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Environment and Behavior 1: Recent Advances in Assessment and Management of Heat Stress in Domestic Animals

Assessing Swine Thermal Comfort by Image Analysis of Postural Behaviors[1]

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ABSTRACT: Postural behavior is an *integral* response of animals to complex environmental factors. Huddling, nearly contacting one another on the side, and spreading are common postural behaviors of group-housed animals undergoing cold, comfortable, and warm/hot sensations, respectively. These postural patterns have been routinely used by animal caretakers to assess thermal comfort of the animals and to make according adjustment on the environmental settings or management schemes. This manual adjustment approach, however, has the inherent limitations of daily discontinuity and inconsistency between caretakers in interpretation of the animal comfort behavior. The goal of this project was to explore a novel, automated image analysis system that would assess the thermal comfort of swine and make proper environmental adjustments to enhance animal well-being and production efficiency. This paper describes the progress and on-going work toward the achievement of our proposed goal. The feasibility of classifying the thermal comfort state of young pigs by neural network (NN) analysis of their postural images was first examined. It included exploration of using certain feature selections of the postural behavioral images as the input to a three-layer NN that was trained to classify the corresponding thermal comfort state as being cold, comfortable, or warm. The image feature selections, a critical step for the classification, examined in this study included Fourier coefficient (FC), moment (M), perimeter and area (P&A), and combination of M and P&A of the processed binary postural images. The result was positive, with the combination of M and P&A as the input feature to the NN yielding the highest correct classification rate. Subsequent work included the development of hardware and computational algorithms that enable automatic image segmentation, motion detection, and the selection of the behavioral images suitable for use in the classification. Work is in progress to quantify the relationships of postural behavior and physiological responses of pigs using thermographs. The results are expected to facilitate *objective* training of NN, hence improving the accuracy of the postural image-based assessment of the thermal comfort state. Work is also in progress to implement the analysis and assessment algorithms into computer codes for *real-time* application.

Key Words: Behavior, Image Processing, Neural Networks, Animal Welfare

Introduction

The attempt to assess and maintain the thermal comfort of pigs (and other agricultural animals) has been based on measurement and modification of the housing air temperature. However, it is commonly recognized that pig well-being and performance are affected not only by air temperature, but also by other important factors, such as air drafts, radiation, floor condition, humidity, group size, nutrition plane, and

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health state (Bruce and Clark, 1979; Boon, 1981; Geers et al., 1986). Yet it is impractical to employ individual sensors to monitor and integrate the effects of the complex thermal, nutritional, and health variables. The inherent lack of compatibility between the air temperature-based assessment and the real thermal needs of the pigs can lead to suboptimal animal well-being and performance even when the air temperature is maintained at the seemingly desired levels. It is this pitfall that prompted the efforts described in this article.

Behavioral Assessment of an Animal's Environment and Comfort

The best way to assess and maintain the optimal environment and thus well-being of the animals is to watch their behavior, a practice that many dedicated animal caretakers follow. This is because animal behavior is an integral response to all thermal, nutritional, and health factors. Pigs, like other farm animals, display the posture of huddling when cold, spreading when hot, and nearly touching one another on the side when comfortable (Mount, 1968). Although watching pigs' behavior is the most effective way to determine and ensure their comfort, caretakers cannot watch the animals and make control adjustments 24 h/d, 7 d/wk. The judgment of animals' thermal comfort level for a given postural behavior may also differ from one caretaker to another. This is the rationale and significance of the present study, which explores a novel, automated assessment and control approach that uses postural behavior of pigs as the integrated biological sensor.

About a decade ago, DeShazer and Randall (1988) predicted that the use of computer vision for improved animal welfare and care would be significant for future electronic livestock management. However, meager information or effort has since been documented on the subject. Belgian scientists Geers et al. (1991) tried this approach with growing pigs. The researchers classified the behaviors of pigs into huddling or spreading according to the occupation percentage of the pig pixels inside different preset windows in a digitized pen image. By comparing the actual occupation percentages with the reference values, decisions could be made to either increase or decrease the environmental temperature set point. However, the method required the existence of a specially designed temperature gradient in the pigpen. The floor occupation percentage by the pigs also depended on age or size of the animals. These limitations present obstacles to real-time application of this potentially superior technique and thus should be overcome.

