Sound analysis to model weight of broiler chickens

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ABSTRACT The pattern of body weight gain during the commercial growing of broiler chickens is important to understand growth and feed conversion ratio of each flock.

The application of sound analysis techniques has been widely studied to measure and analyze the amplitude and frequency of animal sounds. Previous studies have shown a significant correlation ($P \leq 0.001$) between the frequency of vocalization and the age and weight of broilers. Therefore, the aim of this study was to identify and validate a model that describes the growth rate of broiler chickens based on the peak frequency of their vocalizations and to explore the possibility to develop a tool capable of automatically detecting the growth of the chickens based on the frequency of their vocalizations during the production cycle. It is part of an overall goal to develop a Precision Livestock Farming tool that assists farmers in monitoring the growth of broiler chickens during the production cycle. In the present study, sounds and body weight were continuously recorded in an intensive broiler farm during 5 production cycles. For each cycle the peak frequencies of the chicken vocalizations were used to estimate the weight and then they were compared with the observed weight of the birds automatically measured using on farm automated weighing devices. No significant difference is shown between expected and observed weights along the entire production cycles; this trend was confirmed by the correlation coefficient between expected and observed weights (r = 96%, P value ≤ 0.001).

The identified model used to predict the weight as a function of the peak frequency confirmed that bird weight might be predicted by the frequency analysis of the sounds emitted at farm level. Even if the precision of the weighing method based on sounds investigated in this study has to be improved, it gives a reasonable indication regarding the growth of broilers opening a new scenario in monitoring systems in broiler houses.

Key words: broiler, vocalization, weight, sound analysis, Precision Livestock Farming

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INTRODUCTION

Intensive broiler farming is based on hybrid genotypes reared in tightly controlled environments under high stocking density with limited space for physical activity (Rauw et al., 1998; Kashiha et al., 2013; Rizzi et al., 2013). Genetic progress in broiler breeding has led to the selection of heavier animals with faster growth rate than before (Rauw et al., 1998; Aerts et al., 2003; Rizzi et al., 2013; Tallentire et al., 2016). Indeed, Havenstein et al., 2003a, 2003b) estimated that genetics contributed 85 to 90% to the 6-fold increase in broiler carcass yield during the last 50 years, and in this scenario, the genetic potential for growth can be compromised by poor environmental quality, poor management, and excessive density, resulting in welfare issues with economic relevance for industry (Marchewka et al., 2013).

Monitoring key production indicators such as body weight, growth rate and feed conversion rate is fundamental in poultry farming to improve the efficiency and profitability of the processing plant and to obtain good performance from current genotypes (Aerts et al., 2003; Chedad et al., 2003; Cangar et al., 2006; Mollah et al., 2010; Rizzi et al., 2013; Fontana et al., 2015a).

The average weight of the flock is generally evaluated either manually or automatically using samples of birds chosen at random within a poultry house. The manual measurement of the weight of a representative number of animals in a building is time and labor intensive,

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since buildings may hold up to 50,000 birds. Today, many farms use "step-on scales" placed on the floor of the poultry house to automatically collect the average weight of the birds in the flock.

Even if the weighing system gives an accurate weight value each time a bird steps onto it, the reliability of this proved method might be limited due to some factors. For instance, the reluctance of heavy birds to visit the weighing scale (which requires the bird to climb up onto the scale) at the end of the production period (Chedad et al., 2003) and the walking ability of fast-growing broilers that decreases with age, reducing their mobility and willingness to move (Nääs et al., 2009). Moreover, sick, lame and very heavy birds reduce their locomotor activity, and extend the time spent in resting and lying behavior (Tullo et al., 2017). Therefore, while current automatic weighers reduce time wasted by the farmer, they may fail to continuously follow the growth trend of the whole flock, while simultaneously not estimating the weight of sick, lame and very heavy birds that are reluctant to move and to jump onto the automated scale.

