Performance of an image analysis processing system for hen tracking in an environmental preference chamber

Mohammad Amin Kashiha,*[1] Angela R. Green,† Tatiana Glogerley Sales,† Claudia Bahr,* Daniel Berckmans,* and Richard S. Gates†

*M3-Biores: Model-Measure-Manage Bioresponses, Biosystems Department, KU Leuven, 3001 Leuven, Belgium; and †Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, 1304 West Pennsylvania Avenue, Urbana 61801

ABSTRACT Image processing systems have been widely used in monitoring livestock for many applications, including identification, tracking, behavior analysis, occupancy rates, and activity calculations. The primary goal of this work was to quantify image processing performance when monitoring laying hens by comparing length of stay in each compartment as detected by the image processing system with the actual occurrences registered by human observations. In this work, an image processing system was implemented and evaluated for use in an environmental animal preference chamber to detect hen navigation between 4 compartments of the chamber. One camera was installed above each compartment to produce top-view images of the whole compartment. An ellipse-fitting model was applied to captured images to detect whether the hen was present in a compartment. During a choice-test study, mean ± SD success detection rates of 95.9 ± 2.6% were achieved when considering total duration of compartment occupancy. These results suggest that the image processing system is currently suitable for determining the response measures for assessing environmental choices. Moreover, the image processing system offered a comprehensive analysis of occupancy while substantially reducing data processing time compared with the time-intensive alternative of manual video analysis. The above technique was used to monitor ammonia aversion in the chamber. As a preliminary pilot study, different levels of ammonia were applied to different compartments while hens were allowed to navigate between compartments. Using the automated monitor tool to assess occupancy, a negative trend of compartment occupancy with ammonia level was revealed, though further examination is needed.

Key words: animal behavior, laying hen, choice test, image processing, occupancy analysis

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INTRODUCTION

Conventionally, an extensive list of welfare indicators is used to assess welfare of livestock animals (Duncan, 1981). Recently, however, many scientists argue that instead of such a list and giving each indicator the same weight, one should directly focus on health and needs of animals (Dawkins, 2004). In addition, it is known that behavior could perform a major role in dealing with the 2 above issues. Behavior is used to assess health through the clinical and preclinical assessment of pain, injury, and disease. It is also important in gauging animals' needs. This is not only carried out through on-farm assessment, but also through the use of choice and preference tests (Kirkden and Pajor, 2006; Scholz et al., 2010). The role of behavior analysis could be more prominent if used in conjunction with new technology.

In recent years, image processing technology has been practiced for animal tracking purposes throughout the world (Sergeant et al., 1998). With the growing need for quality control and animal welfare management, the demand for automatic animal identification and behavior monitoring as well as traceability has increased. According to Van der Stuyft et al. (1991), image processing systems have been used for the production market, but more specialized research systems are needed to track animal behavior in research studies with custom animal housing and specific data collection requirements (Lay et al., 2011).

Image processing technology is widely used in precision livestock farming and in supply chain management to identify (Kashiha et al., 2013b), track (Kashiha et al., 2014), and monitor behavior and health status of agricultural animals (Yang et al., 2010; Kashiha et al., 2013c). Image processing systems are comprised of a

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[1]Corresponding author: amin.kashiha@biw.kuleuven.be

camera connected to a PC via a capture card. Captured videos are then encoded and recorded on an external hard drive. These videos are subsequently decoded and analyzed.

The use of image processing technology has been extended to animal behavior and welfare research because it offers tools to monitor and to obtain feedback on animal location and resource utilization. For instance, image processing tracking systems have been proven as effective to monitor animal feeding and drinking behavior (Kashiha et al., 2013a), growth (De Wet et al., 2003), and activity (Leroy et al., 2006; Calvet et al., 2009).

In choice tests, animals are provided with multiple choices among situations or resources. The choices must be registered to determine animal preferences. Identifying animal location (choice made) and time spent at that particular location is essential for assessment of environmental preferences. Choice-tests as applied in animal behavior and welfare research may benefit from the use of leading-edge technology. Researchers previously used radio frequency identification (**RFID**) to monitor animals when they had to choose between available compartments. Sales (2012) implemented and evaluated such system for its use in an environmental animal preference chamber (**EPC**) to detect hens transiting between compartments of the EPC. The system faced difficulties because their RFID system detection range did not cover the entire test bird area, conflicts were caused by multiple RFID tags within the same detection zone, and visits shorter than the RFID antenna scan interval could not be detected. In another study, Green et al. (2008) developed an EPC to assess responses of laboratory mice to atmospheric ammonia. They used infrared sensors for automatic tracking of mouse movements. Infrared tracking was sufficient for summarizing group behavior, but ineffective in recognizing individual mice and required a backup video system to verify their data. More recently, image processing-based tracking methods have been used in tracking animals subjected with choice tests (Straw et al., 2011). Accordingly, objectives of this study were based on employing image processing technology in tracking layers during choice tests.

The objective in this study was to evaluate the performance of an image processing system applied within a stainless-steel EPC for poultry, by performing the following tasks:

- Tracking hen navigation through detection of a hen navigating the compartments.
- Comparing this to human video observations to identify potential image processing misdetections and their causes.
- Validating choice-test study positioning data, which consisted of collecting occupancy data and videos from a choice-test study with a bird and comparing the detected events.

The above system can have many applications for monitoring laying hens' behaviors. An immediate example for this is ammonia aversion (Sales, 2012). In periods of extremely cold weather, energy conservation in a laying house usually results in a restricted ventilation rate (Deaton et al., 1982) and an increase in air pollutants, particularly ammonia (Deaton et al., 1984). Elevated ammonia concentrations over a few days can cause a significant loss in egg production (Cotterill and Nordskog, 1954; Garner et al., 2012; Leinonen et al., 2014), and hens can lose a significant amount of weight with a reduced feed intake (Kristensen and Wathes, 2000). Moreover, previous studies through manual observations showed that laying hens significantly preferred fresh air [approximately 0 ppm by volume (**ppm$_\mathbf{v}$**)] to an ammoniated atmosphere (Deaton et al., 1982).

