Evans, 1992a). Further analysis and algorithm development should improve blood spot detection rates for the hyperspectral system.

#### **Cracked Shell Detection.**

The hyperspectral imaging system was generally not able to consistently detect cracked or checked eggs. Varying the exposure times and employing various spectral and spatial analyses for the data did not improve the system's detection accuracy. Further research using the current configuration is not planned. However, in preliminary trials a different vision system combined with a physical modification has shown to be capable of high percentage accuracy for both cracks and checks.

## **References**

- BAMELIS, F. R., TONA, K., DE BAERDEMAEKER, J. G. and DECUYPERE, E. M.** (2002) Detection of early embryonic development in chicken eggs using visible light transmission. *British Poultry Science* **43**:204-212.
- BRANT, A. W., NORRIS, K. H. and CHIN, G.** (1953) A spectrophotometric method for detecting blood in white-shell eggs. *Poultry Science* **32**:357-363.
- CAMPO, J. L. and GIL, M. G.** (1998) Internal inclusions in brown eggs: relationships with fearfulness and stress. *Poultry Science* **77**:1743-1747.
- CHALKER, II, B. A.** (2003) Methods and apparatus for non-invasively identifying conditions of eggs via multi-wavelength spectral comparison. *US Patent 6,535,277*, issued March 18, 2003.
- CHO, H.-K., CHOI, W.-K. and PACK, J.-H.** (2000) Detection of surface cracks in shell eggs by acoustic impulse method. *Transactions American Society of Agricultural Engineers* **43**:1921-1926.
- DAS, K. and EVANS, M. D.** (1992a) Detecting fertility of hatching eggs using machine vision: I. histogram characterization method. *Transactions American Society Agricultural Engineering* **35**:1335-1341.
- DAS, K. and EVANS, M. D.** (1992b) Detecting fertility of hatching eggs using machine vision: II. Neural network classifiers. *Transactions American Society Agricultural Engineering* **35**:2035-2041.
- DE KETELAERE, B., BAMELIS, F., KEMPS, B., DECUYPERE, E. and DE BAERDEMAEKER, J.** (2004) Non-destructive measurements of the egg quality. *World's Poultry Science* **60**:289-302.
- DE KETELAERE, B., COUCKE, P. and DE BAERDEMAEKER, J.** (2000) Eggshell crack detection based on acoustic resonance frequency analysis. *Journal of Agricultural and Engineering Research* **76**:157-163.

- ELSTER, R. T. and GOODRUM, J. W.** (1991) Detection of cracks in eggs using machine vision. *Transactions American Society Agricultural Engineering* **34**:307-312.
- FRENCH, N. A.** (1997) Modeling incubator temperature: the effects of incubator design, embryonic development, and egg size. *Poultry Science* **76**:124-133.
- GIELEN, R. M. A. M., DEJONG, L. P. and KERKVLJET, H. M. M.** (1979) Electrooptical blood-spot detection in intact eggs. *Transactions Instrumentation and Measurement* **IM-28**:177-183.
- GOODRUM, J. W. and ELSTER, R. T.** (1992) Machine vision for crack detection in rotating eggs. *Transactions American Society Agricultural Engineering* **35**:1323-1328.
- HAN, Y. J. and FENG, Y.** (1994) Egg shell inspection using global image analysis. *Applied Engineering in Agriculture* **10**:109-114
- LERNER, I. M. and TAYLOR, L. W.** (1947) Seasonal and daily fluctuations in the incidence of blood spots. *Poultry Science* **26**:662-667.
- LIU, Y., OUYNAG, A., ZHONG, C. and TING, Y.** (2004) Ultraviolet and visible transmittance techniques for detection of quality in poultry eggs. *Proceedings SPIE* **5587**:47-52.
- MAULDIN, J. M. and BUHR, R. J.** (1995) What is really happening in your incubator? *International Hatchery Practice* **9**:19-22.
- MERTENS, K., DE KETELAERE, B., KAMERS, B., BAMELIS, F. R., KEMPS, B. J., VERHOELST, E. M., DE BAERDEMAEKER, J. G. and DECUYPERE, E. M.** (2005) Dirt detection on brown eggs by means of color computer vision. *Poultry Science* **84**:1653-1659.
- PATEL, V. C., MCCLENDON, R. W. and GOODRUM, J. W.** (1996) Detection of blood spots and dirt stains in eggs using computer vision and neural networks. *Applied Engineering Agriculture* **12**:253-258.
- PATEL, V. C., MCCLENDON, R. W. and GOODRUM, J. W.** (1998) Color computer vision and artificial neural networks for the detection of defects in poultry eggs. *Artificial Intelligence Review* **12**:163-176.
- SCHOUENBERG, K. O. P.** (2003) Method and device for detecting undesired matter in eggs. *US Patent 6,504,603*, issued January 7, 2003.
- SHAFEY, T. M., GHANNAM, M. M., AL-BATSHAN, H. A. and AL-AYED, M. S.** (2004) Effect of pigment intensity and region of eggshell on the spectral transmission of light that passes the eggshell of chickens. *International Journal Poultry Science* **3**:228-233.
- SMITH, D. P., MAULDIN, J. M., LAWRENCE, K. C., PARK, B. and HEITSCHMIDT, G. W.** (2005) Detection of fertility and early development of hatching eggs with hyperspectral imaging. *Proceedings 11<sup>th</sup> European Symposium on the Quality of Eggs and Egg Products*, Doorwerth, The Netherlands, May 23-26, 2005, Pages 176-182.
- WORLEY, J. W. and GOODRUM, J. W.** (1995) Strobe versus incandescent lighting for egg crack detection using machine vision. *Applied Engineering in Agriculture* **11**:549-554.