One of the principal objectives of Precision Livestock Farming (**PLF**) is to develop automated on-line monitoring tools (Guarino et al., 2008; Tullo et al., 2013) to control animals' behaviors and their biological responses in an accurate way (Tefera, 2012; Fontana et al., 2016). The application of sound analysis techniques has been widely studied (Montevecchi et al., 1973; Marx et al., 2001; Feltenstein et al., 2002) to measure and analyze the amplitude and frequency of animals sounds (Moura et al., 2008). It is perceived that automated animal monitoring with images or sounds can potentially be used to support farmers in animal husbandry (Halachmi et al., 2002; Ismayilova et al., 2013; Rizwan et al., 2016); indeed, audio and image processing were applied to several animal species (Bardeli et al., 2010; Curtin et al., 2014; Bowling et al., 2017).

Therefore, the aim of this study was to identify and validate a model that describes the relation between the peak frequencies (**PF**) of broiler vocalization and bird weight, and to explore the possibility to develop a tool capable of automatically detecting the growth of the chickens based on the frequency of their vocalizations during the production cycle.

MATERIALS AND METHODS

The study was conducted in 2 commercial farms, rearing broiler chickens according to the EU regulation 2007/43/CE. Sound recordings were made during 8 production cycles, 2 in the UK (Round 1 and 2), following the RTFA-ACP standard, and 6 in The Netherlands (Round 3 to 8), with an automated, non-invasive and non-intrusive method in both farms. About 27,500 one-day-old chicks were placed in both houses in all the considered rounds according to the EU regulation 2007/43/CE regarding animal density in poultry meat production.

Data collection and sound analysis of Round 1 to 3 were previously described in the study of Fontana et al. (2015b).

Sound recordings of Rounds 4 to 8 were made in an intensive broiler farm located in The Netherlands; the house dimensions were 65 m × 19 m and the total floor area available to the birds was 1,235 m^2.

Sounds were automatically collected with the commercially available PLF sound monitoring system, previously developed for pig cough detection (SOMO, SoundTalks NV, Leuven, Belgium).

This commercial system consists of condenser microphones shielded from the harsh environment (C-4 Matched Studio Condenser Microphones, Behringer GmbH Maschinenfabrik und Eisengießerei, Kirchardt, Germany) and a sound card (Maya 44, ESI Audiotechnik GmbH, Leonberg, Germany). The microphones were phantom-powered with limited susceptibility to non-directed noise, and were able to capture the sound from near-field sources, i.e., the animals directly beneath the recording microphone. The recordings were performed at 16-bit integer precision and with sampling frequency of 22.05 kHz (standard WAV file format). The sound card was placed in an embedded board (×64 architecture), running a GNU/Linux operating system. The system was remotely monitored through an internet wireless connection. The microphone was suspended from the roof of the broiler house at a height of 1 m from the ground level. The recordings were continuous (24/7), with the audio data grouped into recordings of 5 min duration. All raw recordings were stored online on external hard drives for subsequent postprocessing (Hemeryck et al., 2015). Data collection lasted for 42 d each production cycle, resulting in about 30,000 five-minutes audio files used for the automated frequency analysis.

Meanwhile, the weight of broiler chickens was automatically collected with 2 commercial "step-on scales" placed on the floor of the broiler house in fixed positions. Animal weights were then stored online every 15 min. Furthermore, scales were calibrated at the beginning of each production cycle in order to avoid any bias in the study.

Sound analysis was automatically performed using MATLAB 2014b (MathWorks, Natick, MA). For the analysis, the frequencies of maximum power (Peak Frequencies—PFs) were determined for each 5-min duration raw audio recordings. For each recording, a power spectral density (**PSD**) was calculated using Welch's method (Welch, 1967), which is an averaging approach to remove the influence of random noise on the spectra of stochastic signals. The PSD was calculated with a frequency resolution of 256 bins and an overlap of 50%, and the Hanning window minimized spectral leakage. The spectral content was transformed to a single sided representation, resulting in a linear frequency axis of 129 bins, ranging from 0 to 11,025 Hz, each of them containing a PF.