The neural network (**NN**) has been increasingly used by scientists and engineers to identify data patterns and their relationships. The NN is a mathematical computational method to model nerve operating systems. It consists of a set of interconnected nodes analogous to neurons in the brain (Figure 1) and functions similarly to human beings in that it learns from experience. This implies that training and learning rules are necessary in the creation and operation of a NN. The training and learning rules enable a network to "gain knowledge" from the available data and then apply that knowledge to recognize new and unknown data patterns. In general, a NN constitutes input-layer, hidden-layer, and output-layer nodes. Between the input and hidden layers and between the hidden and output layers, nodes are fully connected by weights (Figure 1). The weights can be computed in many ways for different training and learning purposes. The number of nodes in each layer and the number of hidden layers determine the complexity of a NN. As an artificial intelligence classifier, NN presumably has the potential to classify the postural behavior of pigs corresponding to their thermal comfort state.

The objective of our research effort was first to test whether the thermal comfort state of pigs subjected to different thermal environments could be classified by NN using certain features of the processed postural images as the input, and, if proven feasible, to proceed with the development of an automated, behavior-based assessment and control method to enhance animal well-being and production efficiency. The new method would contain the essential components and steps as shown in Figure 2.

Feasibility Study

The feasibility study was conducted to test the hypothesis that the postural behaviors of group-housed pigs subjected to different environmental conditions could be reasonably classified by a NN with properly chosen feature representation of the spatial distribution of the pigs. The following sections describe the experimental procedures and results.

Experimental Pigs and Housing Environment

Early-weaned pigs at an initial age of 2 wk were used in this study. Cold, comfortable, and warm

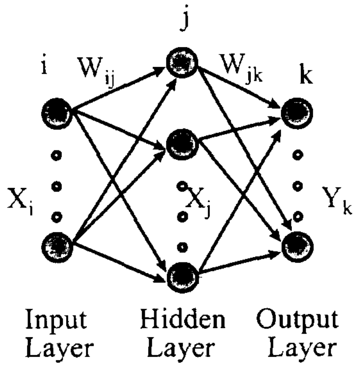


Figure 1. Schematic representation of a three-layer neural network (NN).

behaviors of the experimental pigs were induced by subjecting them in 10-pig groups to the respective thermal conditions inside four indirect calorimeter chambers (1.52 × 1.83-m floor dimension). The air temperature inside the chambers was maintained at 24.4, 26.7, 28.9, and 31.1°C, respectively, for the first week and was reduced by 1.1°C each following week. The concomitant relative humidity was 40 to 55%. Plastic-coated wire mesh floor (TenderNova, Farm-Tek, Dyersville, IA) over a shallow pull-plug manure pit was used. Continuous illumination of 27 lux was provided throughout the trial period. The pigs were given ad libitum access to commercial starter and grower diets. They were acclimatized inside the chambers for 3 d before measurements started. A complete description of the Iowa State indirect calorimeter system can be found in a previous publication by Xin and Harmon (1996).

Behavior Recording and Classification

A camera (Canon T-70 with command back; Canon U.S.A., Inc., Lake Success, NY) was mounted on each chamber ceiling and was programmed to photograph the entire floor area of the chamber at 40-min intervals. The photographs containing the postural behaviors were manually selected and digitized by scanning for subsequent processing and analysis. The pictures containing pigs in motion were considered not to reflect the comfort of the pigs and were excluded from the analysis. An example of the digitized raw behavior images of the pigs and their surroundings is shown in Figure 3.

The postural behaviors of the pigs were classified to represent three states of thermal comfort, i.e., cold, comfortable, and warm, corresponding to the posture of huddling together, nearly contacting one another on the side, and spreading apart to avoid body contact. The same qualitative criteria had been used by Mount (1968) to classify the thermoregulatory behavior of pigs. The relative spatial positions of the pigs presumably contained all the information needed for the behavioral classification by the image analysis.

Segmentation of the Postural Images

The first step toward the behavioral classification by image analysis was to segment the pigs from their background, including the floor, feeder, drinker, manure (if present), and portions of chamber wall. This procedure involved application of image-processing techniques of thresholding, edge detection, and morphological filtering. It is not the intention or scope of this paper to describe such image-processing techniques, which have been presented in depth by Shao (1997) and Shao et al. (1997). Because of the similar color of the white pigs and the white chamber wall, manual coloring of certain raw images (portions of the walls) was used to establish image contrast. This shortfall was subsequently overcome by using a contrasting background during the development of hardware and software for automatic image segmentation. The result of the image processing was a binary image with the pigs in white color (1) and the background in black color (0). For presentation purposes, the colors of pigs and background were reversed. The binary images for the raw images in Figure 3 are presented in Figure 4.

