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Automatic detection of changes in pig group lying behaviour using image analysis

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Abstract. *Environmental factors provide important information for the better management of pig farms and they have significant effects on pigs' production efficiency, health and welfare. Due to the physiological and morphological limitations on thermoregulation of pigs, they change their lying behaviour to adapt to high and low temperatures. In hot conditions they avoid physical contact with others in the pen during resting time and vice versa. Visual monitoring of pig behaviours, usually practiced in small scale farms, is unreliable, expensive and time consuming in large scale farms. The development of image analysis systems could be a reliable and non-intrusive technique for automatic assessment of pig group behaviour. The aim of this study was to develop an algorithm for identification of pig group lying behaviour under commercial farm conditions using an optical method. Pigs were monitored by a top view CCD camera and animals were extracted from their background using image processing algorithms. The x–y coordinates of each binary image were used for ellipse fitting algorithms to localize each pig. As a result, ellipse parameters such as "Major axis length", "Minor axis length" and "Centroid" could be calculated for all fitted ellipses. In order to determine the group lying behaviour, the Delaunay triangulation algorithm was applied. By means of the region properties and perimeter of each Delaunay triangule it was possible to automatically find the changes in lying behaviour of grouped pigs and the distance between pigs with high accuracy*

Keywords. *pig, lying behavior, image analysis Delaunay triangle, ellipse fitting*

Introduction

The welfare of an animal can be defined using its behaviour, physiology, clinical state and performance (Averos et al., 2010; Costa et al., 2014). One of the most important factors affecting welfare throughout the stages of breeding, growth and maturity is the environment in which animals are maintained. The environmental temperature has direct effects on pig behaviours. At high temperatures, pigs tend to lie down in a fully recumbent position with their limbs extended and to avoid physical contact with others, in order to be able to transfer as much heat as possible to the environment, and prefer to lie in wet parts of the pen. At low environmental temperatures, pigs will adopt a sternal lying posture and huddle together (Hillmann et al., 2004; Huynh et al., 2005; Spoolder et al., 2012; Costa et al., 2014; Debreceni et al., 2014). Observations of lying behaviour of pigs have already been made in numerous studies, often in conjunction with other behavioural and/or physiological features of the animals. However, these investigations have generally been carried out under experimental conditions, reflected by a small number of pigs in the pen. Experiments have been carried out to study the lying postures and space occupation (Ekkel et al., 2003), and to assess optimal temperature ranges for fattening pigs of different weights kept in pens (Hillmann et al., 2004). The results showed that with increasing temperature, pigs used the dunging area more often and laid more often without contact with pen mates, whilst pigs showed huddling at lower temperatures. Such data have generally been collected either by direct observation of the pen or with the aid of video recordings. These methods are labour-intensive and time-consuming (Stukenborg et al., 2011). Image processing has been an important technique for a wide variety of applications in agriculture and food engineering. This technique is an alternative, non-contact way to replace human observation of the animals and causes no disruption to the animals' normal behaviour (Tillet et al., 1997; Shao and Xin, 2008; Costa et al., 2013; Kashiha et al., 2014). There are several recent studies in the literature where computer vision has been applied to pig behaviours. A real-time image processing system was developed to detect movement and classify thermal comfort state of group-housed pigs based on their resting behavioural patterns by Shao and Xin (2008). The results showed that this system effectively detects animal movement, and correctly classifies animal thermal behaviours into cold, comfortable, or warm/hot conditions. Recently, another research group has performed image processing in pigs focusing on behaviour classification (Costa et al., 2013). The aim of this study was to develop an innovative method for measuring the activity level of pigs in a barn in real time. An infrared-sensitive camera was placed over two pens of the piggery, images were recorded for 24 h a day for eight days during the fattening period, and the activity and occupation indices were calculated every second in real time using software. In a similar study, Costa et al. (2014) evaluated the relationship between pig activity and environmental parameters in a pig building by means of image analysis. They showed that there was a significant relation between pig activity index and ventilation rate, temperature and humidity. Although these studies have concentrated on lying parameters by image analysis, no specific patterns for changes in lying behaviours in different environment temperatures were investigated in groups of pigs under commercial farm conditions. Therefore, the main purpose of this study was to identification of the lying pattern of pigs, the location of pigs during lying time and the distance between them using image analysis technology involving charge-coupled device (CCD) cameras.

