RESEARCHREPORT

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ANIMAL WELFARE

Title: Development of a Real Time, Behavior-Based Swine Comfort Controller
NPB #99-108

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I. ABSTRACT

An innovative, animal welfare-enhancing environmental controller prototype has been developed. Unlike the conventional controller that uses merely air temperature to decide the operation of heating, cooling and ventilation devices, the new controller makes the decision according to the animals' resting behavior – a practice typically used by dedicated swine caretakers. Animals exhibit distinctive resting behaviors under cold, comfortable, and hot sensations. Obviously air temperature is not the only factor influencing thermal comfort of the pigs. Drafts, floor type and conditions, nutritional level, and health status of the animals are important contributing factors as well. Animals have the inherent thermoregulatory behavior of huddling when cold, resting side by side when comfortable, and spreading out when hot. Taking advantage of this inherent animal behavior, a computer imagery system is used to automatically capture the behavioral image, process and analyze it, and then classifies it into the proper thermal comfort state. The target temperature is then adjusted according to the classified thermal comfort status, which in turn determines the operation of the heating, cooling and ventilation devices. Behavioral images involving pigs in motion (eating, drinking, simply playing around, etc.) do not adequately reflect their thermal comfort status, and are thus excluded from the classification. Proper representation of spatial distribution of the pigs on the floor, i.e., selection of the image feature, is crucial and challenging to the success of this novel approach. Finding the image features independent of live body weight makes the matter even more challenging. Adequate computation speed is another requirement of this real-time system. All these components and requirements are integrated in the newly developed, real-time controller prototype. Laboratory-scale testing of the controller shows very satisfactory performance. Further testing and refining of the system under production settings is the logic next step.

II. INTRODUCTION

The conventional environmental controller is not interactive with the thermal needs of the pigs in that it uses only air temperature as the input to decide the heating, cooling, or air exchange needs. It is well known that thermal comfort of the animals is affected not only by air temperature but also by drafts, humidity, radiation (in some cases), floor type and condition, nutritional plane, and health status of the animals. Consequently, a seemingly ideal temperature may not match the actual thermal needs of the animals. However, it is impractical to physically monitor all the influencing thermal and biological factors. This explains why the dedicated animal caretakers spend fair amount of time in barns observing the resting behavior of the animals and fine-tuning the temperature setpoint. Animals integrate all the external and internal factors and exhibit their thermal comfort level by their resting pattern. Specifically, huddling, nearly touching, and spreading are the common resting behavior of animals when feeling cold, comfortable, and hot, respectively. Given that observation of resting behavior provides a comprehensive assessment and improved control of the animal comfort and thus the microenvironment, doing so manually has obvious limitations. It is the goal of this research effort to develop an automated computer imagery system that will perform that very task around-the-clock.

III. OBJECTIVES

Develop a real-time prototype of behavior-based swine welfare controller by programming and linking the previously developed function modules into a holistic, user-friendly system.

IV. PROCEDURES

The prototype welfare controller consists of image capturing devices (camera and image frame grabber), image processing unit (PC and image processing software), environmental sensing unit (A/D board), and peripherals. A graphical illustration of the controller working process is shown in figure 1. A schematic of the controller components is shown in figure 2. A flowchart of its operational logics is shown in figure 3.

The process begins by capturing the behavioral images of the pigs every 2 seconds. This image is called the raw image because it contains both the pigs and the background such as floor, feeder, drinker, and possibly manure. The raw image is checked to see if it involves any pigs in motion. If so, it is considered inadequate for thermal comfort classification and no further processing is performed. If not, the raw image is processed to segment the pigs from the background. Image pixels of the pigs are assigned the value of 1 and those of the background assigned value of 0. Thus, the segmented image is a binary image.

Next, spatial distribution of the binary image is expressed by mathematical representation. This step is called the feature selection. A human expert can easily tell the spatial distribution pattern and the thermal comfort state of the animals. However, expressing this distribution for a computer to understand is quite challenging. The challenge intensifies when the process desires the feature selection to be immune to the changing body size or growth of the pigs. This step plays the most critical role to the success of the assessment and control process. After experimenting with various feature selections, we finally selected moment invariants, object compactness, run frequency, and occupation ratio as our feature set for the classification of comfortable and cold conditions. The complex nature of the behavioral images and the desire for reliable classification of the thermal comfort state warrant the use of combination of these features, as opposed to a single feature. The feature vector for each image is described as:

$$v = [c, a, f, \phi_1, \phi_2]^T$$

where:

v - feature point in the 5-dimensional feature space

c - compactness of the objects in an image

a - ratio of occupied area of the objects to its minimum bounding box

f - frequency of the pixel changing from background to foreground

ϕ_1 - first moment invariant of the objects in an image

ϕ_2 - second moment invariant of the objects in an image

Details of the mathematical expressions of the features are beyond the scope of this report and omitted. However, they are readily available upon request of NPPC.