Feature Extraction of the Segmented Postural Images

The huge amount of data (expressed in pixels) contained in each binary image prohibits rapid, efficient manipulation of the images, e.g., as the input

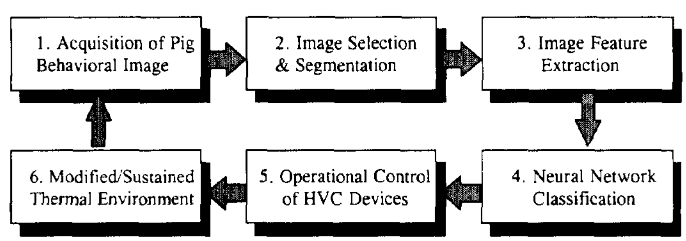


Figure 2. Schematic representation of the behavior-based environmental assessment and control for growing pigs.

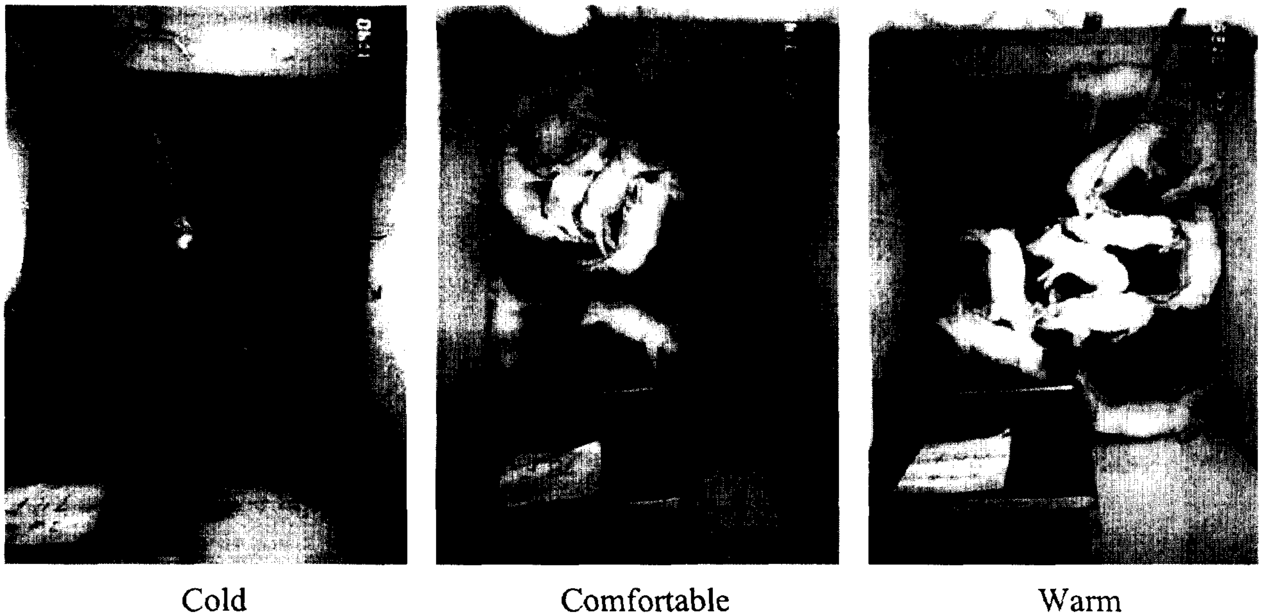


Figure 3. Example postural behaviors of young pigs exposed cold, comfortable, and warm conditions.

to a NN. Thus, proper features that characterize the behavioral images while reducing the magnitude of the original data set are essential. Features are represented by mathematical expressions. The following features were examined in this study (refer to Shao et al., 1998, for details). They all represent the relative spatial distribution of the pigs on the floor, with each having unique characteristics.

