DEVOTION
Journal of Research and Community Service

Volume 3, Number 12, October 2022
e-ISSN: 2797-6068 and p-ISSN: 2777-0915

ROLE OF COMPUTER SCIENCE (ARTIFICIAL INTELLIGENCE) IN POULTRY MANAGEMENT

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ABSTRACT

KEYWORDS
Precise livestock farming, animal welfare, sensors, broiler chickens, laying hens, microclimate intensive production

The precise control of animals is the focus of a new strategy to enhance animal welfare in the poultry industry. We notice that good welfare circumstances significantly impact the health of the birds and the quality of the poultry products, which affects economic effectiveness in the production of poultry. An innovation that can aid farmers in more successfully controlling the environment and birds' health is using technology solutions in various animal production systems. Additionally, as public concern over chicken breeding and welfare increases, resolutions are being developed to improve control and monitoring in this area of animal agriculture. PLF (precision livestock farming) uses various techniques to gather real-time data about birds. By spotting diseases and stressful conditions in the early stages and enabling action to be taken swiftly enough to avoid the negative impacts, PLF can assist prevent reducing animal wellbeing. To enhance precision livestock farming, this review links the potential uses of the most recent technology to monitor laying hens and broilers.

INTRODUCTION

Chicken production has increased by more than double over the past 30 years, reaching 25.9 billion birds in 2019 and up to 80% in 2020 over the previous year (1). Poland was the top chicken meat producer in the European Union in 2019, with 13.3 million tons produced, ranking among the leading exporters globally with 1.5 million tons, or 9% of total global exports. Poland produced 2.6 million tons of poultry meat (2). Poultry meat production, which continues to be the main category of total meat production (3), is anticipated to increase in the coming years (4). As a result, there is a continuing need to look for ways to increase poultry production efficiency while raising the animals' quality and welfare. We find that in chicken production, the birds' interest substantially impacts the quality of the products, which may impact economic efficiency (5).

Birds that exhibit natural behaviors, are healthy, and have a happy emotional state are said to have a high level of welfare (6). Behavior disorders, which can show in a variety of behaviors, including increased aggression, lameness, cannibalism, or feather plucking and result in financial losses, are one of the most significant problems in today's chicken production that can have a substantial influence on welfare (7, 8, 9, 10, 11, 12). Additionally, to decrease expenses, modern chicken farms tend to reduce the number of personnel while maintaining or increasing the number of birds, which lowers the welfare of the herd and prevents it from exhibiting a particular species' behavior (13). Monitoring animal behaviors, feeding practices, and environmental factors are crucial to enhancing production efficiency and raising animal welfare. Additionally, as public concern over chicken breeding and interest increases, more effective measures for management and monitoring are being developed. Because there is no direct human-animal contact, Precision Livestock Farming (PLF) tools allow the unattended collection of broadly understood data on housing conditions and animals in real-time. This enables the gathering of accurate information (14). An automated management system based on real-time data can be developed (Figure 1) to govern animal welfare, health, and performance using data from many sources that have been acquired by sensors or other equipment (15). The compatibility of precision tools with commercial poultry farm equipment based on the gathered data is a crucial factor that enables the successful use of PLF tools (16). PLF technologies can assist in identifying animal welfare issues early on, improving and accelerating management decisions, and minimizing financial losses in the long run (17). In this review, we outline the various technologies that can be incorporated into chicken production systems to manage better the environment, human health, and animal welfare. The practical uses are examined, as well as the possible effects of such technologies on wellbeing.

RESULT AND DISCUSSION

Monitor Production Parameters and Behavior through tools

For various farm tasks, many PLF tools are available on the market. With the use of empirical research conducted in conditions conducive to large-scale farming, this study seeks to present a comprehensive overview of PLF instruments currently available on the market as well as an analysis of their potential future applications in the commercial poultry industry. This review focuses on the optimization of production cycle management opportunities within five key areas—housing and microclimate control, weight monitoring, sound analysis, locomotion and activity tracking, and disease detection and hygiene maintenance aspects—rather than on the direct use or adaptation of technology by farmers and the resulting socio-economic impact.

Control of the Environment of Shed

The next overview looks at various topics in turn, including general herd maintenance guidelines, environmental conditions deviations, the need to monitor ambient air temperature, the importance of ventilation, the impact of ventilation on other factors (such as harmful gases), the lighting programme and its negative effects, and other uses of light as part of rearing conditions and their optimization using the associated PLF tools.