In this project we use the minimum distance classification method. Namely, the distances of an unknown feature point (i.e., the feature vector representing a new image) to the vector center of different classes are calculated, and the point is classified into the class that has the minimum distance to the unknown. Each class has an initial vector database that is established from behavioral images of known thermal comfort state. Once the new image is classified, its feature vector enters into the corresponding feature database as the newest data, and the oldest feature vector is discarded. This process is called the database updating. It enables the system to learn and update the behavior changes as pigs grow, thereby maintaining the feature selection independent of the body size change.

If the minimum feature distance between the new image and the established classes is within a certain range (C), the classification becomes uncertain. In this case, an unknown message is issued, and no action will be taken on the temperature setpoint, and no database updating performed.

Hot condition is relatively easier to distinguish. Specifically, morphological filtering (i.e., opening, thinning, and erosion operations) is used to obtain the number of blobs in the image. Pigs under hot conditions spread part, and the number of blobs by and large corresponds to the number of pigs. A threshold value of the blob number is used to determine if the behavior belongs to the hot condition.

Based on the classified thermal comfort state, the temperature setpoint is increased, unchanged, or decreased. The measured air temperature is then compared with the new setpoint to determine the operation of the heating, cooling, or ventilation devices. In the case where the behavior-based temperature setpoint is outside the predefined setpoint range, an alarm signal is issued to warn the user.

The controller software is implemented in Visual C++. Several commercially available image-processing tools are used for image feature extraction and D/A and A/D conversion. Coding in Visual C++ provides fast speed of program execution and friendly user interface. We assume that the users are not versed with image processing. Thus the controller system embeds a friendly user-machine interface, through which the user can configure the system to adapt to different application conditions such as the number of pigs in a pen. It also allows the user to test and adjust system parameters to optimize its performance.

V. RESULTS

A prototype of the real-time, behavior-based swine welfare controller has been developed. The algorithms for image motion detection, segmentation, feature selection, and classification have been tested in the laboratory settings with simulated pigs of different sizes. Figure 4 shows an example result of the image motion detection. Figure 5 shows an example result of image segmentation, which involves elimination of the simulated pig manure on the floor. Figures 6, 7, and 8 show, respectively, a snapshot of the controller display for the comfortable, cold, and hot conditions. Finally, table 1 lists the values of the selected image features for smaller and larger pigs under comfortable and cold conditions. It can be seen from the data in table 1 that considerable differences in feature magnitude exist between the two thermal comfort states. Combination of the features yields perfect correct classification rate of the thermal comfort category. The features are also reasonably independent of the body size. The learning and database-updating capability as discussed in the procedure section further improves the versatility of the features for different body sizes.

We have made significant progress toward our ultimate goal – commercial adoption of this novel welfare controller. The next logic step is to test and refine the controller prototype under production settings with live animals. A number of questions remain to be answered or investigated before the controller is ready for commercial adoption, such as the pace of temperature setpoint adjustment, tolerance of pig movement in the motion detection, integration of multiple-pen images, and above all, quantification of the advantage of the new controller over the conventional controller with regard to animal well-being and production performance. Obviously there exist considerable differences between the lab setting with simulated pigs and the production setting with live pigs. These differences will likely require refinements of algorithms and parameter settings in the controller. We hope that future funding can be available that will allow us to pursue this final testing and refining stage and ultimately make this new technology available to the swine producers.