Fourier Coefficients (FC). The FC are invariant with size, position, or orientation of the images. The feature of being invariant is very useful for minimizing the effects of body weight/size of the animals on the

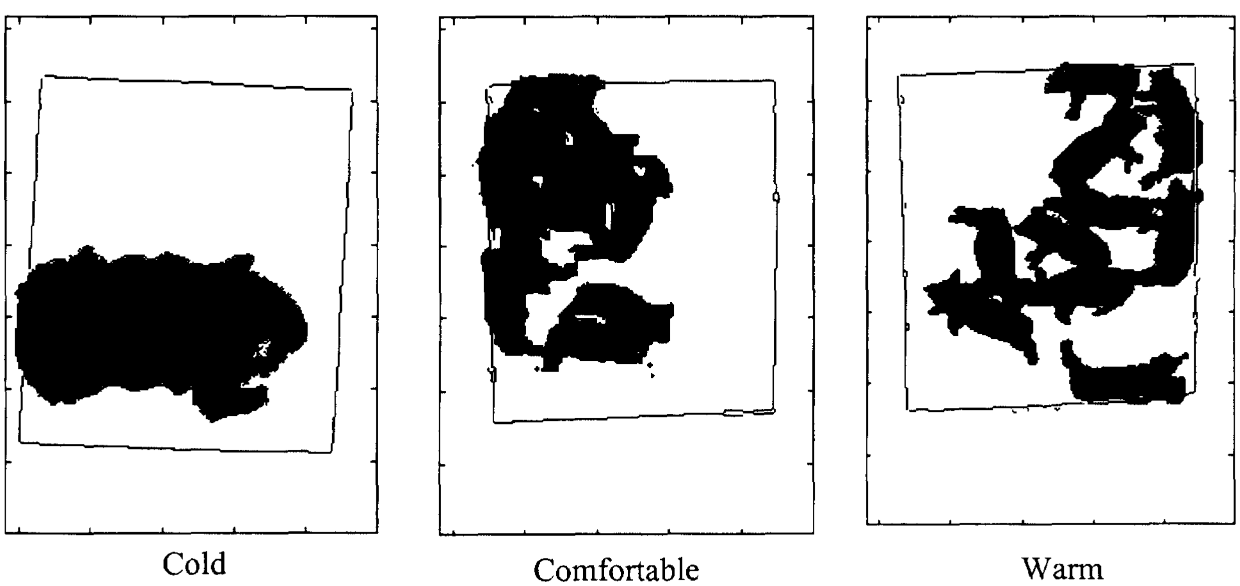


Figure 4. Example binary images corresponding to the pig behavior images as shown in Figure 3.

Table 1. Correct classification rate of the pig thermal comfort behaviors by the NN using the selected features as input. Values in parentheses represent correctly classified images vs. total images involved

Image for	Fourier coefficients	Moment (M)	Perimeter(P) & area(A)	M, P&A
Training	99% (136/138)	92% (125/136)	96% (96/100)	99% (134/136)
Testing	78% (51/65)	73% (46/63)	86% (31/36)	90% (57/63)

classification. Generally most information of an image can be represented by the first few FC (Oppenheim and Schafer, 1989). The FC, denoted as F(u, v), has the following expression:

$$F(u, v) = \sum_x\sum_y f(x, y)e^{-j2\pi(ux+vy)/N}$$

where x and y are spatial domain coordinates, u and v are frequency domain coordinates, N is the size of the image, and f(x, y) is the gray level of the pixel. The first 8 by 8 FC were found to contain majority of the image information in this study and were thus used as the feature.

Moment (M). The $(p+q)^{th}$ order M of an image, denoted as m_{pq}, is defined as

$$m_{pq} = \sum_x\sum_y x^p y^q\ f(x, y)$$

where x and y are coordinates of the pixel, and f(x, y) is the gray level of the pixel.

Moment m_{pq} is uniquely determined by f(x, y), and, conversely, m_{pq} uniquely determines f(x, y) (Papoulis, 1965). The first M, m_{00}, is simply the area of the object(s) in the binary image, and the higher-order M describe the spatial distribution of the object pixels. Objects clustering in a small region near the origin lead to a small M. Conversely, objects spreading in a large region result in a larger M. In our case, a smaller M is associated with cold-state posture, whereas a larger M is likely to be associated with warm-state posture.

However, M defined by the above equation may be significantly affected by shifted objects. Namely, objects clustering in several small regions can still have a fairly large M if they are far away from the origin. To overcome this problem, central M, denoted as μ_{pq}, is used; μ_{pq} is defined as

$$\mu_{pq} = \sum_x\sum_y (x - \bar{x})^p\ (y - y)^q\ f(x, y)$$

where $\bar{x} = m_{10}/m_{00}$ and $\bar{y} = m_{01}/m_{00}$.