The kept herd must be properly densified to the fullest extent possible in order to minimise diminished welfare and rising stress levels during the production of chicken meat and eggs (22). The maximum density of chicken kept for meat production in a farm or poultry house may not exceed 33 kg•m2 in accordance with Directive 2007/43/EC (23). This amount could be raised to 39 kg or even 42 kg•m2, but only under certain conditions (23). The stocking density for laying hens cannot exceed nine animals per square metre of usable land, according to Council Directive 1999/74/EC (24). (with the potential to go up to 12 animals per m2 provided that the requirements, such as a larger available substrate area, are met). A minimum of 750 cm2 of cage area is needed for each egg-laying hen raised in a cage, and the cage should never be any lower than 35 cm. Keeping track of a single animal in a huge herd that is densely populated is challenging for farmers. PLF methods provide more effective farm management by providing data on the entire herd that is automatically obtained 24 hours a day, 7 days a week. According to Hartung et al. research.'s (25), farmers who use PLF systems favour integrated data over conventional management techniques and generally do not perceive any drawbacks other than the potential for high prices. However, they also think that PLF can result in greater profitability. According to Jones et al. (26)'s research, management approaches had superior long-term impacts on welfare and the environment to stocking density reduction. 2.7 million Birds were housed at five various stocking densities for the large-scale study, which revealed that housing conditions might have an even more significant impact on welfare than density itself (27). Commercial farms needed to control animal welfare more due to increased consumer awareness of the given diet and overall housing conditions for birds in large-scale farming (28). An autonomous farming system that can provide better feed and nutrient usage modifications can help to improve and maintain the environment's conditions (29). Animals may consume less food, which would limit their growth (30), feel more stress, and have higher mortality rates if environmental conditions differ from acknowledged norms (32). To maintain an accurate welfare status, animals must have constant access to water, and feeders must enable them to obtain entire meal combinations suited to their age and productivity needs (33). The Kai-Zen Feeding Robot (Metabolic Robots, Kfar Tavor, Israel) is primarily used to adjust the feed dose to the demands of the herd at the current stage of development. It can optimise the Food Conversion Rate (FCR) and perhaps raise it by up to 4%. (34). With the aid of the self-sufficient solar Feed Cast (Little Bird Systems, Fayetteville, NC, USA) system, farmers can precisely adjust proper feed formulation and environmental conditions, including temperature and lighting programmes. Real-time information about feed use and other data, such as water intake (35,36). Modern chicken coops are equipped with water metres that may be used to track daily water usage by either each row or the entire coop (37, 38). Based on data gathered, water intake patterns can be used to diagnose feed quality issues or general flock health. Water intake typically decreases when a flock's health is compromised, whereas it increases when feed quality problems, such as greater salt levels, are present (37). Monitoring water use might also reveal leaking infrastructure, costing farmers more money. Poultry farmers must be careful to use resources as efficiently as possible due to the intensive nature of production (30). By tracking and documenting the behavior of the birds in real-time, precision livestock farming can be applied to the poultry sector. Due to the size of the installation, manually verifying the equipment's proper operation is complicated in large-scale agriculture. In studies carried out by Kashiha et al. (39), The effectiveness of automatic monitoring in broiler houses was amply demonstrated by the employment of the dynamic system (Fancom BV, Panningen, The Netherlands), cameras, and subsequent image processing techniques. This system allowed for the real-time detection of 95.24% of anomalies. The information acquired could lead to quicker and more effective steps for replacing or repairing faulty equipment parts, like feeders, fans, and heating systems (16). The preservation of normal gaseous pollutants, the preservation of microclimate management, and the health and welfare of birds are all directly impacted by such acts.

When monitoring how environmental elements influence the onset of behavioural issues in broilers, it is crucial to pay attention to the proper ambient temperature. It shouldn't exceed 35 °C during the first week of production; thereafter, it should decrease by an average of 5 °C per week until it reaches 21 °C, or ambient temperature. This layout reduces the risk of heat stress, associated stress, and behavioural disorders (40). Birds must waste up to four times as much energy to keep a healthy body temperature when temperatures are below what is suitable for them, which also impacts their capacity to produce (41). Due to genetic selection for anticipated gains, modern broilers grow quickly, limiting the development of circulatory and respiratory systems suitable for the animal's size and demands (42), making them more susceptible to heat stress (43). After being exposed to heat stress for 3 hours (ambient temperature: 36 °C), the birds' skin surface temperature increased by 6 °C, and their body temperature increased by 3 °C (44,45). The relationship between the body core and surface temperature of broiler chickens has been verified by studies by Giloh et al. (46) based on observations with a thermal imaging camera. From 8 to 36 days after chronic exposure to high ambient temperature, as well as during and after exposure to heat stress with or without adequate ventilation, this connection was similarly strong across all age groups. Without the need for individuals to take control measurements, temperature sensors provide constant access to information about the present temperature. Correct height positioning of the sensors is necessary. Blanes-Vidal et al. (47) claim that in order to get temperature readings that are as accurate and realistic as possible, the sensor must be mounted 0.6 m above the ground. The most straightforward method of controlling environmental factors is normally to maintain the right temperature by changing ventilation and heating (48).