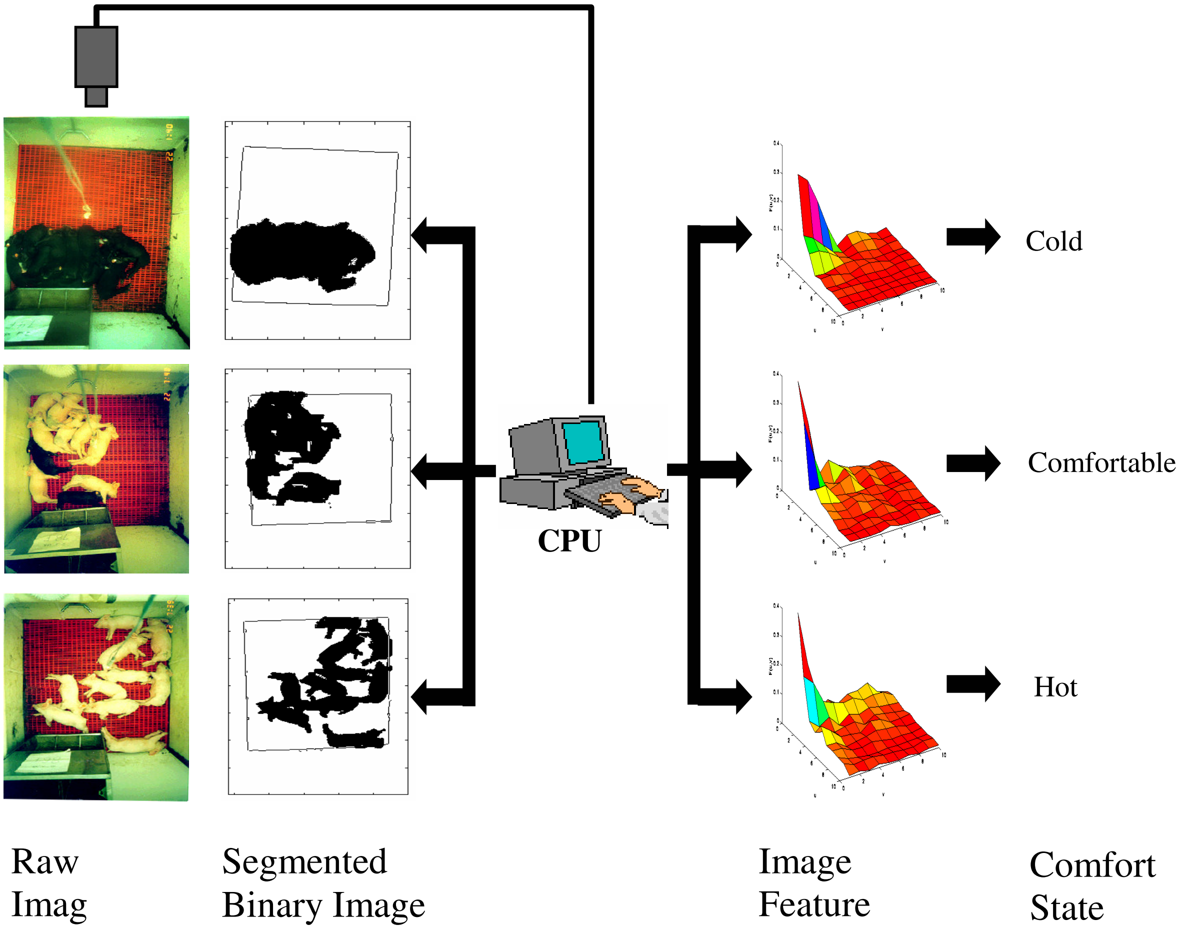


Figure 1. Graphical illustration of the working process for the behavior-based, swine welfare controller.