Therefore, in a preliminary pilot study, the image analysis system was employed to investigate ammonia aversion by laying hens through monitoring compartment occupancy. This is based on the hypothesis that hens tend to prefer compartments with lower ammonia concentration and avoid those with higher concentrations.

MATERIALS AND METHODS

EPC

An EPC composed of 4 stainless-steel compartments (1.2 m × 1.2 m × 1.2 m occupancy space, with conical subfloor and attic space) was located at the Environmental Research Laboratory of the University of Illinois at Urbana-Champaign. Further details on the design, development, and operation of the EPC have been documented by Sales (2012) and Sales et al. (2013). Experiments were conducted in accordance with the principles and guidelines presented in Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010).

The 4 EPC compartments were interconnected by passageways that allowed a test bird to walk from one compartment to either of the adjacent ones. A video camera was mounted from each cage's ceiling above the bird area in the center at a height of 46 cm. These cameras captured video of the compartments for 16 d. They were equipped with a motion detection system. This system replaced a compartment image with no pixel movement with a blank screen as illustrated at the right side of Figure 1a. Setup is shown in Figure 1b, and hardware information of the cameras is provided in the next section. There were 4 cameras and 4 images, which were stitched as shown in Figure 2a.

Image Acquisition System

An animal tracking system based on image processing technology was added to the EPC to automatically

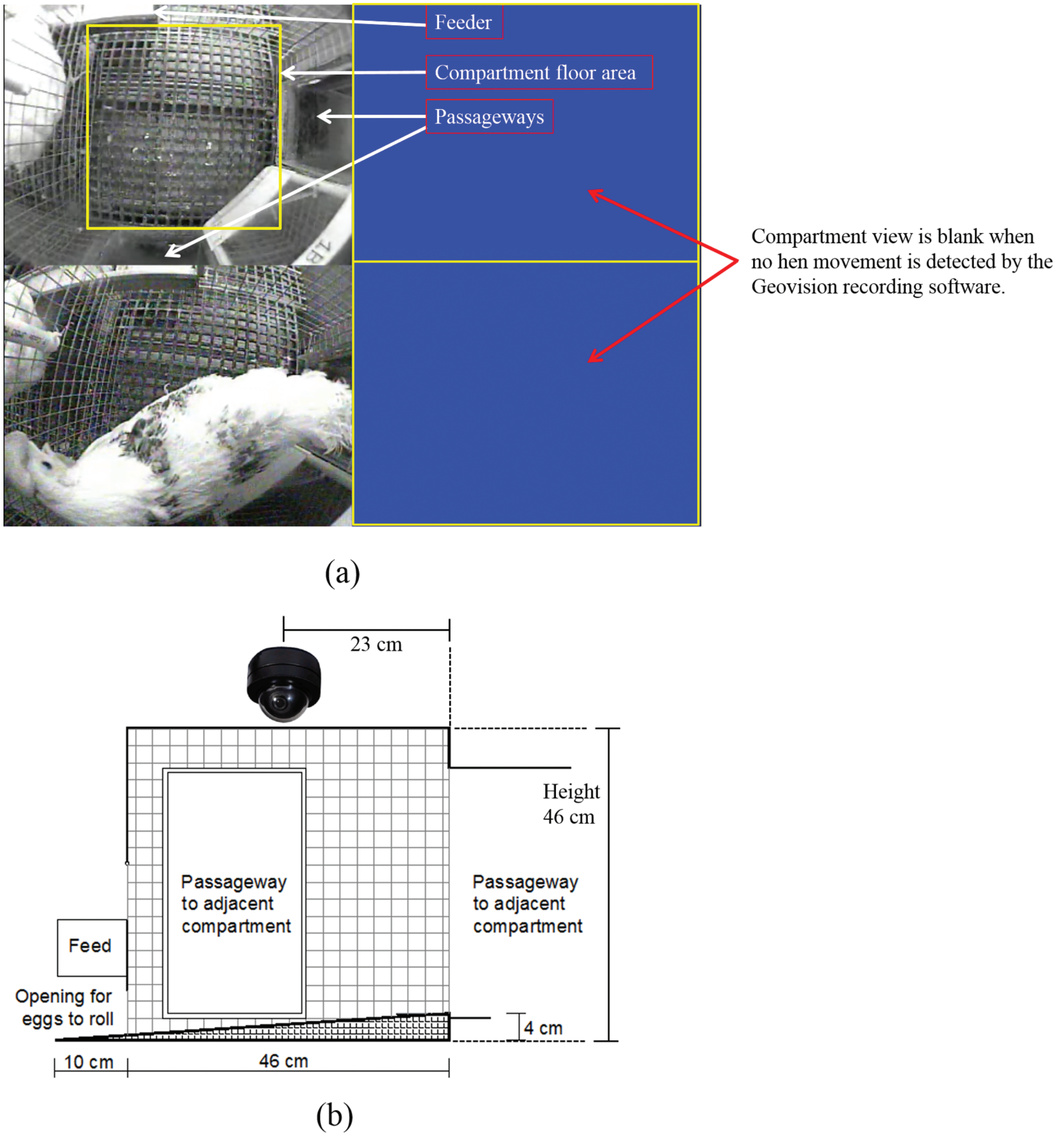

Figure 1. a. Screenshot of the environmental animal preference chamber video monitoring system; b. Cross-section of a cage showing side view of the test bird area with access to 2 passageways. Schematic courtesy of Sales (2012). Color version available in the online PDF.