Consistent weather conditions are necessary to prevent heat stress during the growing season (49). Fan ventilating systems with side input ventilation outperform natural ventilation for regulating temperature and relative humidity, claim Jones et al. (26). More than 80% of the energy used in commercial buildings goes toward heating, while up to 40% goes toward ventilation. (50). In facilities for cattle, a suggested range of humidity is 50 to 70 percent (51, 52). It can also be controlled with plenty of ventilation. When the relative air humidity is lower than 50%, there are more dust particles in buildings. (30). Because of the increased air humidity and high temperatures in the summer, birds could feel uneasy (28). Birds cannot sweat, so they often cool themselves by exhaling or raising their wings (skin exposed to airflow). Heat stress can happen if ventilation is ineffective (30). The birds can maintain the growth at the anticipated level with effective thermoregulation when airflow is no more than 2 m•s1 (53). Wintertime over-ventilation might result in up to a 30% increase in production costs (50). Ammonia levels in livestock barns rise due to reducing ventilation efficiency, such as saving money on energy and heating (54). Poor ventilation causes moisture to build up in livestock buildings, which causes wet litter (54), bacterial growth and increased nitrogen production from the nitrogen in the feces (55). The issue that affects livestock buildings more frequently than the buildup of moisture is the greater concentration of NH3, CO2, and air dust (54). According to European guidelines, according to European guidelines, carbon dioxide and ammonia concentrations shouldn't exceed 5000 ppm and 20 ppm, respectively (23).

In livestock barns, ventilation is critical in regulating the temperature, humidity, and level of dangerous gases (56). According to Czarick and Fairchild's research (57), the relative air humidity was below 60%, the air temperature was within the normal range, and the CO2 and NH3 concentrations were still at acceptable levels. At a steady temperature, a rise in humidity above 70% causes increased concentrations of CO2 (>5000 ppm) and NH3 (>20 ppm). Low weight gain and sluggish chicks are caused by high carbon dioxide concentrations, whereas NH3 increases illness susceptibility. Analyzing the composition of the air can be a valuable tool for identifying potential health issues. Early detection of the infection stage (250 oocysts per g1) was made possible by pilot research by Grilli et al. (58), which was based on a comparative analysis of the volatile organic compounds (VOCs) released by healthy and coccidiosis-infected animals. The impact of ammonia content (0, 13, 26 and 52 ppm) on broiler growth and their immunological response to the Newcastle virus was investigated by Wang et al. Four treatment groups were created from the flock of one-day-old broilers (n = 480), with an equal number of males and females in each group. Twelve randomly-chosen birds from each group studied the immune system and the effects of ammonia concentration on growth. Throughout weeks 0–3 of the production cycle, concentration was measured using a MiniWarn Multi-Gas Monitor (Draeger Co., Germany). The relative weight of a chick's lymphoid organ was unaffected by the ammonia content, although the importance of other organs fell. The 52 ppm group had a considerably greater antibody titer against Newcastle Disease Virus (NDV) hemagglutination inhibition than the 26 ppm group (p 0.05). Therefore, it is clear that keeping an eye on environmental factors in livestock buildings, such as air humidity, ventilation, temperature, and gas concentrations detrimental to birds, can significantly enhance bird farming (26). Light-related concerns like wavelength, intensity, and lighting schemes are crucial in intensive poultry production (60, 61). In contrast to the previously prevalent fluorescent bulbs, light-emitting diodes (LEDs), which provide monochromatic, full-spectrum light comparable to natural daylight, are now more frequently utilized in livestock barns. The three most significant benefits of LEDs are their longer lifespan, lower energy use, and cheaper maintenance expenses (62, 63). Additionally, it has been demonstrated that monochromatic light favors the values of production metrics (64, 65, and 66). Animals may be affected by artificial illumination since humans only have three types of cones in their retinas, whereas birds have four classes (67). Most naturally occurring behaviors in poultry, which have a visual range of 315 to 750 nm, are triggered by vision (63). That range allows poultry to perceive UV-A light (68). Although UV-A wavelengths (100-400 nm) have a detrimental effect on weight increase during the production period, James et al. study.'s (69) show that they can minimize mortality (by 75% compared to the control group) and improve the economics of broiler production. Chickens are more reactive to red light (630–780 nm), which, according to reports, makes them more aggressive (66, 70). Final live body weight (BW) and breast muscle yield can both be increased by exposing the 6065 K light to more of the blue light spectrum (68). The combination of blue and green light impacts the immune system during the manufacturing cycle. Compared to a single monochromatic light group, levels of IgG in the green-blue illumination group increased by up to 40.3% (anti-Newcastle virus) and up to 48.7% (BSA) (71). In a different investigation, Olanrewaju et al. demonstrated the dependence between BW, BW increase, and light color (72). Compared to the 2010 K ICD vulnerable group, the group reared under cold-led light levels (5000 K, color temperature expressed in kelvins) was much more significant. Birds may experience stress from improperly chosen illumination or lighting program effect (73). Brighter lighting is thought to affect the effectiveness of rearing due to increased avian activity (60). It is believed that to maintain the welfare and feed intake of the chickens, the light intensity in broiler production must be at least 80% of the usable area and cannot be less than 20 lx when measured at the birds' eye level (23).

