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Real-time analysis of chicken embryo sounds to monitor different incubation stages

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ABSTRACT

The objective of this paper is to develop an algorithm that could be used in order to reduce the spread of chicken hatching in industrial incubators for chicken eggs. The approach that is used is based on frequency analysis of sounds recorded inside the industrial incubator and aims at identifying the time at which all the eggs inside the incubator have reached the internal pipping stage. The developed algorithm is able to be calibrated automatically in order to adjust for sounds around the incubator and the acoustics of every incubator. The algorithm has been implemented in a Digital Signal Processor and applied in real-time in an industrial environment. It is shown that the algorithm can correctly identify the time at which 93–98% of the eggs have had been in the internal pipping stage. This level of accuracy is considered adequate for a practical application focusing on reduction of the hatching window.

1. Introduction

In industrial incubators, the hatching times of chicken eggs can vary considerably (Tona, 2003). This causes considerable economical loss by operating the incubator for a longer period of time than in an ideal case where all chickens would have hatched at the same time (Decuypere et al., 2001). Also, this spread in hatching affects the time for first access to food and water in the newborn chickens and therefore their further growth (i.e. chickens that have later access to water and feed will not start to grow as fast as those that have immediate access (Noy and Sklan, 1999)). Considering further that commercial chicken farms have a fixed growth cycle that varies from 39 to 42 days depending on the growing house and the required final weight, it is evident that a delay in first access to water and food will have a huge economic impact on the chicken farm (Noy and Sklan, 1999).

To overcome this problem, considerable research has been conducted with the goal of reducing the hatching window (i.e. the time between the first and last hatched chicken). Various approaches have studied the effect of temperature variations in an incubator (Van Brecht et al., 2003), CO_2 concentration (De Smit et al., 2006) and different temperature profiles during the incubation and hatching periods (Mortola, 2006). However, the above approaches are mostly based on experience, and do not account for different flock ages, storage times or egg sizes that all affect the incubation time.

As an addition to conventional methods, Precision Livestock Farming (Berckmans and Guarino, 2008; Wathes et al., 2008) has shown potential in monitoring and control of various processes ranging from bees (Ferrari et al., 2008) to poultry (Gates and Xin, 2008), pigs (Exadaktylos et al., 2008a) and cows (Cangar et al., 2008; Jahns, 2008). In relation to monitoring of the incubation process, research has been conducted in relation to thermoregulation (Tzschentke, 2008), egg shell cracking (Deng et al., 2010), egg weight (Mertens et al., 2008) and the conductance of egg shells (Bamelis et al., 2008). Finally, in line with earlier research on chicken acoustics, Bamelis et al. (2005) have studied the sound response of chicken during hatching and have indications on the biorhythm of hatchlings and the time to stop the incubation process. On a larger scale, egg sound production has been studied and initial results have been presented in Silva et al. (2010).

The purpose of this paper is to study the individual chicken sounds as can be recorded during three stages of the incubation process; namely (1) the internal pipping (IP) stage that occurs at day 19 of the incubation process and can be defined as the stage when the chicken embryo has penetrated the air cell and converted from vascular to lung respiration; (2) the external pipping (EP) stage that occurs 12–24 h after IP and is when the chicken has broken the eggshell and is trying to come out of the egg; and (3) the hatched stage (HT) that occurs 8–12 h after EP and is the stage in which the chicken has come out of the egg. This information is subsequently used to develop an algorithm for automatic identification of the stage at which all eggs in an incubator (i.e. 100% of the eggs) have reached the internal pipping stage (IP100).

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Being an important milestone in the development of the chicken embryo, IP is a point where changes in the incubation environment can quickly affect the embryo development. Therefore, identification of the IP100 point can be used as a trigger for action with the aim for the hatching window to be reduced. This last claim is based on evidence that different temperature, CO_2 and ventilation profiles during hatching can provide a smaller hatching window (e.g. De Smit et al., 2006) but has not been implemented in this study. However, application of such a technique can have the opposite effect if it is applied to eggs that have not reached the IP stage yet, making the identification of this point crucial in the potential success of any action.

Finally, the algorithm has been converted to its online equivalent and has been applied in real-time to the incubation process using a Digital Signal Processor (DSP). The main difference in studying the individual sounds at different incubation stages and creating an automatic algorithm for application in a commercial incubator environment lies in the environment itself. The recording that can be acquired inside an incubator does not consist of individual sounds, but of sounds produced by all the eggs in the incubator. Furthermore, the fan noise needs to be considered along with environmental sounds coming from outside the incubator. The developed algorithm accounts for the above issues by identifying the frequency ranges that the relevant information is present.

2. Materials and methods

2.1. Experimental data

Three different sets of experiments were conducted during this work. The first consists of acquiring individual embryo and chicken sounds (as described below) and was used in identifying the sound characteristics that were later used in order to develop an automatic algorithm for detection of internal pipping. The second has resulted in continuous recordings inside industrial incubators while the third one involves the real-time testing of the algorithm that has been developed.