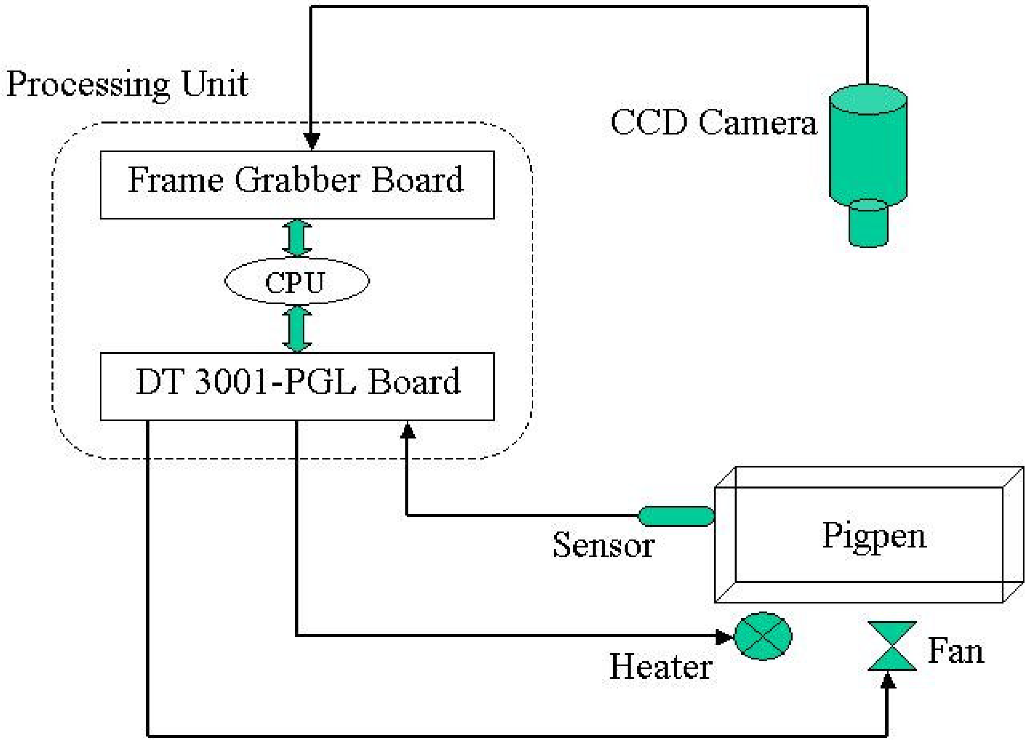


Figure 2. A schematic of the system components in the behavior-based, swine