Material and methods

Animals and housing

The observations were conducted at a commercial pig farm in the UK. A series of rooms each housed 240 finishing pigs; rooms were 14.35 m wide × 20.00 m long, mechanically ventilated and subdivided into 12 pens, each 6.75 m wide × 3.10 m long, and with a fully slatted floor. All pens were equipped with a liquid feeding trough and one drinking nipple. From the 12 pens in the room, two pens were selected for the experiments, each containing 22 pigs. The white fluorescent tube lights were switched on during day and night. Room temperature was recorded over the total experimental period with 16 temperature sensors arranged in a grid pattern. The experimental phase started after placement in the pen and lasted 15 days.

Image processing

The camera (Sony RF2938, EXview HAD CCD) was located 4.5 meters above the ground with its lens pointing downward and directly above each pen to get a top view of the pen (Fig. 1). Cameras were connected via cables to a PC and video images from the cameras were recorded simultaneously for 24 hours during the day and night and stored in the hard disk of the PC using Geovision software (Geovision Inc.) with a frame rate of 30 fps. The original resolution of an extracted image from the video was 680 × 480 pixel^2 and extracted from the 360 h of recorded videos. To develop algorithms for continuous automated identification of changes in pigs lying behaviour, the location of each group of pigs needs to be known during certain periods. After downloading the recorded data, the video files were visually investigated and labelled (24 h/day for five days) in order to evaluate animal lying times during the study. Four 10-min durations (duration 1, from 6.00 to 6:10AM; duration 2, from 12.00 to12:10 PM; duration 3, from 18.00 to 18:10 PM; duration 4, from 0.00 to 0:10 AM) were selected based on observations that showed almost all pigs lying in these times during the 24 hours in a day.

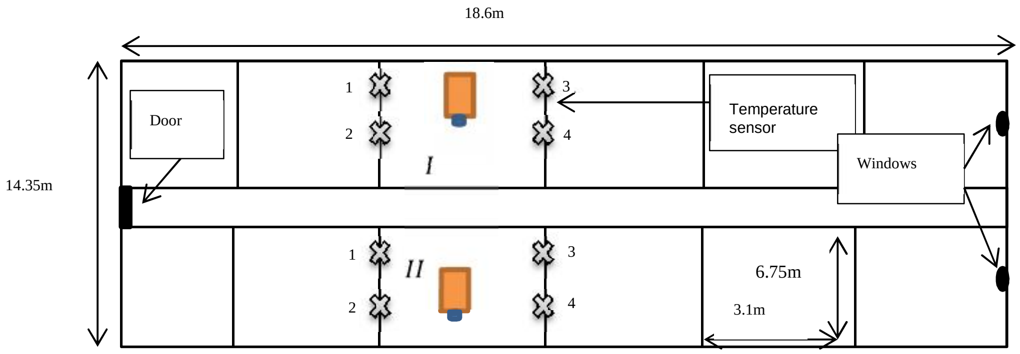

Figure 1. Top view of the research barn

In order to remove Barrel distortion in the images, camera calibration was carried out using the ‘Camera Calibration Toolbox’ of Matlab and 25 images of a checkerboard pattern were taken in different orientations for each camera (Wang et al., 2007). Each pen was virtually subdivided into four zones (Fig. 2a); zone four being near the corridor and zone one against the outer wall. Images from each camera were then analysed using background subtraction algorithms. The grey image was converted into a binary [0, 1] image with threshold and 1 assigned to the object and 0 assigned to the background. Erosion and dilation orders with disk structure were used for smoothing of edges. To remove small objects from the image a morphological closing operator with a disk-shaped structuring element was used (Gonzalez & Woods, 2007) (Fig. 2b).