Moment μ_{pq} can further be normalized by the following equation:

$$\eta_{pq} = \mu_{pq}/\mu_{00}^{\gamma}$$

where $\gamma = 1 + [(p + q)/2]$, for $p + q = 2, 3, \ldots$. For this study, m_{00} and the first seven η_{pq} (η_{11}, η_{20}, η_{02}, η_{21}, η_{12}, η_{30}, and η_{03}) were used.

Perimeter and Area (P&A). The magnitude of P&A of the processed pig images is affected by the spatial position of the pigs. For instance, a larger P&A will result if pigs spread than if they huddle. Even if images of two different behavioral states (say, comfortable vs warm) have a similar A, the P for the comfortable state is likely shorter than that for the warm state. The reason is that pigs under warm conditions would tend to spread more and consequently leave more body contour exposed as compared with pigs under comfortable conditions. This is especially the case after the images have been processed with an opening filtering operation, which removes the small, extended body parts, such as the feet, from the image (refer to Shao et al., 1998 for details).

Combination of M and P&A. Although the normalized central M (η) alone could give some good indication about spatial distribution of the pigs, it may fail to handle some extreme cases. For example, if pigs huddle in two groups and the distance between them is large, the corresponding η will also be large, which could lead to misclassification. Under such circumstances, P&A may provide an additional feature that helps achieving the right classification.

Neural Network Classification of the Pig Postural Images

A three-layer back-propagation perceptron NN was used in this study to classify the pig postural images. The back-propagation training and learning (Lippmann, 1987) is an iterative gradient algorithm to minimize the mean square error between the actual outputs of the network and the desired output. The NN was trained with 100 to 138 images and its performance was tested with 36 to 65 images. Details of the NN training principle and procedure was described by Shao (1997) and Shao et al. (1997). The image segmentation, feature extraction, and NN classification were performed under the environment of Matlab 4.2c (The MathWorks, Inc., Natick, MA).

Results of Feasibility Study

The results of the postural behavior classification by the NN are listed in Table 1. As shown, 99, 92, 96, and 99% of the training images were correctly classified with FC, M, P&A, and combination of M and P&A, respectively, as the feature input to the NN. The corresponding classification rate for the testing images were, respectively, 78, 73, 86, and 90%, with combination of M and P&A as the feature producing the highest correct classification rate. The results thus demonstrated that classification of the thermal comfort state of group-housed pigs by NN analysis of their postural behaviors is feasible.

The lower correct classification rate for the testing images arose mainly from the low correct classification rate for the warm category, where the distinction between the comfortable and warm states was less clear. Better training of the NN with more objective measure(s) of the thermal comfort, particularly near the borderlines of the categories may improve the model performance. This may be done by relating the behavioral features to the corresponding physiological responses of the pigs. Increasing the size of training images may also improve the NN performance.

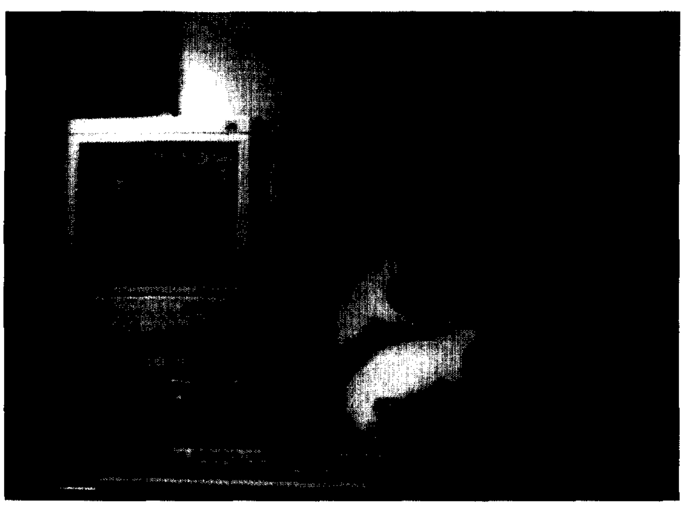


Figure 5. System components for development of automatic segmentation and selection of pig postural images, including a PC with an image grabber, a CCD video camera, commercial slat flooring, and artificial cartoon-cut pigs.

