



Original papers

An innovative approach to predict the growth in intensive poultry farming

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ABSTRACT

Chicken weight provides information about growth and feed conversion of the flock in order to identify deviations from the expected homogeneous growth trend of the birds. This paper proposes a novel method to automatically measure the growth rate of broiler chickens by sound analysis.

Through the application of process engineering, Precision Livestock Farming (PLF) can combine audio and video information into on-line automated tools that can be used to control, monitor and model the behaviour, health and production of animals and their biological response.

The aim of this study was to record and analyse broiler vocalisations under normal farm conditions, to identify the relation between animal sounds and their weight. Recordings were made at regular intervals, during the entire life of birds, in order to evaluate the variation of frequency and bandwidth of the sounds emitted by the animals.

Two experimental trials were carried out in an indoor reared broiler farm; the audio recording procedures lasted for 38 days. The recordings were made, in an automated, non-invasive and non-intrusive way and without disturbing the animals in the broiler house. Once a week, 50 birds were selected at random and their weight recorded in order to follow the growth trend in the birds.

Sound recordings were manually analysed and labelled using the Adobe® Audition™ CS6 software.

Analysing the sounds recorded, it was possible to find a significant correlation ($P < 0.001$) between the frequencies of the vocalisations recorded and the weight of the broilers.

The results explained how the frequency of the sounds emitted by the animals was inversely proportional to the age and to the weight of the broilers; the more they grow, the lower the frequency of the sounds emitted by the animals.

This preliminary study, conducted in an indoor reared broiler farm, shows how this method based on the identification of specific frequencies of the sounds, linked to the age and to the weight of the birds, might be used as an early warning method/system to evaluate the health and welfare status of the animals at farm level. This is the basis for a further development of an automated growth monitoring tool.

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1. Introduction

The demand for meat is rapidly growing all over the world (Tullo et al., 2013) and poultry is one of the cheapest sources of animal protein. Currently, more than 50 billion chickens are produced every year by specialised industries according to FAOSTAT (2015).

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Broilers are the fastest-growing farmed species and their performance is influenced by adequate environmental conditions such as environmental temperature, relative humidity, air and litter quality, and ventilation speed. Thank to the progress in farming technologies, broiler chickens now mature at a higher rate than in the past, have higher feed conversion efficiency, a reduced slaughter age and a higher final weight (Aerts et al., 2003; Rauw et al., 1998).

Chicken weight provides information about the growth and the feed conversion efficiency of the flock. Nowadays, the weight of the birds is automatically collected by a single solid “step on scale” placed on the floor of the house. The high numbers of animals inside the flock and the insufficient funds of scales make impossible to collect the weight of all flock. Manually measure the weight

of a significant number of animals requires manpower and deprives the farmer of useful time. Due to this, it might be useful to automatically collect simultaneously information about the growth trend of all the birds inside the flock to identify deviations from the expected homogeneous growth trend of the birds (Fontana et al., 2014; Mollah et al., 2010), having also details about the health and welfare status of the animals.

Since the animal health strongly depends on good welfare, during the last years many progresses have been made in developing new indices/indexes and procedures to assess animal's health and welfare status (Fontana et al., 2015). Nevertheless, these monitoring procedures are time consuming and require trained manpower (Aydin et al., 2014). For this reason, one possible way to make animal welfare assessment easier and faster could be the application of audio and video data analysis (Ferrari et al., 2013; Tefera, 2012; Tullo et al., 2013).

Image analysis, in particular, was successfully used to estimate the body weight of the animals (Mollah et al., 2010), while audio analysis have been widely used to better identify specific behaviours and vocalisation patterns in different animals' species (Chan et al., 2011; Vandermeulen et al., 2013).

Animals use vocalisation to express different inner states provoked either by internal or external events, and also to reveal some of their behavioural needs (Aydin et al., 2014; Vandermeulen et al., 2015). For instance, chicken broiler vocalisations have been studied (Feltenstein et al., 2002; Marx et al., 2001; Montevecchi et al., 1973) to better understand the vocal pattern of this species in relation to environmental temperatures and stress situations (e.g. high/low temperatures). Moreover, information technologies have been used to monitor feed intake, body weight and growth trend (Aydin et al., 2014).

The non-invasive nature of the audio and video equipment allows its use in long term monitoring of animals, without disturbing them (Aydin et al., 2013; Fontana et al., 2015).