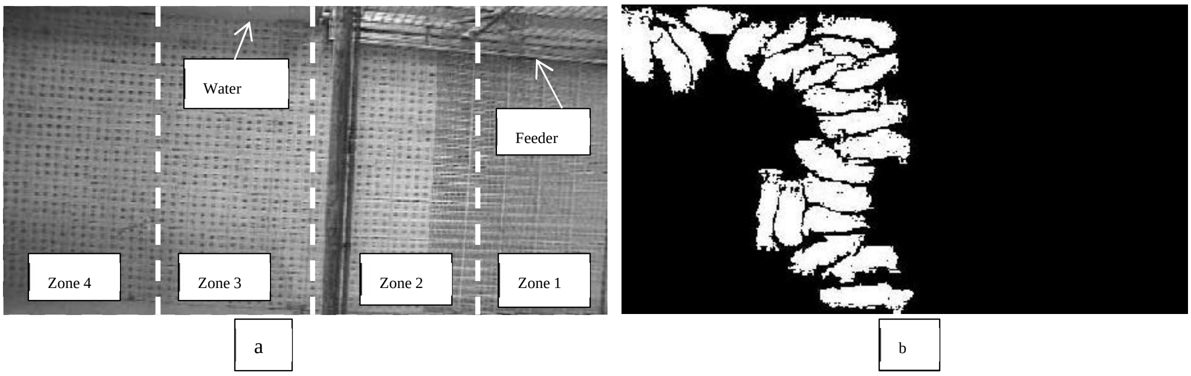

Figure 2. The background and four zones in pen I (a), binary image after applying morphological operators (b).

Since the single pig in the image is similar to an ellipsoidal shape, the x–y coordinates of each binary image could be used for ellipse fitting algorithms to localize each pig. As a result, ellipse parameters such as “Major axis length”, “Minor axis length”, “Orientation” and “Centroid” could be calculated for all fitted ellipses to separate the touching pigs (Fig.3). Therefore each pig's body was extracted as an ellipse using the direct least squares ellipse fitting method and the aforementioned ellipse parameters (McFarlane and Schofield, 1995; Leary, 2004; Kashiha et al., 2013).

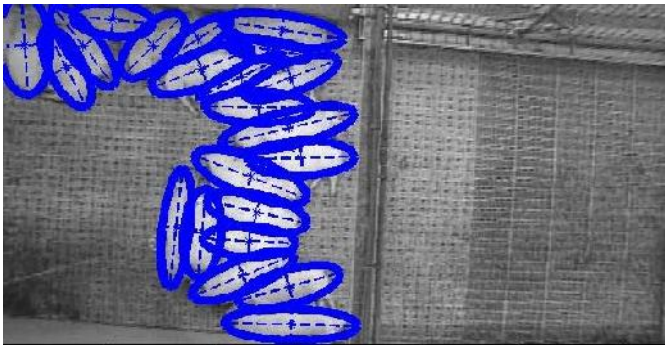

Figure 3. Ellipse fitted to each pig with their parameters

Delaunay triangulation(DT) was performed by using the P points in a plane DT (P), such that no point in P was inside the circumcircle of any triangle in DT (P) and the circumcircle of a triangle was the unique circle that passed through all three of its vertices (Hansen et al., 2001). Delaunay triangulation maximized the minimum angle of all the angles of the triangles in the triangulation and tended to avoid skinny triangles. In this study the method used for the computation of the Delaunay triangulation was implemented in MATLAB software and we used the centre of each ellipse (Fig. 3) obtained from the image as a triangulation point. Furthermore, for getting a set of non-overlapping triangles with the minimum of the inner angles, at first the algorithm in MATLAB transformed the 2D points to 3D, here it computes the convex hull in 3D, and then projected the lower part of the hull back to 2D to obtain the triangulation (Häfner et al., 2012). Fig. 4 shows the black colour channel with 22 vertexes (number of pigs) of a sample image from the image database along with the Delaunay triangulation.