Usually, too little light hurts birds' behavior, altering how they express themselves and raising their level of fear. Increased light levels boosted health, causing natural behaviors (60). Other investigations revealed that birds housed under lower intensity settings (5 lx) were more active and had an even distribution of behaviors throughout 24 hours than those kept under 50 and 200 lx, respectively (74,75). Despite the information about the detrimental effects of this substandard illumination (5 lux), the broiler business continues to utilize it (60). Additionally, the length of the daylight has a significant regulatory influence—adverse effects of lighting on feeding habits and overall animal welfare (76). Birds held in cages with 16 hours of light (L) and 8 hours of darkness (D) exhibit more activity than those kept in cages with 24 hours of light (77). In their investigation of a herd of Cobb broiler males, Bayram and Zkan (78) noted differences between the 16L:8D and 24 h continuous light schedules in the behavior of the animals, including resting, standing and walking, pecking, and eating (control group). The experiment's findings suggest that the herd has more socialization and is less susceptible to stress than the control group. Aggression in the pack may be caused by less time spent sleeping and resting, which may be brought on by more frequent feeding, drinking, and pecking. Theoretically, a more extended day would result in less hostility and similar behaviors. It is important to note that such a treatment can decrease feed intake (36, 79). Monitoring light conditions may enhance animal welfare, lessen stress, control animal behavior, especially aggressive behavior, and manage feeding habits. To provide accurate measurement results, the reading from the light-measuring sensors installed in the building must be comparable to the bird's eye level. The results of the study demonstrate other applications for light stimulation. It was feasible to efficiently boost the movement and feed intake of the birds by using enrichment in the form of point lasers to pique their attention without negatively compromising leg health (80). Lasagabaster et al. (81) found encouraging surface decontamination for Salmonella using pulsed light with the proper spectrum. The main benefits of such a treatment over washing eggs, which would compromise their natural defenses, are the lack of temperature variations that occur during disinfection of the eggs and the ability to carry out the procedure at low humidity.

Monitoring of weight

The methods for automatic weighing that have the potential to be employed in large-scale farming are presented in the chapter that follows. The decrease of costs incurred, such as service costs, is a crucial element in large-scale profit-driven production from an economic perspective. It takes the farmer and the handler a lot of time and effort to weigh a large herd regularly. Most frequently, step-on-scale is used (82). Pan scales are an example of an automatic weighing technology that involves substantially less active human labor. Pan scales have the shape of a platform suspended low over the trash and use an electrical device to calculate the weight of the person who has just stepped on it (83). It may be possible to gather a more significant number of measurements if the scales are positioned so that the animal can climb them to get to the drinker, feeder, or other enrichment. Scales, also used to monitor wild birds, are the solution utilized in the case of the laying hens and are placed inside the nests (for example, at the entrance) (84).

