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Precision livestock farming in egg production

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Precision livestock farming in egg production

Abstract
This article focuses on precision livestock farming (PLF) as it pertains to egg production. Specific contents include: (1) an overview of evolution in the egg industry that is reflective of what is now known as PLF and the new trend of egg production, (2) prominent characteristics of modern egg production systems that necessitate further development and adoption of PLF technologies, (3) some examples of PLF tools or technologies for establishment of science-based production guidelines or applications in field operations, and finally (4) outlook of PLF for egg production. For the fundamental principles and elements of PLF, readers can refer to the opening paper by Berckmans (2017) in this issue.

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Poultry or Avian Science

Comments
Evolution of the Egg Industry

Egg production has undergone remarkable advancements over the past six decades. A recent life cycle analysis (LCA) study on the U.S. egg industry, conducted by the Egg Industry Center (Pelletier et al., 2014), revealed drastic reductions of 54–63% in total environmental footprints (greenhouse gases, acidification and eutrophication emissions) from 1960 to 2010. In the meantime, egg supply increased by 30%. These outcomes stemmed from advancements in poultry breeding and genetics, nutrition, disease prevention and control, housing equipment and environmental control, and utilization efficiency in feed and other natural resources as well as increased crop yields. For instance, during the period of 1960–2010, laying hens in the USA showed a consistent increase of 1.16 extra eggs each year, i.e., 58 extra eggs per hen annually from 1960 to 2010. In the meantime, egg supply increased by 30%. These outcomes stemmed from advancements in poultry breeding and genetics, nutrition, disease prevention and control, housing equipment and environmental control, and utilization efficiency in feed and other natural resources as well as increased crop yields. For instance, during the period of 1960–2010, laying hens in the USA showed a consistent increase of 1.16 extra eggs each year, i.e., 58 extra eggs per hen annually from 1960 to 2010. Feed conversion (FC) (kilogram of feed intake per kilogram of egg output) improved from 3.41 to 1.98 for the same period. Protecting the birds from the influence of seasonal climates has made their productivity much more consistent year-round. An example of maintaining relatively constant indoor temperature despite the largely fluctuating outside weather is illustrated in Figure 1. The same LCA study also identified two “hot spots” that have profound impact on environmental footprints of the operation, namely, feed efficiency and manure management, where further improvements should be focused on. For instance, while FC averaged 1.98, it ranged from 1.8 to 2.2 for the laying-hen flocks surveyed. Clearly, those operations with a poorer FC of 2.2 can particularly benefit from exercising some PLF principles and practices.

While the egg industry enjoys these highly commendable advancements and always looks for new ways to provide the population nutritious and affordable protein at unprecedented efficiency, new challenges never stop emerging. Today, concerns over animal welfare or well-being have led to increasing pressure for the industry to develop and adopt alternative egg production systems that better accommodate natural behaviors, thereby, yielding plausibly improved welfare of the animals. Accordingly, new guidelines or regulations concerning how eggs will be produced now and in the future have been established in various parts of the world, predominantly the European Union (EU) and USA. The banning of conventional cage production in the EU as of 1 Jan. 2012 is an example of the movement toward alternative housing systems. The changes in distribution of layer housing styles in EU from 2012 to 2014 are depicted in Figure 2. In the United States, the state of California passed Proposition 2 in 2008 that went into effect 1 Jan. 2015. The law stipulates that all shell eggs sold in California must comply with the rules that include allocation of at least 750 cm²/hen living area (compared with the current industry standard of 432 cm²/hen) when a cage houses at least nine hens, plus the periodic on-farm food safety inspection. To date, more than 100 retailers, grocers, restaurant chains and entertainment companies in USA have pledged to source only cage-free eggs by 2025 or 2030. These pledges amount to more than 72% of the current U.S. national layer inventory that would have to be converted from the present mostly conventional cage production systems (~90%) to cage-free production systems. A recent study conducted through a private-public coalition partner-