and continuously determine where a bird was located. The purposes of this system were to record a single hen at a certain compartment, to be capable of operating in harsh environments, and to be built at a relatively low cost. Thus, the system consisted of the following elements:

- A commercial surveillance vision system (Geovision GV-1240A D-Type Combo Card, Geovision Inc., Taipei, Taiwan) including 4 color mini dome analog cameras (Aventura, CAM5D24DNVP) with a 2.4-mm fixed lens; these are weather-proof (IP66) and vandal-proof. Camera resolution was 550 TeleVision Line (**TVL**) during the day and 600 TVL at night.
- A 4-channel VNS-04 Analogue to IP Camera Encoder produced by Aventura, recording rate of 30 frame per second, maximum resolution of 704 × 480 pixels, Moving Pictures Experts Group 4/H264 compression.
- Geovision RemoteViewlog (http://www.geovision.com.tw/english/5_8.asp#) software for merging, tiling, and decoding recorded video files.
- Videos were analyzed in Matrix Laboratory (**MATLAB**) software (2013a version, Mathworks, Natick, MA).

Video Set Description

In total, 16 (d) × 8 (h; average of events per day) × 3,600 (seconds in 1 h) = 460,800 frames were considered for continuous data analysis. Out of this video set, 20 (sessions) × 30 (minutes per session) × 60 (seconds in a minute) or 36,000 scan samples were obtained and used for algorithm development. This represented a rate of 7.8% of labeling. The Validating Choice-Test

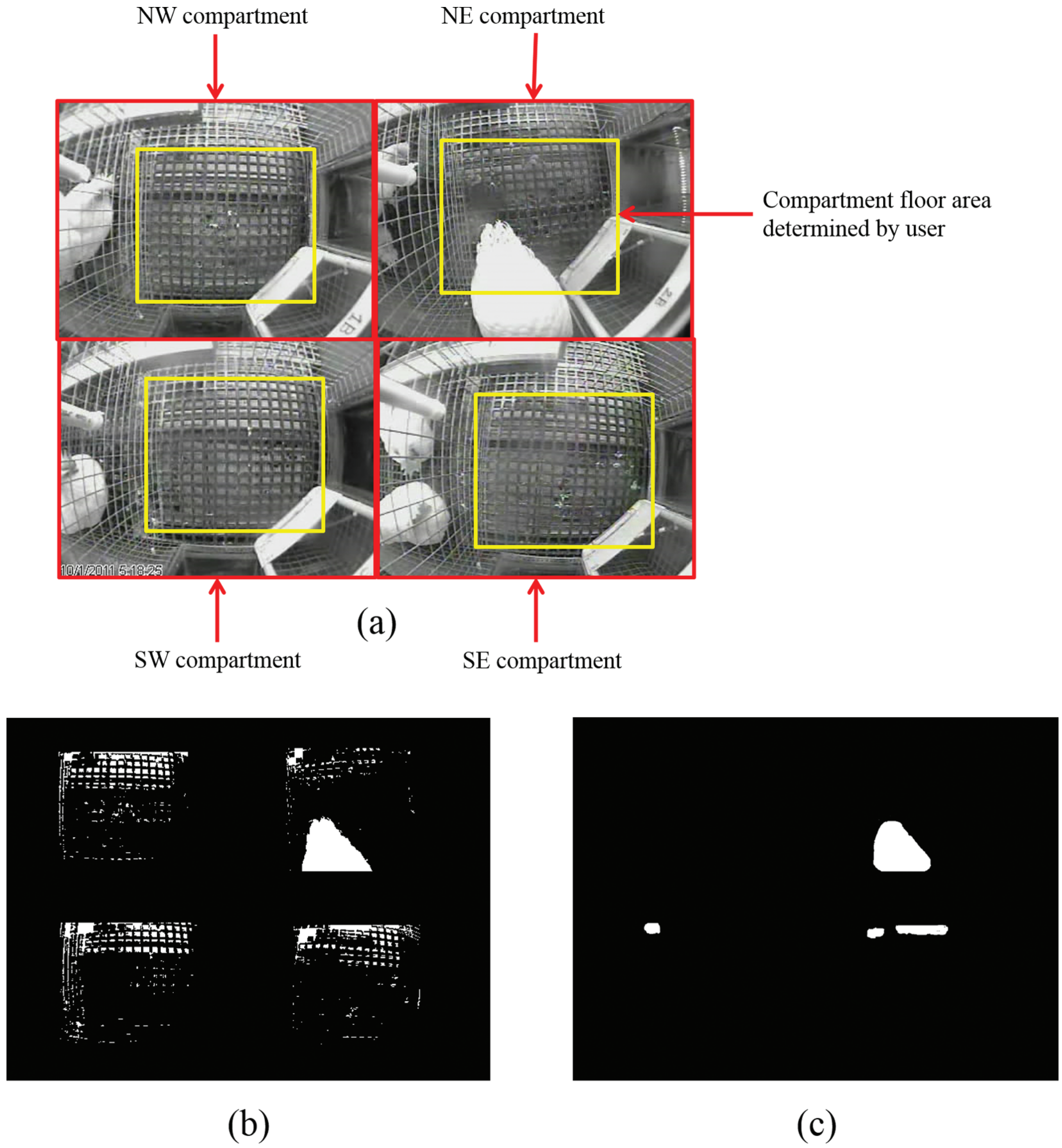

Figure 2. a. Top-view image of the environmental animal preference chamber. NW = northwest; NE = northeast; SW = southwest; SE = southeast. Birds to left of each compartment are companion birds (not included in analysis), and the single test bird is partially visible in the NE compartment. b. Binarized version of part a; c. Binarized image (part b) after applying morphological operators. Color version available in the online PDF.