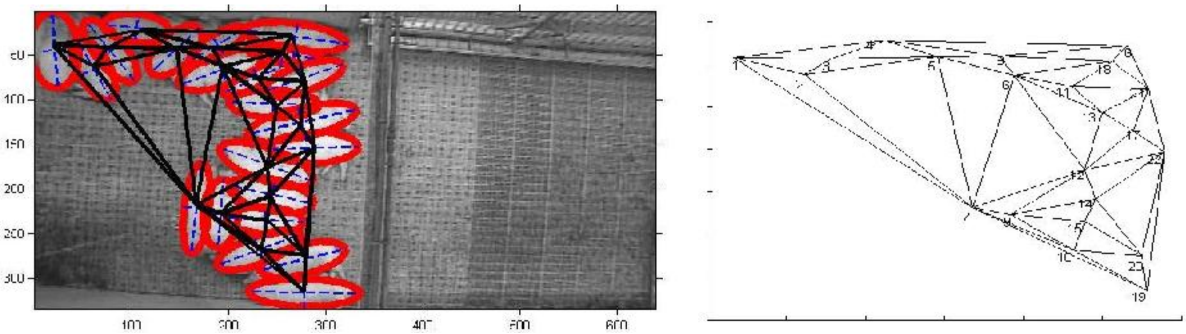

Figure 4. Delaunay triangulation along with the fitted ellipse

The perimeter of each triangle in the Delaunay triangulation shape reflects how closely pigs touch each other, and is calculated as: $P = l1 + l2 + l3$ where l represent the length of side of the triangle (in pixels). The next step was to extract the major and minor axis of each fitted ellipse for defining the lying pattern between grouped pigs which was shown as:

$$Lying\ pattern = (number\ of\ triangles\ with\ certain\ pattern/number\ of\ all\ triangles) \times 100 \qquad (1)$$

Where the certain pattern could be defined as: if *P* was less than 200 (in pixels) it was considered as a '*close pattern*', if it was between 200 and 350 it was considered as a '*normal pattern*' and *P* more than 350 was considered a '*far pattern*'.

Results and discussion

In order to validate the automated image processing technique, the percentage of correct estimates of each pig with reference to manual labelling is shown in Table 1 after the x-y coordinates of each body were determined by the ellipse fitting method. There were 15 (days) ×10 (min) × 4 (times in a day) × 2 (pens) of video duration, and each video consisted of 600 frames (one frame per second). We only selected pictures with no locomotion or active behaviour.

Table 1. The percentage of correctly estimated locations of the body of each pig

Day	Pen			
	I		*II*	
	Number of frames	Correct estimation (%)	Number of frames	Correct estimation (%)
1	1375	95.76	1519	94.18
2	1575	93.12	1713	97.70
3	1348	94.31	1496	95.36
4	1572	95.13	1620	100
5	1514	94.08	1377	97.48
6	1647	98.66	1780	95.95
7	1347	97.69	1104	92.10
8	1540	96.14	1385	91.48
9	1444	93.97	1531	94.94
10	1280	94.41	1609	93.62
11	1551	99.50	1705	96.58
12	1300	93.50	1380	95.06
13	1606	93.21	1690	90.49
14	1575	93.15	1545	97.67
15	1630	95.89	1597	93.29
Total	**22304**		**23051**	

By computing the x–y coordinates of each binary image we found the centre of each fitted ellipse (pig) so the number of pigs in each image was calculated and then compared with the number of pigs in each pen. The results showed that the correct estimation of pig body location using image processing techniques was 95.14 %, on average. There were a few reasons behind false identification: first and foremost because the project was carried out in a commercial farm, there was a water pipe in the middle of each pen (2.5 meter from the floor) which caused some invisible areas in images. Furthermore, as time progressed, soiling by flies dirtied the camera lenses and reduced the visibility. The temperatures of each sensor in the two pens during the 15 days of study are shown in Fig. 5 Over the recording period, temperatures ranges were14.3-22.3 ^{o}C for pen *I*, and 13.7-22.2 ^{o}C for pen *II*.