The combination of audio and video information into automated tools could be used in early warning systems to detect health or welfare problems (Precision Livestock Farming – PLF) (Costa et al., 2013). PLF develops on-line tools to continuously and automatically monitor farm animals (Viazzi et al., 2011) during their life, without imposing additional stress to them. The PLF approach can be applied to different aspects of management, with a focus on the animals and/or on the environment, and at different scales, from the individual to the entire flock/herd (Wathes, 2009). Moreover, PLF may also be used to aid the management of some complex biological production processes, to measure the growth trend and to monitor the animal activity (Halachmi et al., 2002; Ismayilova et al., 2013; Tullo et al., 2013).

The aim of this study was to record and analyse broiler vocalisations under normal farm conditions, to identify the relation between animal sounds and their weight. The relation between Peak Frequency (PF) of sounds emitted by broiler chickens during the production cycle and their weights (both measured with an automated and a manual scale) were investigated.

2. Material and methods

Two experimental trials were carried out in an indoor reared broiler farm located in the UK; the first one took place in June and July 2013 and the second one in August and September 2013.

The farm where the experimental trials took place was an indoor broiler farm rearing birds to the Right to Farm Act (RTFA) Assured Chicken Production (ACP) standard. The house dimensions were 61 m × 21 m; broilers are kept indoors and the stocking density allowance is less than 38 kg/m² for the entire production cycle. Inside the house there were 2,340 nipples drinkers and 385 feed

pans available to birds. 27,940 COBB 500 chicks, of one day old, were placed inside the house at day 1 (after hatching) in both trials.

Sound recordings were collected using a professional handheld solid state recorder (Marantz PMD 661 MK II) which was connected to two different directional microphones placed at an intermediate height of between 0.4 m and 0.8 m (depending on the height/age of the animals in order to keep the same distance among animals and microphones during the entire data-collecting procedure).

The supercardioid/lobe microphone (Mic. 1) was a Sennheiser K6/ME66" (frequency response: 40–20,000 Hz ± 2.5 dB) and it was held by a short tripod microphone stand (Quiklok A341) above the feeder.

The (cardioid) microphone (Mic. 2) was a Sennheiser K6/ME64" (frequency response: 40–20,000 Hz ± 2.5 dB) and it was placed on a long tripod (Quiklok A492 Heavy-Duty Boom Mic Stand) directly above the drinkers.

Both the microphones were slightly inclined towards the floor in order to capture preferentially the sounds coming from the birds walking exactly in front of the microphone axis.

The recordings provided a sound image of background noise, and gave a better idea of the overall condition inside the broiler house.

The Marantz PMD 661 MK II recording machine had a large range of potential recording settings. The settings found to give the most sensitivity to bird sounds in the poultry house environment were:

Rec. Format: PCM-16, Stereo Sample Rate: 44.1 k
Level Control: Manual Low Cut: Off High Cut: Off

Animal sounds were recorded from day 1 to day 38 of the cycle production during each experimental trial.

Recordings were made for one continuous hour, using two different microphones, at regular intervals every Monday, Wednesday and Friday, with the same position of the equipment along the trial procedures. After the placement of the equipment, the operator used to leave the broiler house in order to not disturb and influence the animals behaviour. The equipment used for the recordings was taken down after each recording session and replaced before the following session. Recordings lasted for one hour in order to have enough audio data to be analysed. The time interval for the recordings was chosen at random in order to increase the variability of the samples collected.

Once a week, 50 birds were selected at random and they were manually weighted through using a manual scale in order to follow the growth changes in the birds. Throughout the production period from day 1 to day 38 house temperature and humidity levels were recorded.

The entire data collection consisted in 16 days of sound recordings for trial 1, 15 days of sound recordings for trial 2, and 6 weekly weight collections for both trials.

In total 55 h 20 min of recordings were collected and 600 birds were weighted during trial 1 and trial 2; only the audio files recorded in conjunction with the weight collection of the birds were included in the data analysis.

In total 600 sounds (50 sounds per day), chosen at random and selected from 12 days of recordings were manually labelled and analysed in this study.