welfare controller.

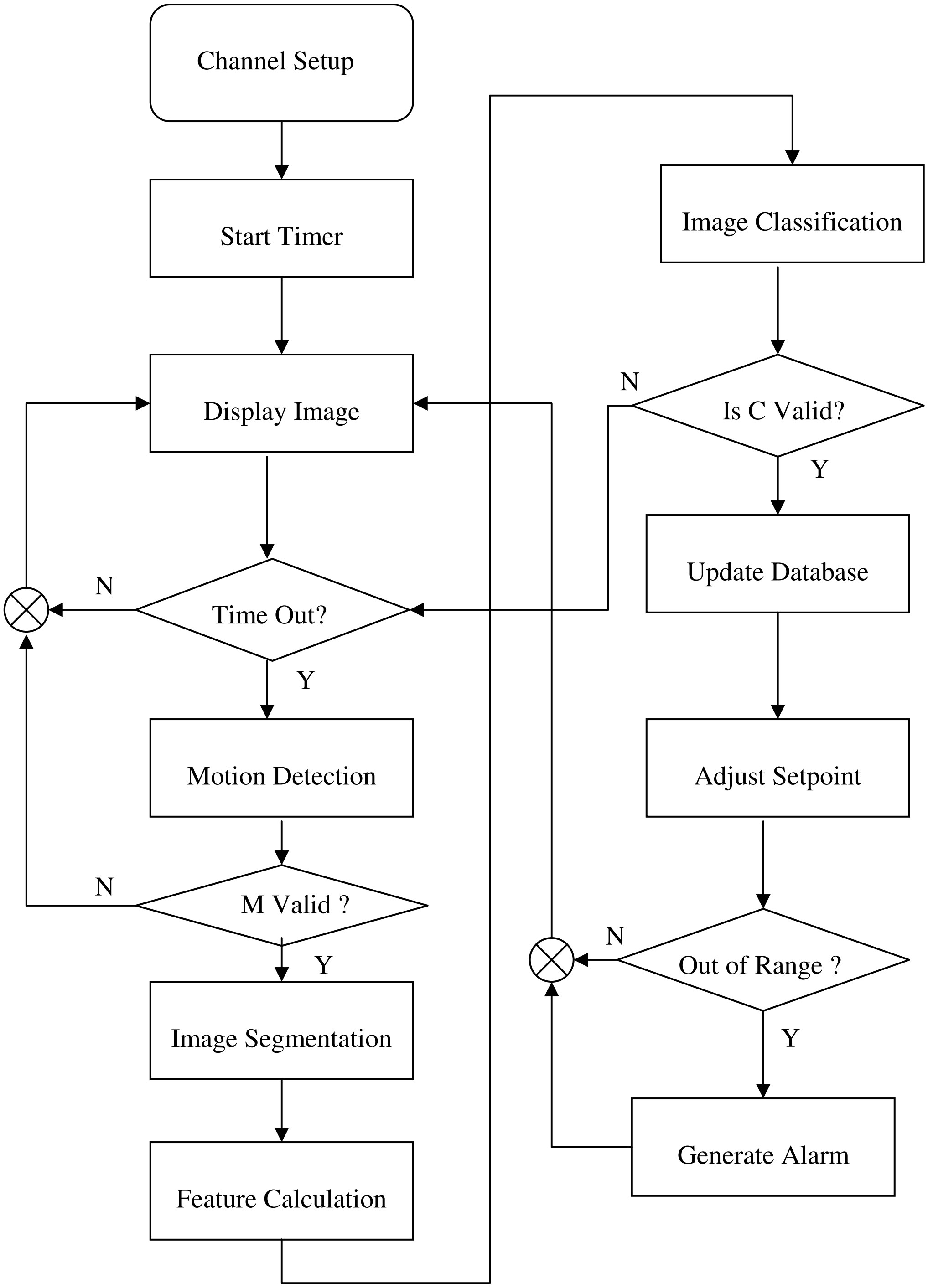
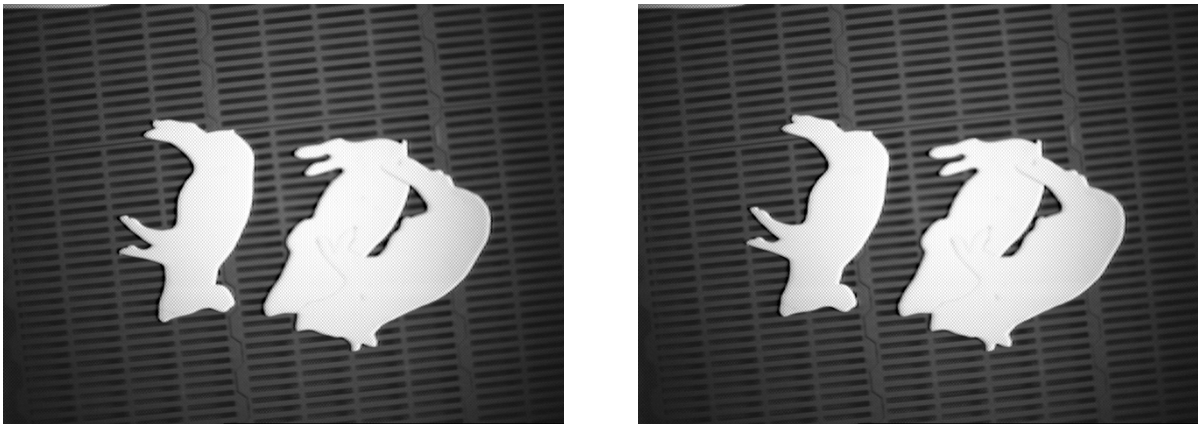