Additionally, due to automatic controls, hens are shielded from the stressors associated with general human contact and capture (85). The data that has been gathered is available to the farmer in real-time. Real-time data collection on current increments is essential to effective farm management because it allows for estimation of the accomplishment of predetermined goals (85) and the likely occurrence of nutritional shortfalls (86), particularly in the case of broilers. Birds do not gain weight at the same pace within a same livestock house, despite the same climatic circumstances and feed availability (87). Automatic weighing is problematic because older birds, especially those over 28 days old, have less mobility and step on scales less frequently than the more active, younger ones (88). One successful method to ascertain flock uniformity is the use of a rod-platform weighing device, which cleverly makes use of the hens' innate perching tendency. Another more inventive technique for streamlining the whole weight assessment process without upsetting or startling animals is the application of audio recording analysis. The frequency range of a bird's vocalisations is inversely correlated with its age and weight; the older the bird, the lower its peak frequency (89). In eight production cycles on two different farms, no significant differences between observed and expected BW were discovered, according to Fontana et al. research(90) .'s ($p = 0.4513$, except last week). To fully automate the forecasting of multiple broiler hens' real-time feed intakes, Aydin et al. (91) used sound analysis. The findings show a significant connection ($R2 = 0.994$) between the data acquired and the traditional feed intake as measured by a weighing scale positioned beneath a commercial feeder. At the same time, 86% of feed intake was successfully tracked by audio analysis of recorded pecking sounds. Real-time feed usage data combined with other performance data (egg production and body weight) will be beneficial for future feed formulation, home set-point temperatures, and possibly even lighting programmes (37).

The problem with using audio analysis can be machine noise. Loud sonic stimulation may directly result in decreased wellbeing. As equipment ages, it must perform more effectively, which raises gas concentrations, air humidity, and feed requirements. In many cases, this makes engines noisier. According to Aydin et alstudy.'s (92) other noises in the environment can be efficiently filtered out by deleting specific frequencies (between 1000 and 5000 Hz) that are higher than the frequency of bird vocalisation. The spectral oversubscription method and a vocalisation detection algorithm can be used to identify tense conditions, claim Curtin et al. (93). By paying attention to an animal's verbal cues, we can increase animal wellbeing (94). For animals kept as pets, audio analysis is a less stressful stimulus because it is a non-invasive procedure.

Analysis of Sound

The methods for automatic weighing that have the potential to be employed in large-scale farming are presented in the chapter that follows. Sound analysis, another method of environmental control, has recently emerged as a valuable instrument for observing animal behavior and welfare (95). There are two sorts of vocalizations between individuals for herd recognition and those made within the same animal to track and assess individual animal health (96). Different approaches to characterizing vocalization features, such as complicated and conventional statistical methods, neural networks, and Hidden Markov models, are distinguished by Manteuffel et al. (97). (HMMs). A technique that performs well in a noisy environment is neural networks. HMMs are highly good at recognizing speech and can analyze various vocalizations (94). It is also being utilized more and more in bioacoustics since it can incorporate complex language recognition with limitations, is simple to expand to continuous voice recognition, and can handle durational variability (30). Because the classifier based on structural risk minimization has a more remarkable ability to generalize than HMMs, Steen et al. (98) used Support Vector Machines (SVM) rather than HMMs in a study on goose vocal behavior (flushing, landing, and foraging). One of three behaviors was classified using SVM based on vocalizations. Over 90% of the three examined behaviors had accurate classification. Ren et al. (99) employed the HMM model to explore the relationship between vocalization patterns and ambient stress stimuli (human presence) to determine the usefulness of vocalization as a stress indicator. The study's accuracy rate using people as the source of stress was above 90%. According to research, age increases the repeatability, variety, and detectability of vocalization patterns. De Moura et al.'s (100) experiment revealed a link between the birds' vocalizations under extreme heat stress and their gathering behavior. The vocalization of the stressed bird is likewise louder. Birds were placed in a closed environment (3 m2) with decreasing temperature (from 30.2 to 24.98 °C, 1.3 °C) in various experiments (101) based on audio analysis (microphone placed 0.2 m and camera 2 m above the box). It was discovered that vocalization increased, and chicks gathered to prevent flock heat loss during lower temperature circumstances. Bright (102) notes that there were noticeably more vocalizations—particularly squawks—in the flock of laying hens where feather-picking occurrences had occurred. Audio analysis is helpful in the entire chicken production process, even before hatching, because birds converse. Exadaktylos et al. (103) devised a method for a real-time environment employing a digital signal processor and frequency analysis to determine the internal piping stage of incubated eggs. Results showed that the estimated time was 93–98% accurate. The noise produced by machines may complicate the use of audio analysis. Reduced welfare may be directly caused by loud audio stimulation. Devices must operate more efficiently as they age, resulting in higher gas concentrations, air humidity, and feed requirements. This often results in louder engines. In their study, Aydin et al. (92) found that removing specific frequencies (between 1000 and 5000 Hz) that are higher than the frequency of bird vocalization effectively filters out other noises from the environment. According to Curtin et al. (93), employing a vocalization detection algorithm in conjunction with the spectral oversubscription method is a valuable tool for detecting stressful situations. Animal welfare can be improved by taking note of animals' vocal cues (94). The fact that audio analysis is a non-invasive technique makes it a less distressing stimulation for animals maintained as pets.