2.1. Sound analysis

Sound recordings were manually analysed and labelled using sound analysis software: Adobe® Audition™ CS6. The first five minutes of recordings were not taken into account during the sound

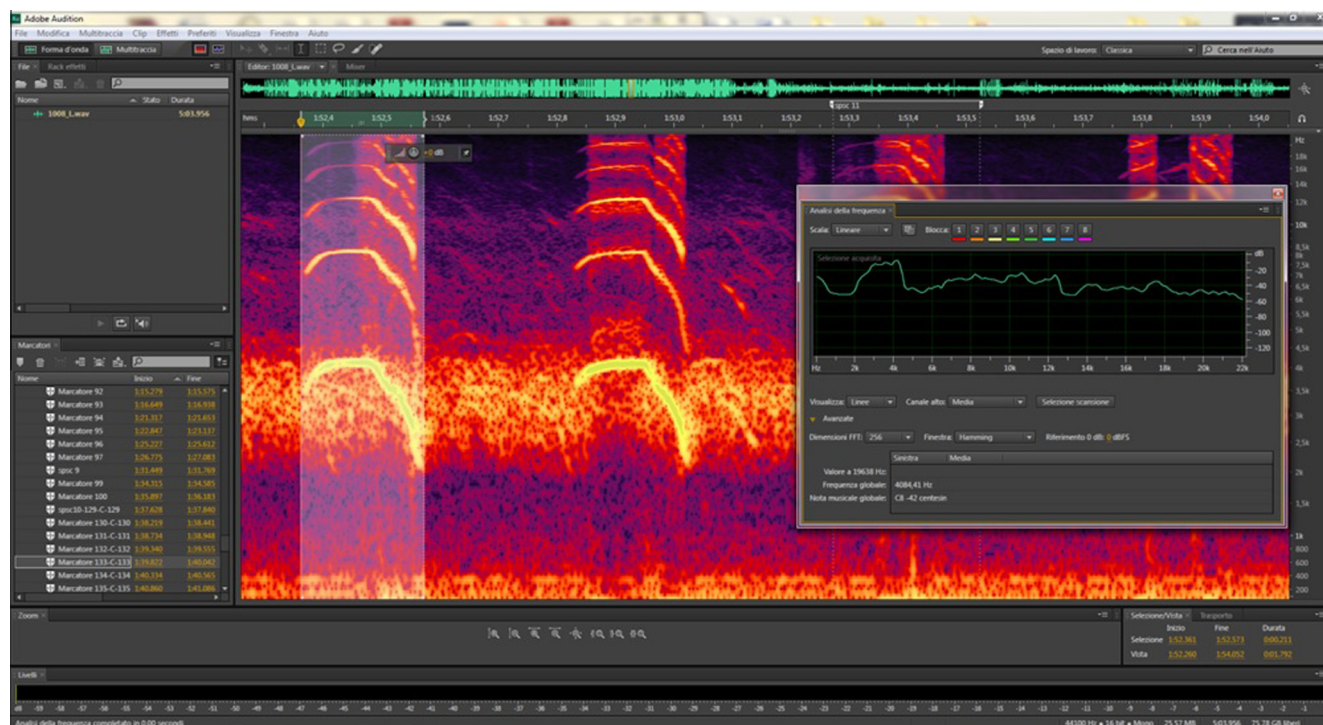


Fig. 1. Screenshot of the Adobe® Audition™ software showing the spectrograms and the frequency analysis window relative to a specific vocalisation. In the main window the time–frequency vocalisation graph is shown, while the inset represents the frequency analysis.

analysis because the behaviour of the animals might have been influenced by the operator during the setup of the equipment used to make the recordings. Every hour-long duration recorded digital file was cut into shorter files of 10 min each in order to simplify the sound analysis.

Sound labelling involved the extraction and classification of both individual animal sounds and general sounds coming from the whole flock on the basis of the amplitude and frequency of the sound signal in audio files recorded at farm level (Tullo et al., 2013).

Labelling is a manual procedure based on acoustic analysis combined with visual spectral analysis, which is used to extract fragments of sounds from the entire recording. The labelling procedure was done offline (after the sound recordings procedure) by selecting and extrapolating those sounds that the operator classified as useful vocalisation sounds (loud and clear enough to be labelled) *via* auditive analysis and visual observation of the spectrogram (Ferrari et al., 2008).

Through Adobe® Audition™ CS6 each sounds were identified and analysed using time (x-axis) and frequency (y-axis).

The Fast Fourier Transform (FFT) was used to perform the frequency analyses using a Hamming window with a FFT dimension of 256 sampled points (Fig. 1).

For each sound the peak frequency (PF = representing the frequency of maximum power) was manually extracted. The frequency range was band pass filtered between 1000 Hz and 13,000 Hz. The lower frequency limit was set at 1000 Hz to remove the low frequency background noise and the upper limit was set at 13,000 Hz to cut off the high frequency noise and also because broilers are sensitive to a frequency range of about 60–11,950 (Appleby et al., 1992; Tefera, 2012).