Positioning Data: Ammonia Aversion Study section below explains how these labeling sessions were chosen.

Tracking Hen Navigation

To detect the hen in a compartment, captured frames were analyzed offline using MATLAB, using the image processing system (**IPS**). The main task for this IPS was to eliminate the background and to extract top-view hen body through image binarization. The binarization procedure was implemented as follows: 1) The image was filtered using a 2-dimensional Gaussian low-pass filter. 2) A global threshold was calculated using Otsu's method (Otsu, 1979). 3) The image (Figure 2a) was subsequently equipped with a hard threshold resulting in Figure 2b. 4) To remove small objects such as compartment grid and edges from the image, a morphological closing operator using a disk-shaped structuring element with a size of 10 pixels (Gonzalez and Woods, 2001) was subsequently applied. The morphological closing operation consists of dilation followed by erosion, using the same structuring element for both operations. Conducting this operation resulted in Figure 2c.

Next, each image was segmented to determine the location of the hen. To segment the image, the hen body was extracted as an ellipse (Zhang et al., 2005) within each pen. The procedure for fitting ellipses to the binary image as displayed in Figure 2c was as follows: 1) Using the direct least squares ellipse-fitting method (Zhang et al., 2005), ellipses were fitted to objects in the image. 2) Ellipse parameters such as "orientation,"

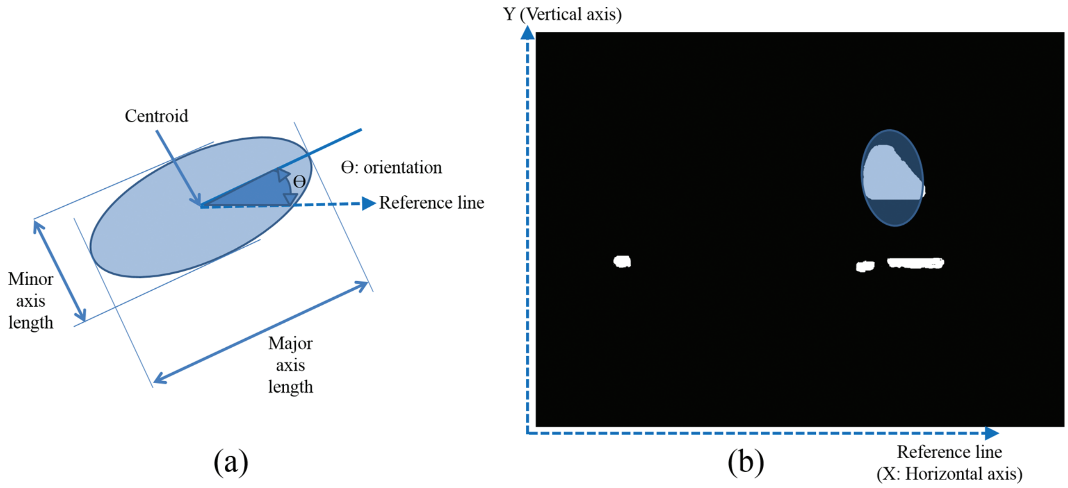

Figure 3. a. Ellipse parameters; b. Ellipse fitted to the partial hen body from Figure 2c. Color version available in the online PDF.

"major axis length," "minor axis length," and "centroid" were calculated for all objects located in the image. To avoid incorrectly identifying other shapes in the pen as birds, a minimum of 360 or 150 pixels and a maximum of 80 or 30 pixels were considered for the major and minor axes of an ellipse, respectively. A hen entering or exiting a compartment was detected using the above thresholds. Figure 3a illustrates these parameters and Figure 3b shows the ellipse fitted to the hen body.

Ellipse Fitting Because hens in the image are similar to an ellipsoidal shape, an ellipse fitting algorithm was implemented to approximate every hen to separate or locate them.

Fitting an ellipse to a general conic can be accomplished by minimizing the algebraic distance over the set of N data points in a least-squares sense. Subsequently, the solution of the minimization problem represents the best-fit ellipse for the given set of points. Each time, 6 edge sample points were randomly selected from the ordered edge points list for one ellipse fitting. The result of finding fitted ellipses is shown in Figure 3b. Mathematical details of the ellipse fitting algorithm have been documented by Fitzgibbon et al. (1999).

Thereafter, ellipse parameters such as "orientation," "major axis length," "minor axis length," and "centroid" for all objects in the image were calculated. Figure 3a illustrates these parameters and Figure 3b shows the ellipse fitted to the hen body that could be detected in a compartment using this method. The other smaller blobs in the figure were ignored because their size was below thresholds.

Hen Choice Test Data Collection

A choice-test study with individuals was conducted in which 4 hens (90 wk of age) were each subjected to a 4-d choice test. Video was collected 24 h per day during this 16-d period and was used 1) for comparing the performance of the automated analysis system to manual assessment of occupancy, and 2) for an initial assessment of aversion to ammoniated atmospheric conditions.

The ammonia concentration was controlled independently in each compartment with a feedback control system, and distinct concentrations were attained within a few ppm_v of the setpoint. Vertical hanging acrylic doors separated each compartment, which improved the control of ammonia at distinct levels, and hens were trained to open them in a separate training apparatus before introduction to the preference chamber. Details of the chamber construction, control system, and ammonia control performance are documented in Sales et al. (2013).