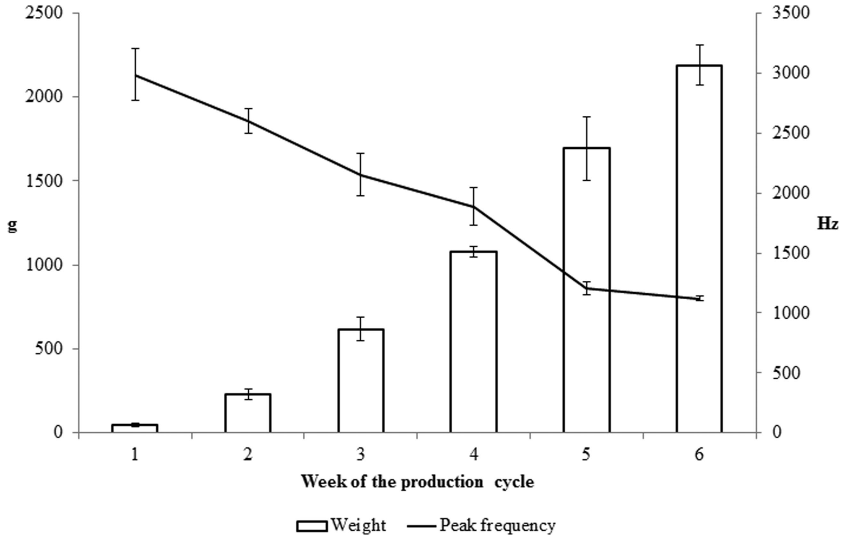

Figure 1. General tendency of the data (weekly peak frequencies and weights) collected during Rounds 1 to 8.

Frequency bins over 1000 Hz were used to effectively filtering out any lower-frequency noise removing the ventilation and feeder lines noises in order to define the PF of broiler vocalization.

Furthermore, the PFs automatically extracted were manually edited to avoid the influence of the outliers. Indeed, PFs out of the range of 1,100 Hz and 3,700 Hz were eliminated from the data set, thus, the sounds automatically collected during dark periods, characterized by background noise with any useful vocalization, were excluded from the analysis (Curtin et al., 2014). Furthermore, this frequency interval was chosen since previous studies showed that broiler vocalize in that frequency range (Montevecchi et al., 1973; Marx et al., 2001; Fontana et al., 2015a).

A dataset with both PFs and weight data, gathered by the age of the broilers, was created for each production cycle. Then, all datasets were merged together in a final dataset with all the weights and the PFs collected in Rounds 1 to 8.

Data availability (PFs and weights) in Rounds 4 to 8 was strongly dependent on internet connection for both data collection and storage. Sounds and weight data were successfully collected during Rounds 4 and 5, providing a completely available dataset for statistical analysis; on the contrary, datasets of Rounds 6, 7 and 8 were not completed due to technical problems (loss of internet connection) occurred during data collection. Afterwards, complete datasets of Rounds 4 and 5 were merged with datasets of Rounds 1, 2, and 3 in order to estimate the polynomial regression to predict the weight of the birds as a function of the PF.

As the animal growth trend is traditionally defined as a nonlinear function (Rizzi et al., 2013), in the present study, a polynomial regression (PROC REG, SAS Institute (2012), was estimated based on Rounds 1 to 5 (4,361 observations). The model used (weight = PF + PF^2) describes the relation between growth trend and PF of broiler vocalization.

Expected weights were estimated by applying the polynomial regression to PFs obtained in Rounds 6 to 8 (935 observations) and then associated to the weights of broiler chickens automatically collected. Since Rounds 6 to 8 were characterized by missing values, these incomplete datasets were used to validate the prediction curve.