2.2. Statistical analysis

The differences among PF extracted from the 600 sounds recorded in the two trials were tested with the PROC TTEST of

SAS 9.3 in order to verify the possibility to model the PF of the sound emitted in the two trials as a function of the age of the broilers. A paired *t*-test was performed to compare PF of sounds recorded at different birds' ages within the same trial. The *t*-test is commonly used to compare vocalisations in farm animals (Manteuffel et al., 2004), and in this case, the paired *t*-test was used to compare dependent variables, such as the sounds recorded in two trials of/in the same farm (McDonald, 2009). The correlation among the PF of the sound emitted, the age and the weight of the birds was also investigated with PROC CORR in SAS 9.3. The PROC REG was used to predict variation in the PF according to the change of age of the birds (in weeks).

The estimation of effects influencing the PF was performed with the GLM procedure in SAS 9.3 using a fixed effect (weight * age) divided in 12 classes (Table 1), since in trial 1 the weight of the birds were manually measured during days 1, 8, 15, 22, 29 and 36 while in trial 2 during days 1, 9, 16, 23, 30 and 37.

The division in classes allowed avoiding the nesting effect due to the strict relation between weight and age but taking into account that the weight of birds were collected in different days in the two trials.

3. Results and discussion

For each sound the frequency analysis was carried out, in order to extract the peak frequency of each vocalisation. The mean weights collected during both trials agree with the growth trend of this breed found in literature using the Aviagen handbook.

Table 2 shows the means and standard deviations of the peak frequency (PF) of sounds recorded in trial 1 and trial 2.

The comparison shown in Fig. 2 shows how there is no difference (*P* value = 0.4508) between PF means of the sounds recorded in the two trials.

Furthermore, the comparison between PF of sounds collected on the same week of age of birds during the experimental trials (Fig. 3) confirmed that the two trials could be considered as the

Table 1

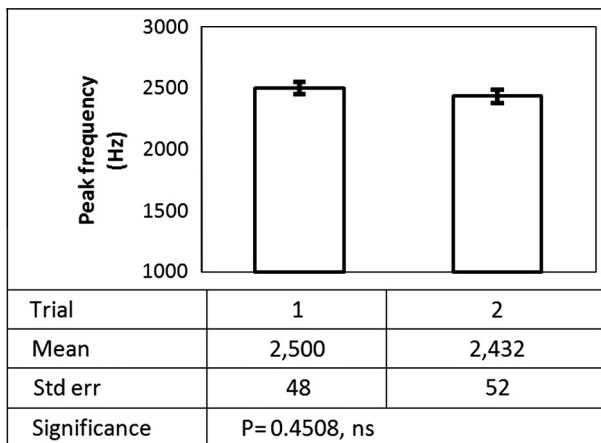
Description of the fixed effect weight * age used in the GLM model. The 12 classes, are the result of the interaction (pairing) of the age with the average weight of the birds.

Weight (g)	Age (d)	Trial	Weight * age
40.72	1	1	1
44.56	1	2	2
198.64	8	1	3
231.42	9	2	4
550.30	15	1	5
608.66	16	2	6
1039.46	22	1	7
1092.84	23	2	8
1529.00	29	1	9
1731.60	30	2	10
2104.28	36	1	11
2275.44	37	2	12

Table 2

50 Chicken broilers randomly chosen were weighted during their entire life, both in trial 1 and trial 2. Means and standard deviations (SD) of the peak frequency (PF) of the sounds recorded in both trials.