Comparing the IPS to Human Video Observations

Video segments were manually labeled for comparison with IPS analysis. The hen's position within the EPC was tracked by the IPS for half an hour per day (15 min in the morning and 15 min in the afternoon) over 16 d while the hen navigated through compartments. The EPC test videos were analyzed every second for hen location by researchers and graduate students at the Animal Welfare and Environmental Sciences Laboratory at the University of Illinois. Preliminary observations allowed for the selection of distributed sessions throughout the experiment to compare automated with manually labeled occupancy. These sessions were not selected according to a fixed time of the day because videos had been captured on an event basis. The behavior of each individual hen was labeled using Jet-audio Player software (Cowon International) and by instantaneous logging of the occupied compartment in Microsoft Excel (Microsoft Corp., Redmond, WA). As explained in above, 36,000 scan samples were obtained and used for algorithm development. For each scan sample, occupancy of a compartment was monitored and logged. Occupancy behavior was defined as the appearance of

Table 1. Ammonia concentration in different compartments during 16 d of the experiment[1]

Replication	Stage	Days	NH_3 concentration in NW[2] compartment (ppm_v[3])	NH_3 concentration in NE[4] compartment (ppm_v)	NH_3 concentration in SW[5] compartment (ppm_v)	NH_3 concentration in SE[6] compartment (ppm_v)
1	Acclimation 1	1	0	0	0	0
	Baseline 1	2	0	0	0	0
	Treatment 1	3, 4	40	20	10	0
2	Acclimation 2	5	0	0	0	0
	Baseline 2	6	0	0	0	0
	Treatment 2	7, 8	0	10	20	40
3	Acclimation 3	9	0	0	0	0
	Baseline 3	10	0	0	0	0
	Treatment 3	11, 12	10	40	0	20
4	Acclimation 4	13	0	0	0	0
	Baseline 4	14	0	0	0	0
	Treatment 4	15, 16	0	40	10	20

[1]Each hen represents a replicate of the experiment.

[2]Northwest.

[3]Parts per million by volume.

[4]Northeast.

[5]Southwest.

[6]Southeast.

20% of the top-view body area of an average hen, which was equal to 14,000 pixels for the physical arrangement in which the experiments carried out. Average area error of this method is 2.5 cm^2. If no hen was present in a compartment or less than the object area mentioned above was detected, that compartment was considered to be empty.

Every second of occupancy detection resulted from the IPS was compared with the same second result achieved from human video observations. Here, a summary of statistics was compared instead of a statistical comparison. True positive (**TP**) rate and false positive (**FP**) rate was calculated for each day, and false negative (**FN**) could be calculated as 100 − TP (Storey, 2003).

Validating Choice-Test Positioning Data: Ammonia Aversion Study

After developing the IPS technology explained above, the whole data set, namely 460,800 frames, was analyzed to investigate ammonia aversion behavior. Each 4-d choice test consisted of 3 different phases of data collection: acclimation (1 d), baseline (1 d), and treatment (2 d).

During the acclimation phase, the hen had time to adapt to the environment in the EPC and learn to navigate between compartments. During the subsequent baseline phase, no ammonia concentration was applied. This functioned as the reference for the treatment phase. In the treatment phase, ammonia concentration of 0, 10, 20, or 40 ppm was randomly assigned to each compartment (Table 1). During these periods, the video of each compartment was captured and occupancy by the hen was assessed using the IPS. As shown in the table, the experiment was carried out in 4 replications. In each replication, setup and timing was kept identical while different ammonia concentrations were randomly applied to different compartments during treatment phases. This helped to cancel the effect of compartment choice for a certain level of ammonia.

Data were summarized per replication. In each replication, acclimation (1 d), baseline (1 d), and treatment (2 d) phases motion events captured by the Geovision system were merged to make a single video file. The time budget of occupancy for each compartment was tallied, and a total occupancy percentage was calculated for each compartment per day. If a hen was not documented in any compartment, it was assigned to be in a passageway between 2 compartments. No assessment of which tunnel was included in this analysis, though it could be added in the future with a logic sequence. Subsequently, a statistical summary of occupancy percentages was compared among the compartments for each day and phase. Finally, a correlation between occupancy in compartments per phase and applied ammonia concentration on the same phase was sought. All compartments were designed and kept in identical situations, thus no compartment effect was included in the assessment, and correlations between occupancy and compartment were not calculated.

RESULTS AND DISCUSSION

Hen Location Tracking

Figure 4 depicts a hen's movement within the EPC including jumps (misdetections) for one day. At time labels E1, E2, E3, and E4, the chart shows a jump from the northeast (**NE**) to the southwest (**SW**) compartment and vice versa, which is an impossible occurrence because these are opposite compartments and