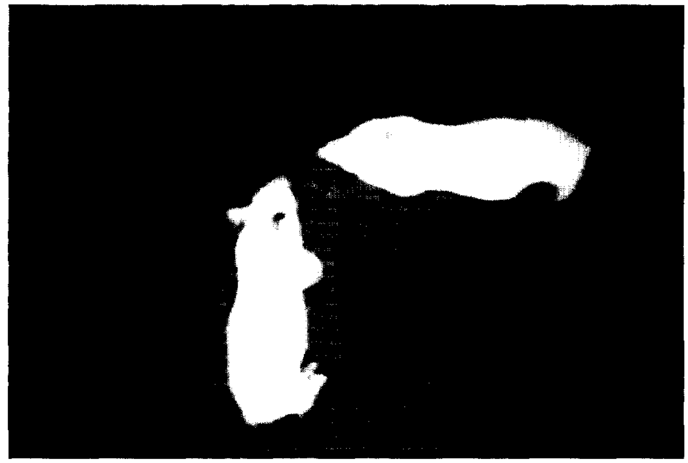


Figure 6. An example raw image of pigs resting on slat floor.

Subsequent Studies

Automatic Segmentation and Selection of Behavior Images

As previously mentioned, the postural images of the pigs used in the feasibility study was selected manually by visual observations to exclude images containing pigs in motion. Segmentation of some images was also done manually by coloring the images to obtain the necessary contrast between the pigs and their background (e.g., chamber wall). Although these manual actions were acceptable for evaluation of the idea, it is imperative that these actions be carried out automatically for real-time application of the behavior-based assessment and control method. A subsequent study was thus conducted to develop the hardware and analysis algorithms to meet the requirement. In the study commercial type, orange plastic slat flooring was used to support artificial pigs (both black and white pigs) that were made from enlarged photos of pigs used in the feasibility study. The system components are shown in Figure 5. Development and evaluation of the computational algorithms were performed in the Matlab 4.2c environment.

A description of the complex mathematical and statistical procedures involved in development of the automatic image selection and segmentation is beyond the scope of this paper and is given in depth by Hu (1998). Instead, selected results of the study are presented here. Specifically, Figures 6 and 7 represent results of the image segmentation algorithm, and Figures 8 and 9 represent results of the motion detection algorithm. These results demonstrate that the algorithms for automatic segmentation and selec-

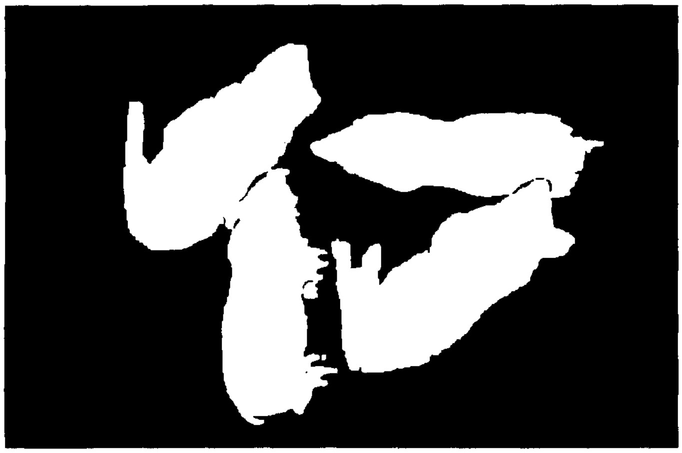


Figure 7. Segmentation result of the raw image shown in Figure 6.

Figure 9. Result of the motion detection revealing movement of the top two pigs. Position of the third (bottom) pig remained unchanged.

tion of postural images developed from this study perform well.