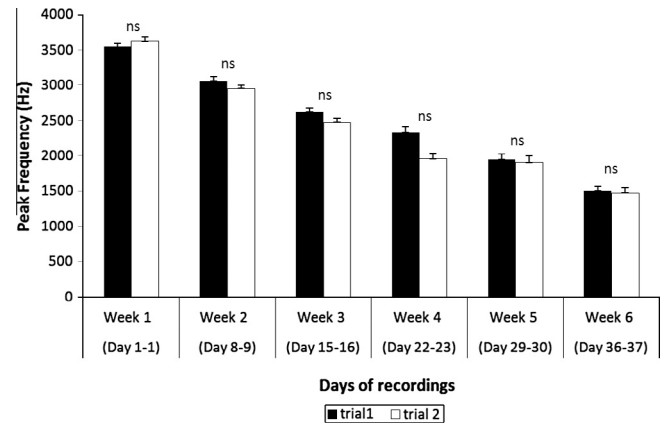
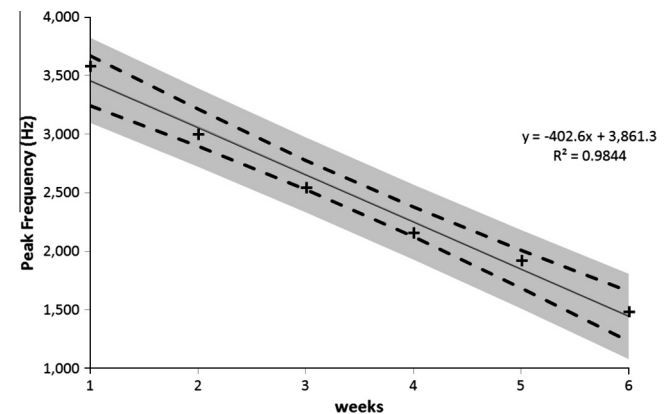
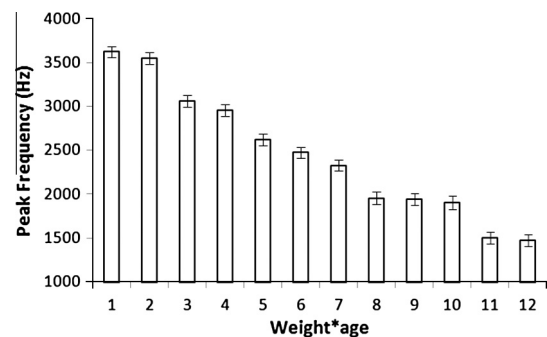
Week	Trial	Day	Mean weights (g) ± SD	Mean PF (Hz) ± SD
1	1	1	44.56 ± 1.5	3545 ± 365
2	1	8	198.64 ± 10.1	3059 ± 459
3	1	15	550.3 ± 21.7	2618 ± 360
4	1	22	1039.5 ± 68.6	2329 ± 605
5	1	29	1529 ± 120.5	1943 ± 569
6	1	36	2104.28 ± 208.5	1506 ± 434
1	2	1	40.72 ± 4.9	3621 ± 402
2	2	8	231.42 ± 1.1	2953 ± 353
3	2	15	608.66 ± 26.7	2474 ± 384
4	2	22	1092.84 ± 74.4	1955 ± 520
5	2	29	1731.6 ± 130.3	1902 ± 585
6	2	36	2275.44 ± 247.0	1475 ± 493

**Fig. 2.** Comparison between PF means of the sounds recorded in trial 1 and in trial 2.

equivalent. This could be related to the use in poultry farming of fast-growing hybrid broilers with typical and homogeneous growth rate across production cycles.

Indeed all the *P* values reported in Fig. 3 reveal the non-significant difference between PF means of the sounds emitted by the animals during specific days of both trials.

In Table 3 the paired *t*-test between days of the same trial were tested to verify the difference between the PF means of the vocalisation during the life of the broiler chickens; the difference is resulted significant in both trials.

**Fig. 3.** Comparison between PF means of sounds emitted during days of the same week of age recorded in different trials.**Fig. 4.** Linear regression of PF in relation to the age of the animals expressed in weeks. Confidence intervals of the mean are reported in dotted lines. Confidence intervals of the prediction are represented by the grey area.**Fig. 5.** LSMEANS(±SEM) of the peak frequency of vocalisation according to the increase of age and weight. *P* < .0001.

As it is possible to see in Tables 2 and 3 and in Fig. 3 each age is characterised by its own typical peak frequency that decreases with the growth of the birds.

Considering the difference between week 1 and week 6 it is possible to see how the peak frequency decreases of about 2000 Hz.

In both trials the average frequency reduction was around 350 Hz per week.

The correlation between weight and age of the broilers resulted highly positive (0.97, *P*-value < 0.001) and was also found a high

Table 3
Paired *t*-test between different days to verify the difference between the PF means of the vocalisations during the entire life of the broiler chickens in trial 1 and in trial 2.