Correlation and regression coefficients between expected and observed weight were estimated using the PROC CORR and PROC REG, (SAS Institute, 2012). Finally, observed and expected weights were compared with the TTEST procedure (SAS Institute, 2012), first on the general trend and successively week by week.

RESULTS AND DISCUSSION

In the present study sounds and weights were automatically collected 24/7 and were merged in a large dataset used for statistical analysis. Data were averaged week by week in order to show the general trend of the PF and the weight along the Rounds 1 to 8.

Figure 1 reports the general tendency of the data (PFs and weight) collected during Rounds 1 to 8.

It is evident how each age is characterized by its own typical PF (straight line) that declines with the growth of the birds; indeed, PF decreases of about 2,000 Hz between wk 1 and wk 6 of the production cycle. This finding is consistent with previous studies of Fontana et al. (2015a) and Bowling et al. (2017) and that demonstrates a strong inverse relationship between body size and vocalization frequency.

Figure 2 clearly shows how the PFs of the bird vocalizations during their life changes according to their age. At the beginning of the round, the PFs were on average 3,263 ± 163 Hz, while by d 40, the average PF were 1,288 ± 75 Hz.

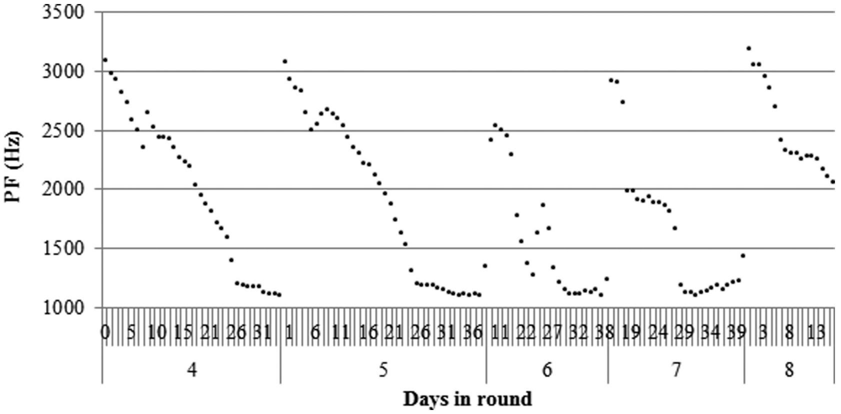

Figure 2. Peak frequency trends collected during Rounds 4 to 8. Rounds 6, 7 and 8 were not complete due to internet failure.