In the first set of experiments, 10 eggs from an unknown parental flock, already incubated for 15 days in a commercial hatchery, were placed in a custom made incubator (internal dimensions in cm $80 \times 60 \times 40$ – length $\times$ width $\times$ height, constructed by the company Petersime nv. that is a producer of industrial incubators) at 37.6 °C and 55% relative humidity. From incubation day 17 until incubation day 21, and at distinct times of the day (10:00, 12:00 and 17:00) every egg was taken out of the incubator and placed in an isolated box. Inside the box a microphone was placed through a hole on the top of the box and could record sounds inside it. Every time an egg was placed in the box, sound was recorded for 5 min. The isolated box had dimensions $16.5 \times 16.5 \times 21.5$ cm (length $\times$ width $\times$ height), its walls were 3.5 cm thick and the microphone tip was placed about 5 cm from the egg. Sound was registered using an electret microphone (Monacor ECM 3005) which is a very common type of microphone that does not need polarising and can therefore work without external power. The microphone had a frequency response of 50–16,000 Hz with a sensitivity of 6 mV/Pa/1 kHz and was connected without a pre-amplifier to a PC with a commercial sound card (Mixtreme 192, supporting sampling rates up to 192 kHz) and the software Cool Edit Pro at a sample rate of 22.05 kHz and 16 bit resolution. Once the chickens hatched, 5 were randomly selected and placed one by one in the same isolated box (without the cover in order to avoid suffocation of the chickens) and sound was recorded for 5 min/chicken. The 5 min sound segments of all the experiments were subsequently analyzed by listening to the recording and the individual chirping sounds were “manually” extracted. The observer was the same for the extraction of all sounds, listened to the continuous recording and using the software Cool Edit Pro, isolated the individual sounds and saved them in individual files for further processing. The continuous recording consisted only of the sounds of interest since the experiment was conducted in an otherwise silent room. The combination of listening and visual observation of the signal with the software Cool Edit Pro allowed for all the sounds in the recording to be identified. In case of the egg sound recordings, if an egg had no cracks during the recording period the sounds that were acquired were labeled as IP (internally pipped eggs) while when an egg was cracked the sounds that were recorded were labeled as EP (externally pipped eggs). The individual sounds of the day-old chickens were labeled as HT (hatched chicken sounds). In total, 979 IP, 1292 EP and 2158 HT sounds were recorded.

The second series of experiments consisted of sound recordings in a commercial hatchery environment. The Petersime AirStreamer™ 4H hatcher was used with a capacity of 19,200 chicken eggs in 4 trolleys with 32 baskets per trolley arranged in two stacks. The temperature and humidity profiles were set for the purposes of different experiments and varied in the different recordings. An electret microphone (Monacor ECM 3005) was placed against the ceiling at the middle of the left side of the hatcher and was connected through a hole in the roof of the hatcher (the gaps between the microphone and the holes were sealed using silicone gel) to a PC and could measure sound inside the hatcher. The sound was recorded using the RecordPad sound recording software at a sampling frequency of 22.05 kHz and 16 bit resolution. The start of the sound signal recording was between incubation day 17 and 18 until the chickens had hatched. After 19 days and 10 h from the beginning of the incubation period, the hatcher was opened (for 2 min to take the baskets out of the hatcher and 2 min to put them back in) at 4–8 h intervals and the eggs of two baskets were manually checked for internal pipping (IP), external pipping (EP) and hatch (HT) by candling (which is the procedure during which a bright light source is used behind the egg to show details of the embryo position through the shell) and visual identification of the broken eggs and hatched chickens. The two baskets that were checked were positioned at the front of the left side of the incubator at 1.8 m from the ground (13th basket from the bottom). This way, the time point at which all of the eggs in the baskets had been in IP stage (i.e. eggs in IP + eggs in EP + hatched chickens) could be identified. This resulted in 12 recordings of about 85 h each.

The third series of experiments consisted of online application of the developed algorithm using a Digital Signal Processor (DSP). The Simulink® environment with the Real-Time Workshop® was used to program the DSP that was the “TMS320C6416T DSK” and is manufactured by Texas Instruments Incorporated and has a 1 GHz processor. The board was connected to a PC using the USB port, initialized using Code Composer Studio v.3 and the output data were read out using a program made in LabVIEW™. Using the same kind of hatchers and measuring equipment as for the second series of experiments, the sound signal was not recorded but rather fed to the DSP that produced the output of the algorithm.

A summary of the collected data is given in Table 1.

2.2. Data analysis

2.2.1. Individual sound characteristics

The individual IP, EP and HT sounds that were acquired during the first series of experiments were analyzed to study the differences between the different sounds. The signal was initially filtered using a 10th order Butterworth filter with a band-pass of 2000–4000 Hz. Experimentation and visual observation of the unfiltered spectra suggested that no relevant information was present outside the 2000–4000 Hz region. This is further supported by the results presented later. Subsequently, the N-point Discrete