Implications
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ship holistically compared three hen housing systems—conventional cage (CC), enriched colony (EC), and cage-free aviary (AV)—in the Midwest region of the USA with regards to animal well-being, environmental impact, food safety, food affordability, and worker health and ergonomics. The study revealed the trade-off nature with each hen housing system. For instance, the AV system allowed hens to exercise their natural behaviors, having greater bone strength and better feather condition. However, the AV flocks had the highest mortality rate of the three housing systems (approximately three times the mortality rate of the CC and EC flocks), higher incidences of cannibalism and keel bone fractures or deformation, and the lowest efficiency in feed conversion. The AV house also had much higher concentrations and emissions of aerial ammonia, fine particulate matters (PM) and airborne bacteria due to manure accumulation (which generates ammonia) and bird activities (foraging, dustbathing, and flying) on the litter floor (Zhao et al., 2015, 2016; Shepherd et al., 2015). A detailed description of the study and final results can be found at www2.sustainableeggecoallition.org/. These challenges remain to be addressed through research and innovation, and PLF will undoubtedly have a central role to play.

**Characteristics of Current and Emerging Egg Production and Need for Precision Livestock Farming Technologies**

As already stated, the egg industry has made considerable strides to achieve its much improved productivity and efficiency today. The following are some features in contemporary intensive egg production and areas where use of PLF technologies can further boost its improvement.

**Thermal environment**

Assessment of thermal environment in contemporary egg production facilities relies on measurements of dry-bulb air temperature at a limited number of locations in a large space, e.g., eight sensors in a 100,000-bird henhouse occupying a space of 183 m length \( \times \) 18.3 m width \( \times \) 6.1 m height. Building ventilation rate (amount of airflow) or mode of ventilation (cross or tunnel ventilation), heating or cooling is adjusted by an environment controller based on the average of the few sensor measurements. In most cases, such an average temperature does not adequately represent the microenvironment surrounding the animals, especially during a minimum ventilation period when spatial distribution of indoor environment tends to be more heterogeneous.

Use of dry-bulb air temperature does not account for other thermal environment factors such as air velocity, relative humidity, and in some cases, radiation that all can have profound impacts on the thermal comfort, well-being, and production efficiency of the animals. It is for this reason that the concept of effective environmental temperature (EET) has been around for years and applied where possible. In addition, different health and/or nutritional states of the animal will affect the adequacy of the seemingly desirable thermal comfort environment judged by air temperature or even EET.

The ultimate biosensor is the animals themselves as they integrate all of the physical, nutritional, and health factors. The output of the animal-based biosensor could be in the form of behavior (e.g., resting pattern), physiology (e.g., elevated body temperature), and performance (e.g., reduced feed intake or egg production). A real-time, non-invasive computer vision system that continually monitors, analyzes resting behavior of the animals, and makes control decisions would provide a more realistic assessment and assurance of the animals’ thermal comfort, as described by Shao and Xin (2008). The “eYeNamic” imaging system for real-time monitoring and analysis of bird distribution inside litter-floor broiler houses (Berckmans and Norton, 2016) is another example of using animal-based biosensor to assess the adequacy of environment and equipment operation.

**Indoor air quality**

To date, there are no reliable and durable electronic sensors that allow for real-time monitoring and of indoor air quality, particularly ammonia and PM, in commercial production facilities. Some portable tool kits are available for instantaneous/intermittent sampling or periodic time-weight average measurement of air quality (Xin, 2005). Techniques enabling real-time measurement of indoor air quality comprise one of the areas that deserves the attention of PLF endeavors.

Real-time monitoring and analysis of animal coughing vocalization offers a great promise for early detection of respiratory issues of the animals. The technology has found applications for swine production in the EU (Berckmans et al., 2015; https://soundtalks.com/products). It would be just a matter of time before the technology finds its way on an egg farm near you!

**Tracking egg production and size**

Modern egg production facilities are typically equipped with egg counters that monitor the number of eggs produced by each tier, each row, and thus, the entire house. While this is a very valuable tool for the operation, it falls short in being able to monitor the number of eggs produced by various segments within the tier or row, which is subject to the influence...
of spatial environmental stratifications. Moreover, all of the collected eggs will not be categorized into different sizes until they reach the central grading station. This, again, does not allow the farm staff to tell where the different sizes of eggs come from in the house and what may have been the causes for the different sizes.