Quantification of Pig Behavioral and Physiological Relationships

As discussed in the feasibility study, an explicit relationship between thermal comfort state of the pigs and the features of their postural images might enhance the performance of the NN. A study is now in progress to quantify this relationship. Specifically, young pigs at 4 to 8 wk of age are exposed to a factorial arrangement of air temperatures at 20, 24, 28, 32, and 36°C with air velocity at 0.1, 0.5, 1.0 and 1.5 m/s. These thermal conditions are used to encompass environmental temperatures ranging from cold to warm. Time series of infrared (**IR**) thermographs of the pigs are taken with an IR thermal imager (Model PM250, Inframetrics, Inc., North Billerica, MA) and are being analyzed. Example thermographs are shown in Figure 10 for pigs at 4 to 5 wk of age. From the thermographs and the environmental data (i.e., air temperature, surrounding surface temperature, and air velocity), surface temperature, floor occupation area (**FOA**), ratio of FOA to the total surface area, and sensible heat loss of the pigs as affected by the thermal conditions will be analyzed, and the relationship between the physiological and the postural behavior of the pigs will be quantified. The results may further elucidate the thermoregulatory responsiveness of the pigs to environmental modifications, which is useful in the determination of image sampling rate and environmental adjustment speed for the real-time operation of the new environmental controller. Detailed description of the experimental procedures and results will be given by Ye (1999).

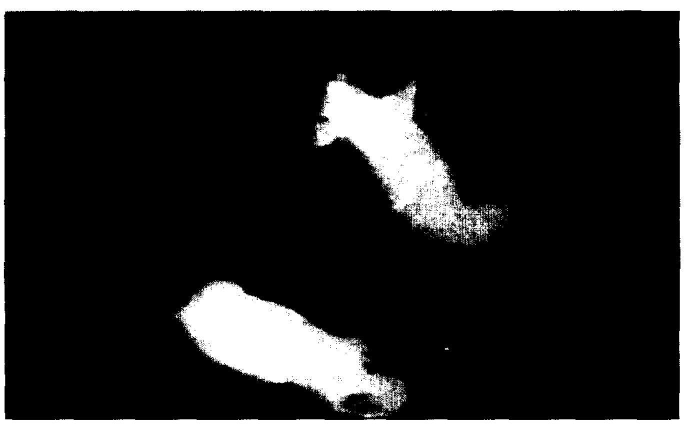
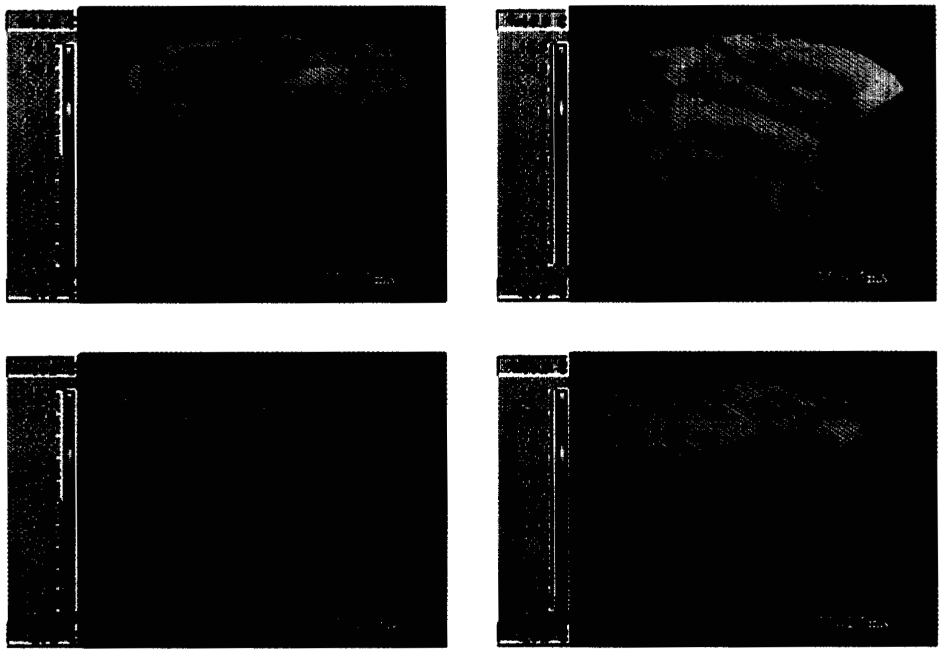