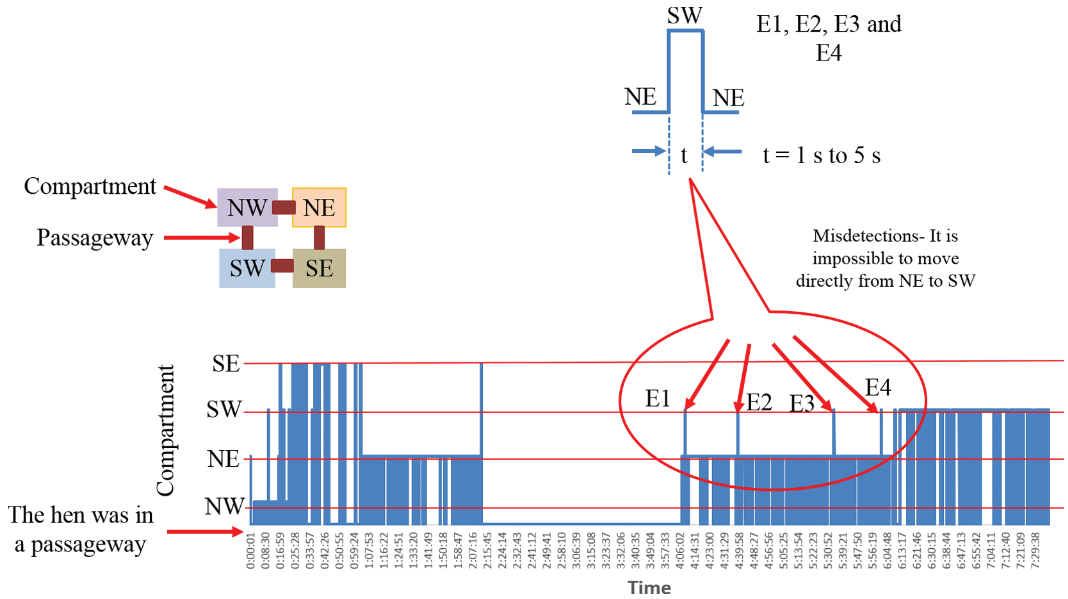

Figure 4. Image processing system (IPS) detection of a hen navigating the environmental animal preference chamber (EPC). Misdetection demonstrates that the IPS failed to detect a hen passing through a compartment in less than 1 s. For example, for events E1 to E4 the hen could only go from the northeast (NE) to southwest (SW) compartment through either the southeast (SE) or northwest (NW) compartment, but no hen was detected in the latter compartments. This was because the hen transited through SE compartment quickly (<1 s). Color version available in the online PDF.

therefore not interconnected (Figure 2a). It was verified with video that the hen moved quickly from NE to SW, being undetected in the NW compartment. Although misdetections were scattered during bird tracking, their causes could be further assessed and minimized for future studies. Some ideas to improve IPS detection within the EPC include installing the camera at an increased height and using color camera. The former will provide a broader camera field of view, and the latter will help to improve image segmentation.

Algorithm Development

The IPS registered 95.9 ± 2.6% of the actual occupancy during trials and 4.2% ± 3.0% false occupancy was reported by the IPS. The distribution of detection rates over the 16 d analyzed was summarized in Figure 5, which was generally uniform from day to day.

Figure 5 compares the IPS success rate with Human Video Observations as reference.

These detection success rates showed that automated video monitoring is suitable for precisely monitoring occupancy of compartments in the EPC. Misdetections were observed, as shown in Figure 5, and were related to 1) the inaccurate segmentations, which were due to variable illumination and similarity of the background to the hen's top-view image; 2) the hen moving faster than the IPS could detect. Higher data quality, e.g., color or 3-dimensional (**3D**) image, might provide a more robust detection system.

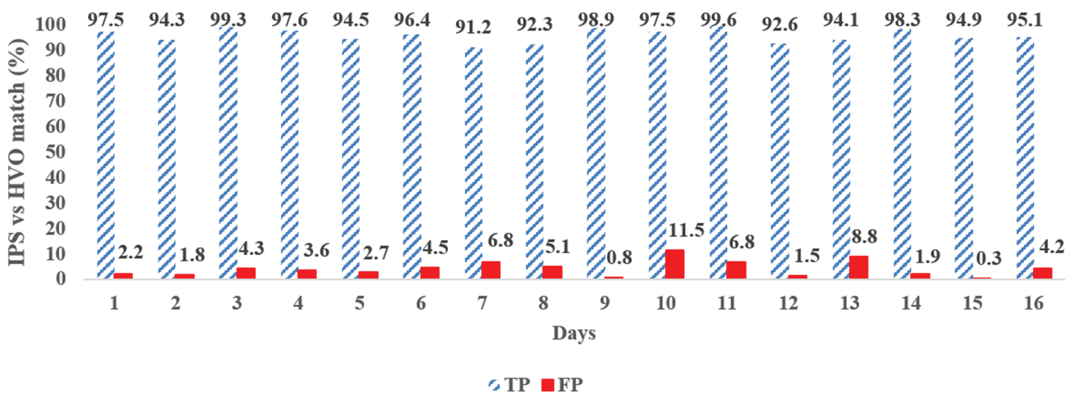

Figure 5. Image processing system (IPS) versus human video observations (HVO) match; TP = true positive; FP = false positive; true negative = 100 – TP. Color version available in the online PDF.

Table 2. Ammonia concentration versus occupancy (Occ.) of 4 environmental animal preference chamber (EPC) compartments (Comp.) during 16 d of the experiment[1]

			NW Comp.		NE Comp.		SW Comp.		SE Comp.		Passageways
Replication	Stage	Day	NH_3 (ppm_v[2])	Occ. (%)	NH_3 (ppm_v)	Occ. (%)	NH_3 (ppm_v)	Occ. (%)	NH_3 (ppm_v)	Occ. (%)	Occ. (%)
1	Acclimation 1	1	0	4	0	15	0	6	0	3	72
	Baseline 1	2	0	0	0	0	0	43	0	32	25
	Treatment 1.1	3	40	0	20	0	10	11	0	71	18
	Treatment 1.2	4	40	0	20	0	10	0	0	86	14
2	Acclimation 2	5	0	0	0	0	0	74	0	21	5
	Baseline 2	6	0	0	0	11	0	88	0	0	12
	Treatment 2.1	7	0	85	10	0	20	1	40	6	8
	Treatment 2.2	8	0	0	10	0	20	99	40	0	1
3	Acclimation 3	9	0	98	0	0	0	0	0	0	2
	Baseline 3	10	0	80	0	5	0	0	0	15	0
	Treatment 3.1	11	10	73	40	0	0	25	20	2	0
	Treatment 3.2	12	10	0	40	0	0	97	20	0	3
4	Acclimation 4	13	0	99	0	0	0	0	0	0	1
	Baseline 4	14	0	1	0	5	0	1	0	93	0
	Treatment 4.1	15	0	1	40	3	10	0	20	96	0
	Treatment 4.2	16	0	2	40	26	10	0	20	72	0

[1]Occupancy in passageways summarizes the time when the hens were not detected in the quad compartments. Each hen represents a replicate of the experiment.