Tracking of Activities and Movement

As the birds gain weight, their amount of physical activity changes. Due to the rapid growth rates obtained by modern broiler chickens, reduced animal mobility is a critical issue for animal welfare (104). This overview section focuses on both affordable and expensive modern technology-based methods for monitoring both the entire herd and specific individuals, with a focus on using these methods to monitor mobility problems.

Leg disorders are still a common health problem in broilers that must be checked for (105,106) to prevent it from getting worse and reducing the comfort of the birds, despite breeding companies' long-term efforts to select for them (100,101). Due to the growing demand in the Asian market, broiler feet rank third in terms of value after breasts and wings (107). Movement variations are an important welfare indicator for broiler production because of their unique nature (108,109,110). Animal inactivity is usually associated to the development of hock burn (discoloration and lesions of the hocks) and footpad dermatitis (FPD), also known as pododermatitis/footpad lesions (ulcers on the underside of the feet), which is a serious problem in the production of broilers (111,112,113,114). Both conditions run in families and are linked to environmental variables including poor litter quality (111,115,116). Foot lesions ache, make it difficult to move, reduce appetite, limit fluid intake, and prevent weight gain (117,118). When heavy production is widely scattered, it is practically impossible to regularly inspect every bird in the herd (110).

The use of radiofrequency identifying devices for tracking people is still another (RFID). Various animal species have successfully used RFID tags to track the movement and location of individuals (119). Because the tags are lightweight, they have no effect on the birds' level of activity or the health of their legs (120). However, their use on farms requires extra modifications due to the high application costs and problems with sensor accuracy in commercial flocks (35). Rodenburg et al. (121) attempted to identify certain birds within a flock in the PhenoLab investigation. For this purpose, video (EthoVision) and ultra-wideband (TrackLab) tracking localisation techniques were used. Track Lab's distance measuring accuracy was 96%, according to the data analysis, which was done in comparison to the results of video observations. Data on the entire herd, however, can also be a useful source of information about the individual's current problems. Animals can be captured without the need of tags or additional sensors by keeping an eye on the herd's "optical flow," or how quickly brightness changes as the video progresses (114,122).

To continuously monitor the kept animals and react quickly when gait scores occur, automatic measures of the herd's optical flow can be used. This method outperforms service personnel's human evaluation in terms of objectivity, labour efficiency, and effectiveness (123). In the Dawkins et al. (124) investigation, the gait score of chickens at 28 days of age could be predicted, which was many days earlier than the manual/visual evaluation. Analyzing information from the herd's optical flow recorders allowed for this. Similar to this, Roberts et al. (125) predicted symptoms in hens up to several weeks before they appeared in the young animals by using data modelling, Bayesian regression, data skew, and kurtosis analysis. Fernandez et al. (126) evaluated the broiler occupancy patterns based on data collected using camera-based techniques throughout nine full cycles of commercial herds. The findings show statistically significant relationships among employment changes, footpad lesions, and hock burns. The "fish-eye" effect could distort the image during recording, however Altera's correction algorithm can reduce this effect (127). For welfare assessment, commercial farms may be able to use automated optical flow and flock behaviour monitoring based on thermal imaging cameras (128,129,130,131,132). In the first three weeks of a broiler chicken's life, Kristensen and Cornou (133) employed activity level measures based on image analysis, which when paired with a filtering model for aberrant results, may be a useful way to offer a maintenance-free system for detecting mobility concerns in birds. Similar to this, infrared thermography identified footpad lesions earlier than usual visual inspection in a research by Jacob et al. (107). Automatic lameness assessment using image analysis also yields positive outcomes for the early gait score assessment in generally healthy birds (score range from 1.4 to 1.9). (134). Piezoelectric crystal sensors were utilised by Naas et al. (135) to measure the highest vertical force produced by both feet during walking episodes and to detect locomotion impairments. Thanks to sensor technology, asymmetry in the male broiler's gait may be detected, allowing for real-time gait analysis (110). Reduced activity has a number of negative impacts, including changes in eating and drinking patterns. The behaviour tracking software EyeNamic can track the chickens' activity level and general movement while also detecting any pertinent irregularities, such as overcrowding or inappropriate bird dispersal (136). In the production of poultry, wireless accelerometer sensors are used to monitor the movement and whereabouts of the birds (137). Kozak et al. (138) employed accelerometers to measure the amount of physical activity in laying hens. The prediction level of the birds' low (egg-laying, sleeping, and minute postural body movements) to moderate (eating, drinking, and stretching) to intense (walking, running, and wing-lapping) activity was 98% correct based on the data collected using a random forest model. In order to distinguish between standing, walking, and scratching in real time, Leroy et al. (139) used image processing techniques and inexpensive cameras as opposed to time-consuming and labor-intensive in-person behavioural observation methodologies. Using machine vision monitoring techniques, Zaninelli et al. (140) looked into numerous nest occupation concerns in laying hens raised in a free-range setting. The mounted sensor took thermographic pictures of the birds using the nest. For a double occupation, the sensor's sensitivity and specificity were 73.8% and 94.8%, respectively, while for a triple occupation, they were 80% and 94.8%.