Trial 1			Trial 2		
Comparison	Difference mean (SEM)	<i>P</i> -value	Comparison	Difference mean (SEM)	<i>P</i> -value
Day 1–Day 8	485.8 (76.7)	—***	Day 1–Day 9	668.4 (73.4)	—***
Day 1–Day 15	926.8 (66.9)	—***	Day 1–Day 16	1174.3 (87.69)	—***
Day 1–Day 22	1216.2 (103.8)	—***	Day 1–Day 23	1674.1 (121.4)	—***
Day 1–Day 29	1602.1 (93.3)	—***	Day 1–Day 30	1740.3 (120.7)	—***
Day 1–Day 36	2039.6 (94.3)	—***	Day 1–Day 37	2146.4 (80.8)	—***
Day 8–Day 15	441.0 (72.2)	—***	Day 9–Day 16	478.9 (79.4)	—***
Day 8–Day 22	730.4 (106.8)	—***	Day 9–Day 23	949.7 (96.6)	—***
Day 8–Day 29	1116.3 (108.4)	—***	Day 9–Day 30	1015.9 (109.0)	—***
Day 8–Day 36	1553.8 (85.5)	—***	Day 9–Day 37	1478.0 (80.6)	—***
Day 15–Day 22	289.4 (91.5)	—***	Day 16–Day 23	485.9 (102.2)	—***
Day 15–Day 29	675.3 (100.7)	—***	Day 16–Day 30	552.1 (107.2)	—***
Day 15–Day 36	1112.8 (81.8)	—***	Day 16–Day 37	999.1 (97.1)	—***
Day 22–Day 29	385.9 (124.8)	—**	Day 23–Day 30	366.3 (136.4)	—*
Day 22–Day 36	823.4 (101.5)	—***	Day 23–Day 37	428.5 (137.0)	—**
Day 29–Day 36	437.6 (101.7)	—***	Day 30–Day 37	362.2 (130.6)	—**

*** *P*-value <0.001.

** *P*-value <0.01.

* *P*-value <0.1.

negative correlation (-0.95 , *P*-value < 0.001) between the PF of the sounds and the age of the broilers. Furthermore analysing the PF related to the weight of birds, it was possible to confirm a significant negative correlation (-0.80 ; *P*-value < 0.001) between the frequencies of the vocalisations recorded and the weight of the broilers, during the different experimental trials.

As it is shown in Fig. 4 the peak frequency of the vocalisations of the broiler chickens is strictly dependent on the age and on the weight of birds.

The regression model is significant ($F = 251.52$, $P < 0.0001$), indicating that the model accounts for a significant portion of variation in the data. The R^2 indicates that the model accounts for 98% of the variation in peak frequency.

The confidence interval (CI_obs_95) of the observed values shows a 95% probability that the true linear regression line of the population will lie within the confidence interval of the regression line calculated from the sample data.

The confidence interval (CI_exp_95) that includes the expected values of the regression model with a probability of 95% (grey area in Fig. 4) indicates the goodness of fit of the regression model.

The results of the GLM were useful to verify the high impact of the weight and the age of the birds on the PF of the vocalisation emitted by the animals during their life. In Fig. 5 are reported the LSMEANS(\pm SEM) of the PF of vocalisations according to the increase of the age and weight of the animals.

There is a decrease of peak frequency in vocalisations according to the age of the broiler chickens.

As reported by Marx et al. (2001) the PF of the vocalisation emitted by one week old chicks ranged from 3000 to 4000 Hz, reinforcing the results of the present study that very young chicks vocalise at high frequency under non-stress condition.

4. Conclusion

Broiler sounds were recorded with two microphones and 600 sounds chosen randomly were manually labelled and analysed; The PF of each vocalisation was evaluated in order to find a relation with the age and consequently with the weight of the birds.

The results indicate that the peak frequency of the sounds emitted by the animals, is inversely proportional to the age and the weight of the broilers; specifically the more they grew, the lower the frequency of the sounds emitted by the animals.

This preliminary study shows that the methodological approach based on the identification of specific sound frequencies emitted by the animals in an indoor reared broiler farm linked to their age and weight, might be used as an early warning method/system or a continuous monitoring system to evaluate the general status of the animals at farm level. Furthermore, the correlation between weight of the birds and peak frequency of the sounds emitted by the animals might open the scenario to an automated tool based on vocalisation to predict the weight and the growth trend of the birds. This allow the farmer to automatically monitor the growth trend of the birds.

Of course further studies, in different farms, with daily data collection are necessary to improve the knowledge on the relationship between vocalisation and weight of birds in order to create an accurate weight prediction algorithm based on sounds emitted by the animals but, this study proves that audio and video data monitoring might be promising technique for the development of an automated growth-monitoring tool for the farming of broiler chickens.

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