[2]Part per million by volume.

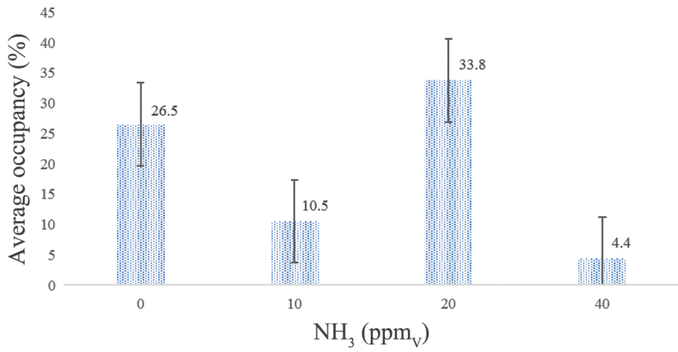

Figure 6. Average occupancy of the compartments versus NH_3 concentration (ppm_v; parts per million by volume) in the environmental animal preference chamber (EPC). Color version available in the online PDF.

Continuous Video Analysis for Ammonia Aversion Analysis

Table 2 shows average occupancy of each compartment in percentage for each period and Figure 6 illustrates this parameter for the whole experiment.

For most of acclimation and baseline stages, hens picked a specific "home" compartment, meaning that they spent most of their time in one compartment (Table 2). The "home" compartment was not the same compartment among the 4 hens tested. Based on results presented in Table 2 and Figure 6, occupancy was lower for compartments with 40 ppm of ammonia concentration while it was higher for 20 ppm compared with lower levels. Moreover, correlation of occupancy with ammonia for data points shown in Table 2 was −16.47 per cent (not significant at $\alpha = 0.05$). Although this correlation is insignificant, it demonstrates that hens tended to avoid compartments with a higher (more than 20 ppm) level of ammonia. Additional replications are needed to form a stronger conclusion regarding hen behavioral responses to ammonia in a choice test.

This initial application of the IPS for assessing occupancy during a choice test demonstrates the successful implementation of an automated system for image analysis for occupancy.

Overall, the IPS performed well in a stainless-steel enclosure containing a hen with cameras installed above the compartments. Each camera covered the entire test bird area of a compartment. This system functioned to track hen navigation through detection of a hen navigating the compartments. To identify potential image processing misdetections and their causes, results of automated tracking were compared with human video observations. During a choice-test study, mean ± SD success detection rates were 95.9 ± 2.6% for an individual bird when measuring compartment occupancy. Sources of misdetection included i) hens in adjacent compartments were visible in camera view and misled the segmentation and ellipse fitting algorithms; ii) similarity of hen's feather color to background and variable illumination; and iii) fast transition of the hen between compartments.

To validate choice-test positioning data in an application, the IPS introduced in this work was subsequently employed to monitor laying hen ammonia aversion. The initial hypothesis was that hens tended to prefer a compartment with lower ammonia level and avoid those with higher levels. Results obtained in this work revealed a trend for aversion of ammonia levels of 40 ppm, but no aversion for 20 ppm or below. Differences observed were not significant, and additional examination including additional replications should be completed to strengthen the analysis.

Considering above results, one might think about advantages of the IPS. First, IPS significantly reduces costs and data processing time compared with the expensive and time-intensive alternative of manual video analysis. Visual observation for a multiple choice behavior would cost about \$50 to \$90 for each hour of data and it could take about 3 times the length of the experiment to be carried out. In comparison, assuming usage of the IPS for 3 experiments and a development period of 6 mo, this would cost \$10 for each hour of data and would take one-fifth the length of the experiment. This is 5 to 9 times cheaper and 15 times faster than visual observations. Second, scoring is affected by expectations of the observer and observer bias could influence subjective scores of animal behavior and welfare (Tuyttens et al., 2014). Thus, lack of the intraobserver repeatability is also an issue in labeling (Van Hertem et al., 2014), which does not exist in automatic monitoring.

In conclusion, the IPS system is suitable for determining the total time hens spend in each EPC compartment and related behaviors such as ammonia aversion. In general, this technology is suitable for choice tests where a top-view camera is of use. For future studies, using color or 3-dimensional cameras and painting hens for identification may contribute to improving IPS performance in the EPC.

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REFERENCES

Calvet, S., H. Van den Weghe, R. Kosch, and F. Estellés. 2009. The influence of the lighting program on broiler activity and dust production. Poult. Sci. 88:2504–2511.

Cotterill, O. J., and A. W. Nordskog. 1954. Influence of ammonia on egg white quality. Poult. Sci. 33:432–434.

Dawkins, M. S. 2004. Using behaviour to assess animal welfare. Anim. Welf. 13:3–7.

Deaton, J. W., F. N. Reece, and B. D. Lott. 1982. Effect of atmospheric ammonia on laying hen performance. Poult. Sci. 61:1815–1817.

Deaton, J. W., F. N. Reece, and B. D. Lott. 1984. Effect of atmospheric ammonia on pullets at point of lay. Poult. Sci. 63:384–385.

De Wet, L., E. Vranken, A. Chedad, J. M. Aerts, J. Ceunen, and D. Berckmans. 2003. Computer-assisted image analysis to quantify daily growth rates of broiler chickens. Br. Poult. Sci. 44:524–532.

Duncan, I. J. H. 1981. Animal rights–Animal welfare: A scientist's assessment. Poult. Sci. 60:489–499.