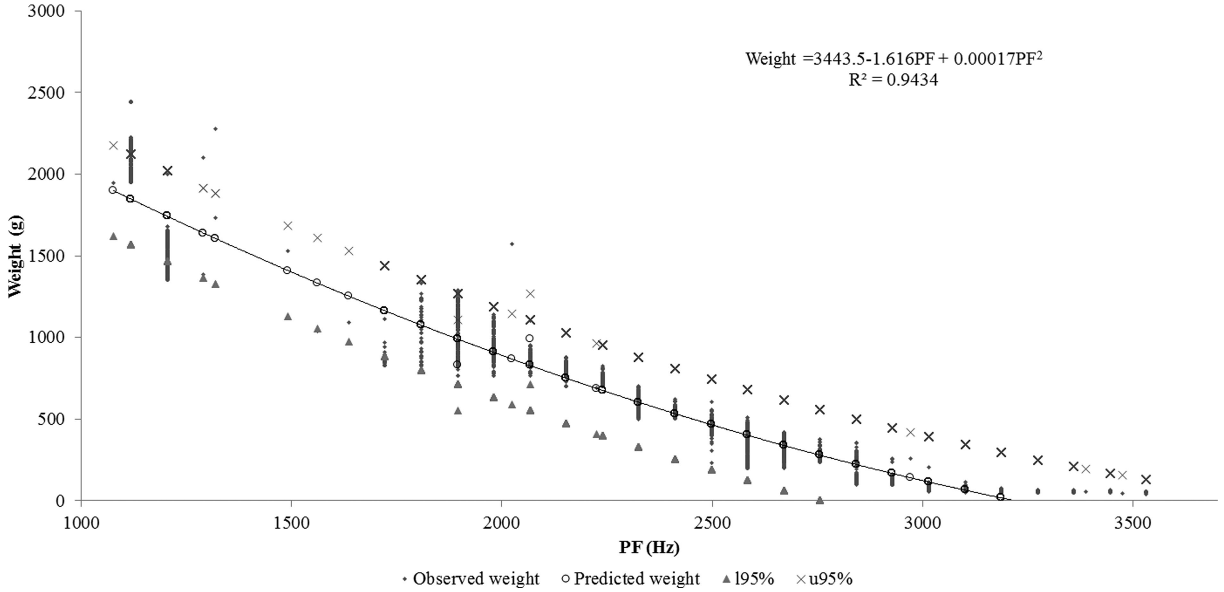

Figure 3. Polynomial regression to predict the weight of the broilers as a function of the PF emitted. l95% and u95% shows the 95% confidence interval of the expected values.

Figure 2 shows also the data availability for Rounds 4 to 8. Datasets from the Rounds 6 to 8 are not complete, reflecting a normal field situation in which technical problems—such as internet failure—may occur causing a considerable loss of data.

The polynomial regression model (Figure 3) was estimated using datasets of Rounds 1 to 5 (4,361 observations) and resulted significant ($F = 36{,}310.8$, $P \leq 0.001$), indicating that the model accounts for a significant portion of variation in the data. The R^2 indicates that the model accounts for 94% of the variation in weight. The identified polynomial regression model was:

$$\text{Weight} = 3443.5 - 1.6101(\text{PF}) + 0.0001698(\text{PF})^2 \; (R^2 = 0.94)$$

where PF was the peak frequency of the sounds (Hz) emitted by the birds.

The confidence interval (l95% and u95%) that includes the expected values of the regression model with a probability of 95% indicating the goodness of fit of the regression model.

Results showed that the PFs of the sounds emitted by animals are inversely proportional to the age and the weight of the broilers, as reported by Fontana et al. (2015b).

The regression coefficients were used to predict the broiler expected weights as a function of the PF on datasets of Rounds 6 to 8. This analysis was performed to validate the prediction curve using a dataset characterized by missing values. This approach was used to simulate problems in the automated data collection that may occur at farm level provoking data losses.

The *t*-test procedure was performed to evaluate the general difference between observed and expected weights calculated with polynomial regression. No significant difference (P value $= 0.4513$) is shown between expected and observed weights along the considered

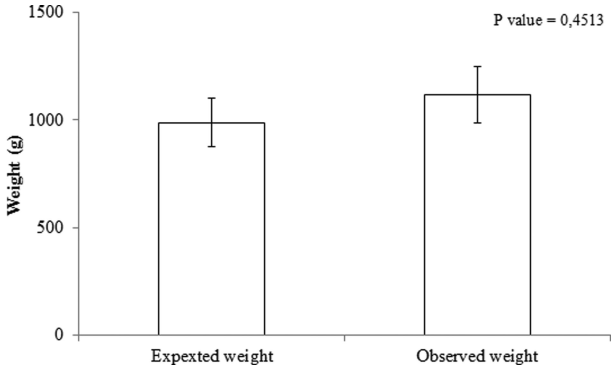

Figure 4. Levels of significance (*t*-test) of the differences between observed and expected weights calculated with polynomial regression.

production cycles (Figure 4). This analogy was confirmed by the correlation coefficient between expected and observed weights that resulted high and positive ($r = 0.96$, P value ≤ 0.001). Furthermore, the regression model between expected and observed weight resulted highly significant ($R^2 = 0.93$, P value ≤ 0.001) indicating a good association between collected data and predicted ones.