Monitoring of feed and water intake

Poultry industry was the leader in adopting continuous monitoring and recording of animal water consumption by installing water meters in the drinking water lines. Today, all poultry houses in developed countries are equipped with water meters. Some water meters are equipped with electronic pulse output connected to the environment controller to record daily water use by each row and the entire house. Water intake pattern provides a quick-and-simple way for diagnosing flock health and/or feed quality issues. For instance, a flock that is being under disease attack will likely see a sharp drop in water intake; too salty feed would cause elevated water intake in the flock. An unusual high water intake could also be caused by leaking drinkers, which would be problematic if not promptly fixed. Compared with the relatively precise water intake monitoring, feed intake by the flock is typically monitored with loadcell scales mounted under the feed bins. As a result, feed use is for the entire house, preventing any analysis of performance by different rows even though the data for egg production and water consumption are available. Therefore, PLF techniques allowing for real-time monitoring of feed by the row or, even better, by the tier would be much desired. Aydin et al. (2015) employed sound analysis to automatically predict real-time feed intakes of multiple broiler chickens and showed promising results. Real-time feed use data, along with other performance data (egg production and body weight), will assist the farm manager in fine-tuning feed formulation, set-point temperature of the house, and possibly lighting program.

Identification and removal of mortality

Identification and removal of normal mortalities by frequent inspection of housing facilities in a timely manner is a routine task performed by on-farm caretakers. This task is labor-intensive, time-consuming, and subject to human errors of missing the dead animals in difficult-to-see areas. Missed mortalities can potentially have adverse impacts on the environmental hygiene and thus flock health. This important task calls for invention of an affordable smart vision system that can automatically
identify the physical location of the mortality and even pick it up. It is a perfect candidate for PLF robot application.

**Body weight monitoring**

Regularly (weekly) weighing a small number of (e.g., 100) of randomly selected pullets or layers is another routine operation procedure in egg production. It is done by manually catching and weighing the birds. The purpose is to monitor the body weight of the flock relative to the target values so that the dietary formation and environment (temperature and lighting) can be adjusted accordingly. This process has the drawbacks of (a) use of time-consuming manual labor; (b) a very small fraction of the birds in a large population (e.g., 100 out of 100,000 birds), and hence, questionable validity of the true flock representation; and (c) added stress in handling the birds. Automated platform weighing scales (either placed on the floor or suspended from the ceiling) have been developed and used in floor-raised broiler and turkey flocks. However, such an automatic weighing system is not yet available for conventional cage or enriched colony egg production. This is another area that PLF technology can and should be applied to. For instance, automatic weighing scales can be built into the perching system in enriched colony houses.

It should be noted that the above-identified areas needing improvement with the conventional production systems are also applicable to alternative housing systems. In fact, in some cases, the needs are much stronger with alternative (cage-free) housing systems than with conventional systems, such as detection of flock health and well-being, improvement of indoor air quality and reduction of air emissions, and homogenizing spatial distribution of environmental conditions.

**Progress in Precision Livestock Farming**

**Layer Research and Commercial Application**

Considerable efforts and progress have been made in PLF research and commercial application over the past decade. The knowledge derived from research has contributed to the foundation for development and refinement of existing production guidelines. However, certain guidelines on the relatively new alternative production systems (e.g., cage-free) have to be based on research done on the conventional systems (e.g., cage) because not enough information on the alternative systems is available. Such substitution may not adequately reflect the actual systems. To address such knowledge gaps, research on the emerging systems is essential.
Summarized below are examples of what has been and is being done to explore PLF techniques and to collect the much-needed research data for improved system design and production management.