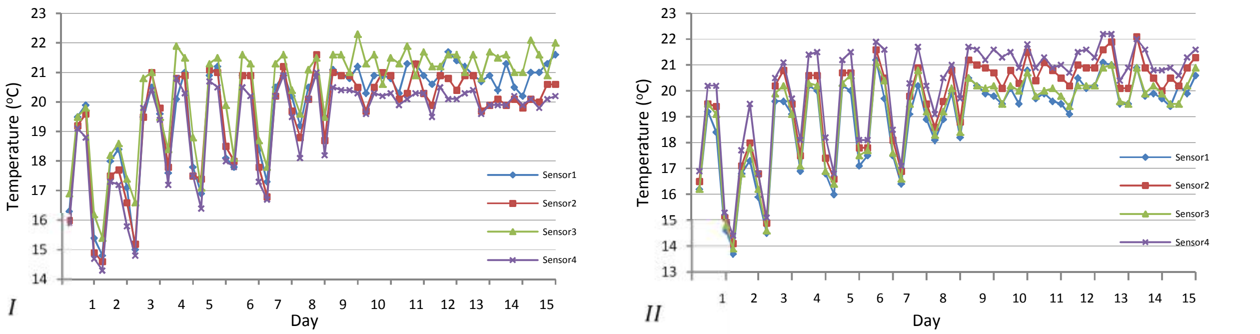

Figure 5. Temperature for both pens for 15 days

Fig 6 shows sample images from the image database with the respective Delaunay triangulations. From this figure it can be seen that the perimeter of each triangle was different as temperature changed during the study. The number of triangles with smaller perimeter was higher at 14.2°C than at temperatures of 19.7 and 22.0 °C. The extracted data from the images were submitted to regression analysis (SPSS 21, IBM, USA) to evaluate the effects of temperature on the lying patterns in both pens (Table 2).

Table 2. Regression analysis for effect of temperature on the determined lying patterns in both pens

Pen	Equation (± Std.Error)	R^2	*p-value*
Pen *I*	% Close= 55.68 (±41.35)+ 0.27(±0.36) temperature^2 -0.16 (±0.01)temperature^3	0.71	<0.001
	% Normal= ln(5.92) (±1.80) + ln (1.09 (±.01) temperature)	0.35	<0.001
	% Far= 121.91 (±39.85)- 1.09 (±0.35) temperature^2 + 0.04 (±0.01)temperature^3	0.52	<0.001
Pen *II*	% Close= 219.85 (±12.75) – 9.03 (±0.65) temperature	0.77	<0.001
	% Normal= ln(2.44) (±0.92) + ln (1.14 (±.02) temperature)	0.46	<0.001
	% Far= 200.14 (±105.85) – 25.93 (±11.66) temperature + 0.85 (±0.31)temperature^2	0.59	<0.001

Table 2 shows the relationship between temperatures and lying pattern was statistically significant for both pens. However, the R^2 values were only high for the close lying pattern.