Table 1 lists the average observed and expected weights obtained week by week using datasets of Rounds 6 to 8. In the same table P values for the *t*-test procedure are reported. No significant difference is shown between expected and observed weights along the first 5 wk of the cycle production. Expected and observed weights slightly differ in the last part of the cycle production (wk 6, P-value: 0.011).

According to the results, weights can be successfully predicted until the last wk of the cycle and the background noises such as feeder and fans do not affect the frequency analysis of the sounds emitted by the broilers. Indeed, at the beginning of the production cycle, broilers vocalize at very high frequency levels (Figure 1) and it is easy to distinguish between animal and environmental sounds. However, with the increasing in the body weight, the frequency level of the vocalizations emitted during the last wk of the cycle production decrease (1,100 Hz), and the background noise in the poultry house covers and partially masks birds' vocalizations, affecting the sound analysis.

This is consistent with findings of Bardeli et al. (2010), Rizwan et al. (2016) and Bowling et al. (2017) that relate the increasing in the body weight to the frequency level of the vocalization emitted.

Moreover, in this study, the PFs of the sounds emitted by the birds were automatically extracted from 5 min recorded audio files, and were modified by applying a filter to exclude frequencies below 1,000 Hz (Curtin et al., 2014). The combination of the filter applied and the high background noise during the last wk might have prevented the identification of birds vocalization PFs.

In this study, we tested whether the automated recognition of PF of the vocalization could be precise enough in predicting the weight of the broiler chickens. The model implemented to predict the weight as a function of the PFs was proven accurate and it was tested to define whether this model could be applied to field data with missing values.

Results of this study revealed the strong relation between PFs of vocalizations and the weight of the birds. The discrepancy between observed and expected values in the last wk of the production cycles could be ascribed to a number of causes such as the filter used to automatically extract PFs and the quality of sounds collected during the last part of the production cycle. Indeed, the more the animals grow, the lower the PFs and the higher the noise of fans and feeding lines.

Incomplete rounds (Rounds 6 to 8) were used to validate the prediction model being successful until the fifth wk of the cycle, opening a new scenario in monitoring systems in broiler houses. However, missing data affected the precise estimation of the broiler weight during the last wk of the rounds. An accurate estimation of the final body weight is fundamental for farmers; for this reason, further studies will be necessary to implement the model investigated for future developments of an automated process. As also reported by (Bardeli et al., 2010) the crucial point to obtain more accurate weight prediction through sound analysis is to improve the reliability of data recordings to avoid losses in data collection.

The current described method gives a reasonable indication regarding the growth of broilers, despite the precision of the weighing method based on the range of

Table 1. Observed and expected average weights in wk 1 to 6 calculated with polynomial regression using peak frequencies. P values represents the significance level of the *t*-test performed on expected and observed weights.

Age	Expected weight ± Std. Err. (g)	Observed weight ± Std. Err. (g)	P values
1st wk	80.0408 ± 41.54	106.3 ± 17.30	0.573 (ns)
2nd wk	393.8 ± 53.09	399.7 ± 53.63	0.865 (ns)
3rd wk	737.6 ± 60.33	805.2 ± 80.13	0.519 (ns)
4th wk	1030.3 ± 100.80	1211.2 ± 54.39	0.140 (ns)
5th wk	1704.5 ± 18.37	1682.7 ± 55.49	0.717 (ns)
6th wk	1829.3 ± 17.53	2316.8 ± 124.60	0.011 (*)

ns = not significant; $^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$ and $^{\dagger}P \leq 0.10$.

sounds investigated in this study has to be improved. PF detection could be the basis for the creation of a comparatively accurate weight prediction algorithm based on sounds emitted by the broilers. This algorithm will allow farm industry to have a cheap but reliable real time monitoring system of the entire flock.

In conclusion, using broiler sounds to predict their weight is a promising method that may integrate, and not replace, the information provided by the automatic weighing scale placed in the broiler houses.

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