The benefit of nest tracking is the ability to closely see the actual laying. In order to analyse the quantity and weight of eggs laid by each hen in the flock each day, Chien and Chen (141) created a form of intelligent nest box. This was made feasible by the use of radio frequency identification (RFID) sensors in conjunction with the Internet of Things (IoT) platform, which were placed on the legs of the hens and the bottom of the nest. Small, body-mounted accelerometer sensors were also used to collect data on the frequency with which laying hens jumped from their perches to the ground, as well as the timing and force of their landings. To improve the welfare of the animals and encourage natural behaviour, perches are added to the laying hen coop. But perches can sometimes be uncomfortable or even dangerous. Utilizing the proper perch for the animals is essential to minimising any negative impacts. Pickel et al. (142) examined the effects of perch form on keel bone and foot pad concerns using pressure sensors wrapped around the perches and other software. They discovered that round and square designs were favoured over square and oval ones. Fattening chicks exhibit similar behavioural requirements (143). Still, further study into the use of comparable perches is not as appealing because to the frequent leg problems caused by intensive growth and larger body weight than in laying hens. Platform-shaped perches are the more secure, well-liked, and ergonomic option, according to study on the perch design employed by slaughter chickens (144). In assessing the level of activity of slaughter hens, a study by Bokkers et al. (145) found that body weight and the motivation for starting/maintaining physical activity are equally important to age. Bizeray et al. looked at the role of environmental changes as a stimulus to increase motor activity in broiler chickens (146). The variety of equipment in the form of extra obstructions on the path to the water and feeder led to an increase in perching behaviour. However, the required equipment and additional enrichments obstruct image analysis by partially concealing the examined birds. Guo et al. created linear elliptic fitting restoration methods for picture recovery (147). As a result, the repair efficiency was higher than 80%. With the help of these methods, behaviour about environmental enrichment can be automatically observed without being affected by human presence.

Diseases Detection and Hygiene Maintenance

Animal welfare standards, such as the AWIN (149) and Welfare Quality (148) protocols, have been developed recently. For the most thorough evaluation of the animals' conditions, multiple indicators are employed to gauge the level of welfare and general health. It is possible to use sensors to monitor the herd for diseases since huge groups of animals are kept in the same or very similar environmental conditions within one and several separate farms. Based on an algorithm that recognizes sneezing in the herd, captured with a microphone put in the box, Carpentier et al. (150) created an automated approach to detect probable respiratory infections. The algorithm's accuracy and sensitivity results were 88.4% and 66.7%, respectively. Because the monitoring system is based on sound analysis, observations may be made in the cattle building around-the-clock, even when it's dark outside. High body temperatures and weakness are early indicators of a potential outbreak, according to Okada et al. (151). They found that highly pathogenic avian influenza (HPAI) was discovered 10 h earlier with a wireless sensor node (WSN) with an accelerometer and thermometer attached to 5% of the flock than with routine monitoring by farm workers. The gadget's main benefit is its two-year battery life, which means utilizing it for longer production cycles, such as those employed with laying hens, eliminates the possibility of discharge or device stoppage owing to short battery life. It is beneficial to use a radio telemetry system in the form of an implantable, wireless sensor network (WSN) to monitor deep body temperature (DBT) (152,153). According to the study, the DBT of broiler chicks measured using the WSN method may be estimated with an accuracy of 0.1 °C. Additionally, the early detection of illnesses is made possible through infrared thermal measurements (154). HPAI was successfully identified by Noh et al. (155) using peak body temperature measurements and a thermal imaging camera. A non-contact, non-invasive means of controlling body surface temperature is infrared technology. A thermogram, or map of the temperature distribution on the animal's surface, is created by translating the infrared radiation that the body emits into pixel intensity (156,157). Infrared approaches do not provide readings of body surface temperature that are as accurate as solid sensors (49). The cleanliness of the livestock facility is a further element that directly influences the prevalence of infections. A novel approach involves using commercially available, autonomously operated robots like the Octopus Poultry Safe (OPS) (Octopus Robots, Cholet, France), a robot created especially for the poultry industry that can clean and sanitize poultry houses. At the same time, animals are present and simultaneously gather environmental data. By routinely turning the litter over, one can aerate it, lessen moisture, and prevent the growth of pathogenic or possibly harmful microbes like Aspergillus fungus and aspergillosis and issues like footpad dermatitis and hock and breast injuries. Numerous options for unattended animal care and managing the environment to be safe for the herd's health are made possible by precision livestock farming. Finding and removing deceased animals is crucial in defending the flock against illnesses. The majority of the time, employees handle this task. It takes a lot of time and labor to manage a vast horde of thousands of animals, and the animals themselves may be hidden in locations where they are rarely observable. The Chicken Boy monitor system can discriminate between live and dead animals using thermo graphic images. It illustrates a portable monitoring tool that measures airspeed, humidity, and temperature, ammonia, and CO2 levels in chicken buildings, among other things (136). The PLF service is very beneficial in maintaining production hygiene since using automated robots or other automated systems that can locate and even pick up deceased folks may be more efficient. Animals are monitored continuously, automatically receive up-to-date health information, and respond faster, reducing the need for treatment and prescription costs (18, 39,132,158).