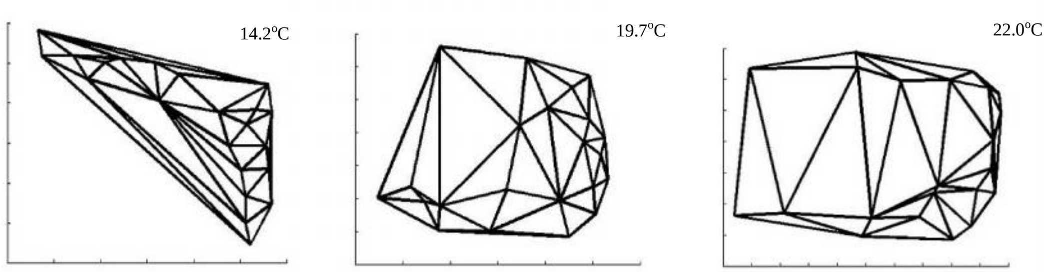

Figure 6. Delaunay triangulation pattern in different temperatures

In our study, video monitoring of pig lying behaviour, which was performed through image processing techniques and using Delaunay triangulation, showed that at higher temperatures, pigs lay down with their limbs extended and in a fully recumbent position so that the number of triangles with perimeter of more than 350 (in pixels) was higher than other perimeter values. In contrast, at lower environmental temperatures pigs adopted a body posture that minimized their contact with the floor and maximised contact with other pigs, so that the number of triangles with perimeter of less than 200 (in pixels) was higher. This result is in agreement with other researchers (Shao and Xin, 2008; Costa et al., 2014) who have reported that in higher temperatures pigs tended to spread out, and in a cold situation they tried to huddling or touch each other. Different lying patterns (in percentage of time) for the two pens during this study are shown in Fig. 7 and 8.

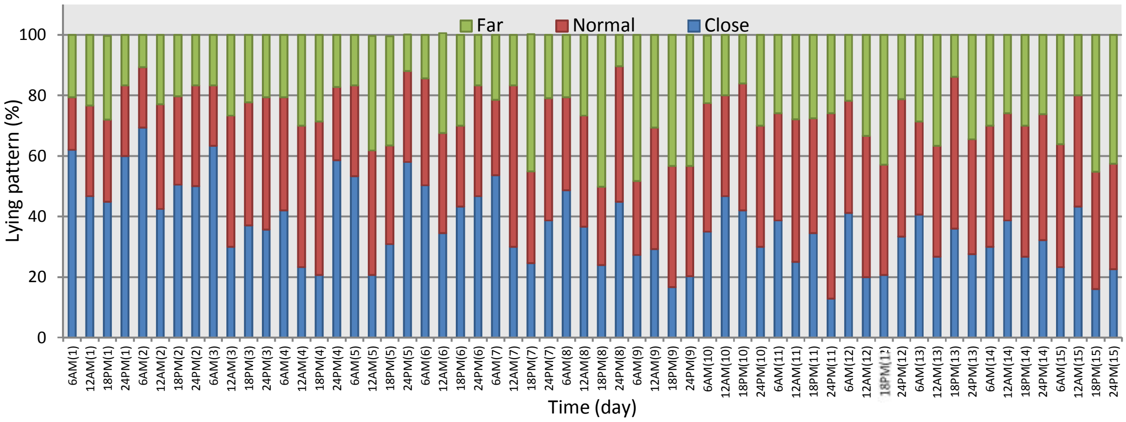

Figure 7. Lying pattern (in percent) over 15 days in pen *I*

By comparing temperatures in the two pens and according to the lying pattern data, the percentage of close pattern over 15 days in pen *II* is about 1.2 times higher than pen *I*.