FASS. 2010. Guide for the Care and Use of Agricultural Animals in Research and Teaching. 3rd ed. Fed. Anim. Sci. Soc., Champaign, IL.

Fitzgibbon, A., M. Pilu, and R. B. Fisher. 1999. Direct least square fitting of ellipses. IEEE Trans. Pattern Anal. Mach. Intell. 21:476–480.

Garner, J. P., A. S. Kiess, J. A. Mench, R. C. Newberry, and P. Y. Hester. 2012. The effect of cage and house design on egg production and egg weight of White Leghorn hens: An epidemiological study. Poult. Sci. 91:1522–1535.

Gonzalez, R. C., and R. E. Woods. 2001. Digital Image Processing. Addison-Wesley Longman Publishing Co. Inc., Boston, MA.

Green, A. R., C. M. Wathes, T. G. Demmers, J. M. Clark, and H. Xin. 2008. Development and application of a novel environmental preference chamber for assessing responses of laboratory mice to atmospheric ammonia. J. Am. Assoc. Lab. Anim. Sci. 47:49–56.

Kashiha, M., C. Bahr, S. Amirpour Haredasht, S. Ott, C. Moons, T. A. Niewold, F. Odberg, and D. Berckmans. 2013a. The automatic monitoring of pigs water use by cameras. Comput. Electron. Agric. 90:164–169.

Kashiha, M., C. Bahr, S. Ott, C. Moons, T. A. Niewold, F. Odberg, and D. Berckmans. 2013b. Automatic identification of marked pigs in a pen using image pattern recognition. Comput. Electron. Agric. 93:111–120.

Kashiha, M., C. Bahr, S. Ott, C. Moons, T. A. Niewold, F. Tuyttens, and D. Berckmans. 2014. Automatic monitoring of pig locomotion using image analysis. Livest. Sci. 159:141–148.

Kashiha, M., A. Pluk, C. Bahr, E. Vranken, and D. Berckmans. 2013c. Development of an early warning system for a broiler house using computer vision. Biosystems Eng. 116:36–45.

Kirkden, R. D., and E. A. Pajor. 2006. Using preference, motivation and aversion tests to ask scientific questions about animals' feelings. Appl. Anim. Behav. Sci. 100:29–47.

Kristensen, H. H., and C. M. Wathes. 2000. Ammonia and poultry welfare: A review. World's Poult. Sci. J. 56:235–245.

Lay, D. C., R. M. Fulton, P. Y. Hester, D. M. Karcher, J. B. Kjaer, J. A. Mench, B. A. Mullens, R. C. Newberry, C. J. Nicol, N. P. O'Sullivan, and R. E. Porter. 2011. Hen welfare in different housing systems. Poult. Sci. 90:278–294.

Leinonen, I., A. G. Williams, and I. Kyriazakis. 2014. The effects of welfare-enhancing system changes on the environmental impacts of broiler and egg production. Poult. Sci. 93:256–266.

Leroy, T., E. Vranken, A. Van Brecht, E. Struelens, B. Sonck, and D. Berckmans. 2006. A computer vision method for on-line behavioral quantification of individually caged poultry. Trans. ASABE 49:795–802.

Otsu, N. 1979. A threshold selection method from gray-level histograms. IEEE Trans. Syst. Man Cybern. 9:62–66.

Sales, G. T. 2012. An investigation of laying hen interactions with ammoniated environments by means of preference testing. PhD Thesis. University of Illinois, Urbana-Champaign.

Sales, G. T., A. R. Green, and R. S. Gates. 2013. Commissioning an animal preference chamber for behavioral studies with laying hens exposed to atmospheric ammonia. Comput. Electron. Agric. 95:48–57.

Scholz, B., S. Urselmans, J. B. Kjaer, and L. Schrader. 2010. Food, wood, or plastic as substrates for dustbathing and foraging in laying hens: A preference test. Poult. Sci. 89:1584–1589.

Sergeant, D., R. Boyle, and M. Forbes. 1998. Computer visual tracking of poultry. Comput. Electron. Agric. 21:1–18.

Storey, J. D. 2003. The positive false discovery rate: A Bayesian interpretation and the q-value. Ann. Stat. 31:2013–2035.

Straw, A. D., K. Branson, T. R. Neumann, and M. H. Dickinson. 2011. Multi-camera real-time three-dimensional tracking of multiple flying animals. J. R. Soc. Interface 8:395–409.

Tuyttens, F. A. M., S. de Graaf, J. L. T. Heerkens, L. Jacobs, E. Nalon, S. Ott, L. Stadig, E. Van Laer, and B. Ampe. 2014. Observer bias in animal behaviour research: Can we believe what we score, if we score what we believe? Anim. Behav. 90:273–280.

Van der Stuyft, E., C. P. Schofield, J. M. Randall, P. Wambacq, and V. Goedseels. 1991. Development and application of computer vision systems for use in livestock production. Comput. Electron. Agric. 6:243–265.

Van Hertem, T., S. Viazzi, M. Steensels, E. Maltz, A. Antler, V. Alchanatis, A. Schlageter-Tello, C. Lokhorst, C. E. B. Romanini, C. Bahr, D. Berckmans, and I. Halachmi., 2014. Automatic lameness detection based on consecutive 3D-video recordings. Biosystems Eng. 119:108–116.

Yang, C.-C., K. Chao, M. S. Kim, D. E. Chan, H. L. Early, and M. Bell. 2010. Machine vision system for on-line wholesomeness inspection of poultry carcasses. Poult. Sci. 89:1252–1264.

Zhang, G., D. S. Jayas, and N. D. G. White. 2005. Separation of touching grain kernels in an image by ellipse fitting algorithm. Biosystems Eng. 92:135–142.