Limitations and Perspectives

Despite the benefits and features that the PLF is said to offer to poultry producers, numerous authors highlight the use and development constraints of this technology. The lack of funding to equip the farm with new PLF systems is one of the significant issues. This ability is typically only available to larger producers because these are substantial investments that do not pay off immediately, furthering the technology lag experienced by small and medium-sized chicken producers (159). Consequently, a system of financial assistance indirectly supported by local governments and national initiatives promoting PLF technologies may be a good answer (160,161,162). Additionally, Werkheiser (163) emphasizes how fewer workers will be needed on farms that use PLF solutions because of how highly automated such equipment is. As a result, employers will hire workers with less experience and worse skills, potentially lowering the calibre of their output. According to Benghazi et al., the cost is the PLF technology's most significant barrier to adoption among chicken growers (164). The lack of an exclusive market offer would provide farmers with suitable instruments, online interpretation of sensor data, straightforward advice on handling crises, long-term solution suggestions, and customer care to ease current concerns or assist with minor technical issues. The PLF solution implementers should also keep a steady line of communication with the poultry farmers, involving them in technology development and utilizing their years of knowledge. This kind of communication should be appealing to scientists and programmers as well because it will lead to the development of better solutions. Unfortunately, doing so requires investing a considerable amount of money in development research, which only a select few can do.

Furthermore, Bahlo et al. (165) note that farm owners may not always wish to share all the information acquired by utilizing PLF technology with the outside world. This relates to the widely held notion of privacy and the concern over rival businesses having an advantage in the market (166). The authors stress the significance of the "feedback" that Banhazi et al. noted earlier (164). Farmers are more interested in swiftly analyzing specific facts or suggestions for appropriate actions than gathering data. Intriguingly, there are worries that PLF solutions tested in animal production can be used for human monitoring, given that medical research for animal agriculture has often been a spinoff of medical research for people. Although it is a very contentious premise, it makes logic. Through, for example, the increasingly common home electronics gadgets, the tested predictive algorithms and technology for identifying animals, including their voice, will keep an eye on people. Therefore, efforts to build adequate legal laws to safeguard the average person should coexist with the rapid growth of PLF technology (167).

CONCLUSION

PLF technologies can aid in the control of various physical and chemical parameters, enhancing the definition of the physiological status of birds and their ability to adapt to farm settings. These evaluations consider body temperature, movement, vocalization, hydration, activity, and social behavior. By incorporating a variety of technological options, precise management offers farmers the chance to take trustworthy, on-the-spot, non-invasive measures of the behavior and physiology of birds. By providing superior alternatives to measure bird health and response, automated systems to monitor physiological and behavioral characteristics can provide essential benefits and instruments to maximize chicken welfare and minimize production losses. This is the desired outcome of employing novel farm management strategies to provide consumers with wholesome food. PLF technologies are still in the early stages of development and are not yet used on farms. For these technologies to be widely used by farmers and consumers, several issues must be resolved. The main problems are the machine learning process, data analysis for larger, more sensitive, and resistant sensors utilized in PLF, as well as training of potential users who need the requisite abilities to apply such solutions. Modern chicken production facilities can present a chance to bring together the interests of farmers and customers while putting a greater emphasis on improving bird welfare.

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