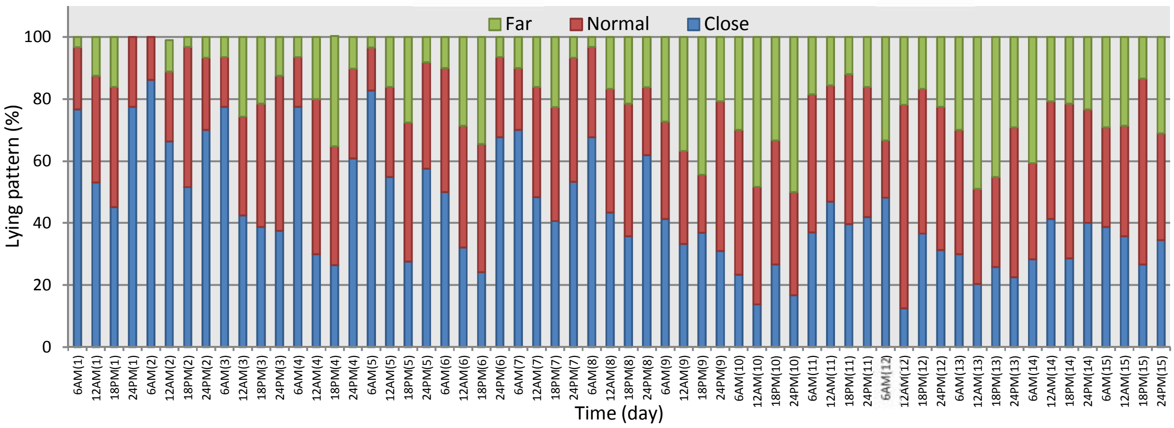

Figure 8. Lying pattern (in percent) over 15 days in pen *II*

Employing modern technology has helped farm managers to improve animal welfare (Kashiha et al., 2014). The proposed method can help to monitor a large number of pigs in different commercial pens and to adjust room temperature for higher welfare and economic outputs. Knowing the position of each pig in the pen during lying time can be used to assess and improve animal welfare, since lying in dunging area has negative consequences for hygiene, resulting in dirtier pigs and pens (Spoolder et al., 2012). Using the x-y coordinates of each pig in binary images and the centroid of each fitted ellipse indicated the specific position of each pig in the pen during the lying time (see Fig. 9). Over the 15 days, the percentage of lying positions was higher in zone 4 (near the corridor) and zone 3 when then the temperature was lower in both pens; similar results were reported by Costa et al. (2014). According to Fig. 9, in both pens pigs tended to lie in zone 4 and 3 more than other zones, but when temperature increased they tended to lie more often in other zones. The percentage of time in different lying zones was different between the two pens during the study; in pen II more than 70 % of the animals were in zone 4 for the first 6 days while there was a fluctuating pattern in pen I. This indicates that the output could be used for assessing the uniformity of room temperature and adequacy of the ventilation system. Automatic identification of pig behaviours using image processing and camera techniques is a non-contact way and thus does not cause disruption to the animals' normal behaviour which occurs when direct observations are made by stock people.

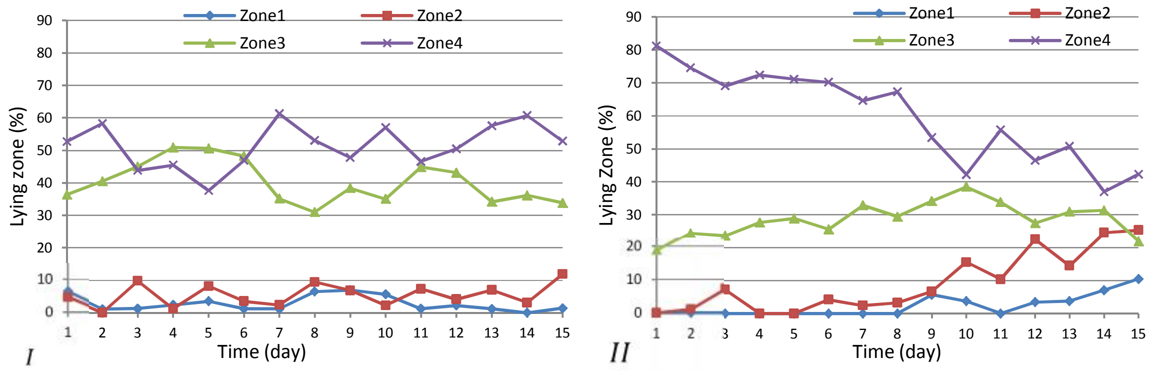

Figure 9. Mean value of location of lying pigs in different zones over 15 days

Conclusion

In conclusion, the method developed can measure, using Delaunay triangulation, the exact location of each pig during lying time and changes in lying behaviour with a high degree of accuracy in commercial farm conditions. Therefore this method could contribute in the future as an important and economically feasible technique in commercial farms for assessment of livestock welfare in terms of the adequacy of environmental conditions. This is an important step towards the development of an automated system that can detect exact lying patterns of pigs by image features over time. However this method needs a greater duration of testing and future development of a method for the detection and removal of moving pigs from the image in order to monitor pig lying patterns in a fully automated way.

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