**Use of sensing technologies to monitor animals**

A novel wireless body-mounted accelerometer sensor has been developed and used to remotely monitor the location and activity of laying hens in cage-free housing systems (Quwaider et al., 2010). The same wireless accelerometer sensor has been used to detect occurrence of jumps from a perch to the ground, time of jump initiation, time of landing, and force of landing (Banerjee et al., 2014). Kozak et al. (2016) also used tri-axial accelerometers to measure physical activity levels of laying hens. With the data collected from the accelerometers, 98% accuracy could be achieved in predicting low- (e.g., small postural movements), moderate- (e.g., walking), and high- (e.g., aerial ascent) intensity physical activities. Liu et al. (2014) investigated a loadcell-based weighing perch system to quantify perching behaviors of laying hens and determined the minimum horizontal distance between laying hen perches. Pickel et al. (2011) investigated pressure load on keel bone and foot pads in perching hens in relation to perch design using pressure sensors wrapped around the perches and the companion software. This technique allows for studying the possible causes of keel bone deformation and proper shape or material for perches.

Radio frequency identification (RFID) sensors coupled with weighing scales have been used to quantify locomotion, feeding, and nesting behaviors of individual birds in group-housing conditions (Tu et al., 2011; Nakarmi et al., 2014; Li et al., 2016; Oliveira et al., 2016; Campbell et al., 2016), ovipo-
sition (Heinrich et al., 2013; Zaninelli et al., 2016a), and free-choice studies (Sales et al., 2015). A system that tracks feeding behaviors and body weight of individual birds housed in groups was developed and described by Tu et al. (2011) and has been adopted by poultry-breeding companies in genetic selection programs. The feeding/weighing stations employ a low-frequency RFID system and precision weighing scales (Figure 3). One bird at a time is allowed to access the feeding/weighing station. From the time-series data, information can be derived in terms of dynamic feeding profile as well as daily feed intake, feeding time, frequency of feeder visit, pecking force, body weight gain, and feed conversion for each individual bird in the group. The system developed by Nakarmi et al. (2014) was used to quantify time budget and locomotion behavior of individual hens kept in a group at different stocking densities, which was verified by human labeling (Figure 4). The same system is being used for studying activities and behaviors of individual birds as influenced by lighting conditions.

One of the key criteria in the guidelines for equipment design and production management in alternative housing systems is the amount of feeder space that should be allocated to the birds. Some guidelines call for provision of sufficient feeder space that allow all the birds to feed at the same time. This requirement has significant ramifications for the system design and production management. For instance, a system with feeders along outsides (e.g., enriched colonies) may have to have additional feeders installed inside the colonies, which would not only complicate the design of the system, but may pose a management challenge (e.g., inspection of feed). However, the criterion lacks substantiation by research data. Do all hens really feed at the same time? If not, what percentage of the group tends to feed simultaneously? What should be the proper feeder space per bird? To answer these questions and refine the existing guidelines, it is imperative to collect data on feeding behaviors of group-housed hens in the alternative housing systems. Consequently, an automatic tracking system has been developed in our lab at Iowa State University, and data are being collected to help address these issues. The tracking system consists of an ultra-high-frequency (UHF) RFID system and a loadcell weighing system that is verified by a video system (Li et al., 2016). Each of the 60 hens in the enriched colony wears a miniature RFID sensor on the neck (and another one on the leg to track nesting behaviors). The results to date show that not all of the hens feed at the same time (Oliveira et al., 2016). In fact, in this case, a maximum of 45 out of 60 hens (75%) fed together (Figure 5). There is also considerable variability among the individual hens in time spent at the feeder although day-to-day variability is rather small for a given bird (Figure 6). Research is ongoing to quantify the impact of varying feeder space and other management schemes on behavioral and production responses of the hens.

**Use of image analysis and modeling to assess behaviors and well-being of hens**

Lee et al. (2011) proposed a framework for predicting feather damage caused by injurious pecking based on automated optical flow image processing and statistical analysis. Applying the proposed method to real-world datasets, the researchers showed promise of the method in predicting feather damage, thus enabling an identification of flocks with probable prevalence of damage and injury later in lay. Kashihara et al. (2014) applied an image processing system for use in an environmental animal preference chamber to detect hen navigation between four compartments of the chamber. During a choice-test study, mean ± standard deviation success detection rates of 95.9% ± 2.6% were achieved when considering total duration of compartment occupancy. The technique was used to monitor ammonia aversion in the chamber. Merchandising and Blatchford (2014) conducted kinematic analysis to measure the amount of space needed for W-36 hens to stand, turn around 180°, lie down, and flap their wings. Each hen was placed in a floor pen (91.4 × 91.4 cm) and filmed using two high-speed cameras. The resulting images were processed using a software program that generated three-dimensional space use for each behavior. On average, hens required a mean area of 563 (± 8) cm² to stand, 1,316 (± 23) cm² to turn around, 318 (± 6) cm² to lie down, and 1,693 (± 136) cm² to flap their wings. The mean heights used were 34.8 (± 1.3) cm for standing, 38.6 (± 2.3) cm for turning, and 49.5 (± 1.8) cm for wing flapping.