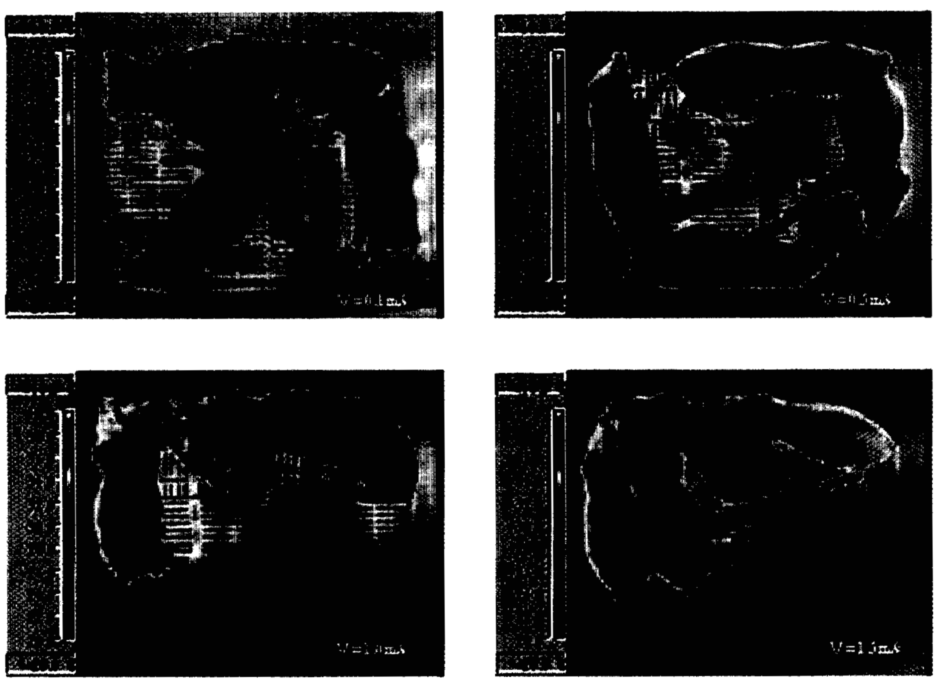
Figure 8. An image with disposition of the top two pigs relative to their previous positions for testing the algorithm of motion detection.

Real-Time Implementation of the Automated Behavior-Based Assessment and Control

The scope of work described thus far is limited to feasibility evaluation of the concept, exploration of feature representations of the postural images, and development of the computational algorithms for automatic segmentation and selection of the postural behavior images. Although the results from these important prerequisite steps are positive, the ultimate goal of the project is to implement the method of automated, behavior-based swine thermal comfort assessment and control in real-time situations. To



(a) 20°C air temperature.



(b) 32°C air temperature.

Figure 10. Thermograms of 4 to 5-week old pigs exposed to 20 and 32°C air temperature and air velocities of .1, .5, 1.0, and 1.5 m/s.

achieve satisfactory real-time implementation, the speed of the imaging analysis system is critical. Although the processing of the images and the efficacy of the computational algorithms can be readily developed and evaluated in the Matlab environment, the speed of manipulation falls far short from that required for real-time operation. It is therefore necessary to develop alternative computer codes to meet the speed requirement. Currently, work is underway to convert the image processing and analysis procedures and algorithms to computer codes on the Microsoft Windows 95/NT platform using the Microsoft Visual C++ 5.0 and Microsoft Foundation Class Library. The system will be able to process the images and make classification or control decisions every 2 s. Some of the key features of the system include interactive setting of the system initial parameters by the user, continuous display of the behavioral images being processed, reduced requirement of computer storage capacity, dynamic display of the resting behavior of the pigs along with their classified thermal comfort state, alarm signal when the thermal comfort state falls outside the thresholds (too cold or too warm) for a prescribed time period, high resistance to noisy signals, and the flexibility of expansion to accommodate multiple cameras simultaneously.

Future Work

Work will continue to develop, test, and refine the program/system. Control peripherals will be added to the system. Selection of optimal feature extraction will be further explored and integrated into the program. Once the development of a prototype controller is completed, its performance will be evaluated comparatively with the conventional, air temperature-based control approach. We hope that the comparative evaluation will first be conducted inside environmental growth chambers and then in production-scale research facilities. Animal well-being, production performance, energy efficiency, and robustness of the system will be among the evaluation criteria.

Implications

Assessment and control of thermal comfort of group-housed animals by observations of postural behaviors provide an interactive means to better meet the dynamic thermal demand of the animals. The research efforts described in this paper aim to replace human observations of the animals with an around-the-clock "computer caretaker" to automatically carry out the assessment and control tasks. Our results thus far have proven promising. Further development and implementation of the system are warranted. Compared with the conventional, temperature-based environmental control approach, the new behavior-based method is expected to be superior for enhancing pig well-being, reducing human labor for animal care, and improving the overall production efficiency.

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