Zaninelli et al. (2016b) developed a monitoring system based on the use of infrared (IR) thermography to identify the presence of laying hens in a closed room of a free-range layer farm. Infrared thermography has also been applied to assess feather coverage/damage in laying hens as compared with manual feather scoring (Zhao et al., 2013; Pichová et al., 2016). Results show that the IR thermography is a useful tool for assessing poultry feather cover quality that is not biased by the subjective component and provides higher precision than feather damage scoring.

**Use of preference test to assess responses of hens to environmental factors**

Lighting is an important factor influencing well-being and productivity of poultry. Extensive work has been done regarding poultry responses to lighting (Ma et al., 2016). However, as new types of lights continue to emerge and find application in animal housing, there is a renewed interest in poultry lighting research. Scientific data are also needed for developing or reaffirming guidelines on lighting intensity for laying hens. Figure 7 illus-
brates a light preference test system recently developed and used in lighting research in our laboratory. Using the setup, Ma et al. (2016) investigated preference responses of W-36 layers to five intensities of fluorescent light (< 1, 5, 15, 30, and 100 lux) and diurnal pattern of light use. The results clearly show that the hens avoid staying in the 100-lux condition (p < 0.05, Figure 8). Hence, provision of such intensity of light would not be in the best interest of the bird’s well-being. In comparison, lower light intensities, especially 5 lux, are much preferred. An intriguing outcome of the study is the relatively constant distribution of dark time (averaging 25 min) throughout the day, which led to a cumulative daily light and dark period of 14 and 10 h, respectively. This diurnal pattern is in contrast to the photoperiod pattern of continuous light (e.g., 16 h) followed by continuous darkness (e.g., 8 h) typically practiced in commercial egg production. The question we may ask is: Do the hens under this intermittent lighting condition have a better welfare than those under the continuous light-dark condition? Of course there is the practicality aspect of applying such an intermittent lighting in layer houses because workers need to inspect the flocks and perform other indoor tasks under visible conditions. However, if the intermittent lighting better meets the welfare of the hens, ways to realize such condition can be achieved through PLF technology. Long-term studies are warranted to affirm the benefits of such alternative lighting programs.

**Outlook of Precision Livestock Farming for Egg Production**

The world’s population will reach approximately 9.1 billion by the year of 2050, and the demand for food is estimated to increase by 70% relative to what it is today (FAO, 2009). The proportion of protein demand is expected to increase even more as people’s living standards improve, especially in developing countries. In the meantime, scrutiny on...
food safety and quality, animal welfare, environmental impact, and working conditions and ergonomics of animal caretakers will continue to mount. The animal agriculture industry also constantly faces the challenge of skilled labor shortage. With finite amounts of natural resources on the planet, improving efficiency of their utilization is imperative to attaining a sustainable development of animal agriculture. There is no doubt that breeding, genetic selection, and biotechnology will continue to play paramount roles in meeting the food demand of the growing population. However, the importance of providing the optimal environment to fully realize the animals’ genetic potentials cannot be overstated. Precision livestock farming technologies will be central to providing such optimal environments and assuring animals health/well-being through real-time monitoring (early warning) and prompting decision-making for intervention. Application of PLF technologies (e.g., intelligent robots) will also relieve humans from those labor- and time-demanding tasks that are essential to the success of animal production operations.

To effectively develop and implement PLF for egg production and animal production in general, it is critical to have collaboration among multidisciplinary scientists (engineers, animal ethologists, physiologists, and economists) along with industry (allied industries and producers) partnerships. These collaborations and partnerships have yielded great dividends and will continue to do so in advancing PLF worldwide.

Literature Cited