Figure 3. Logic flowchart of the real-time swine welfare controller.

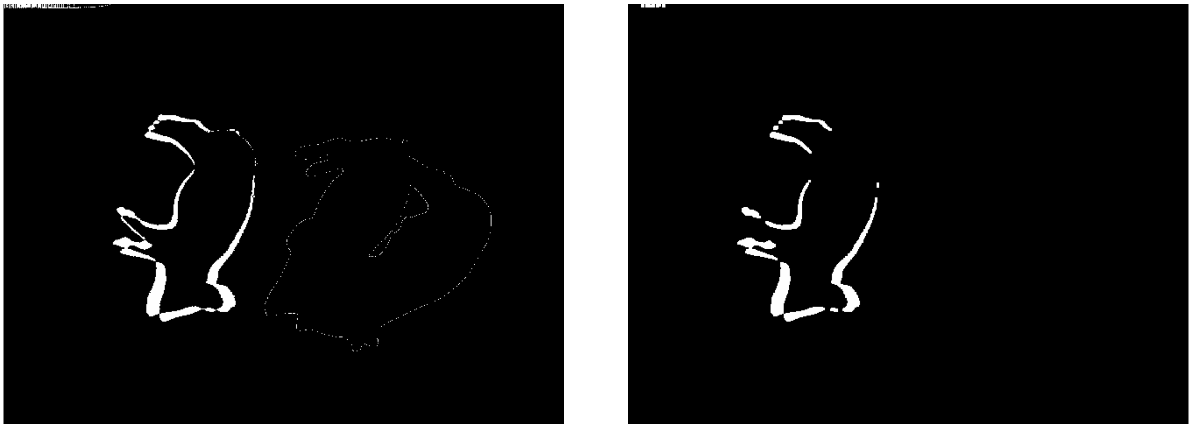


a). Original raw image – gray level

b). Raw image with motion – gray level

c). Original image – binary level

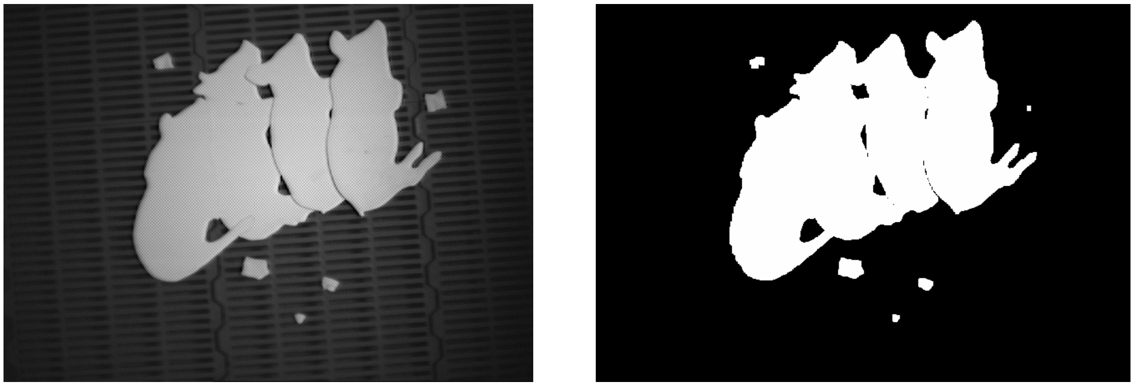
d). Motion image – binary level



e). Image after XOR motion detection

f). Image after opening operation

Figure 4. Example result of image motion detection.



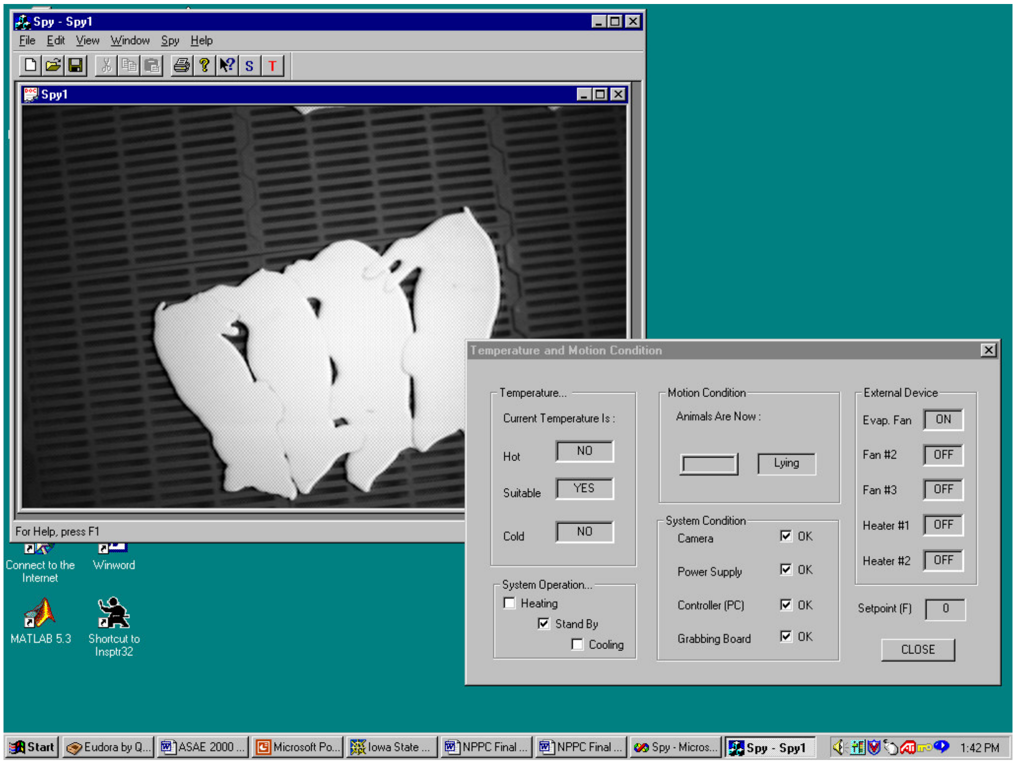
a). Raw image with simulated manure

b). Segmented binary image, still with manure

c). Image after opening operation

d). Final image with manure eliminated

Figure 5. A sample result of image segmentation, noise reduction, and manure elimination.



Temperature and Motion Condition

Temperature...
Current Temperature Is :
Hot: NO
Suitable: YES
Cold: NO

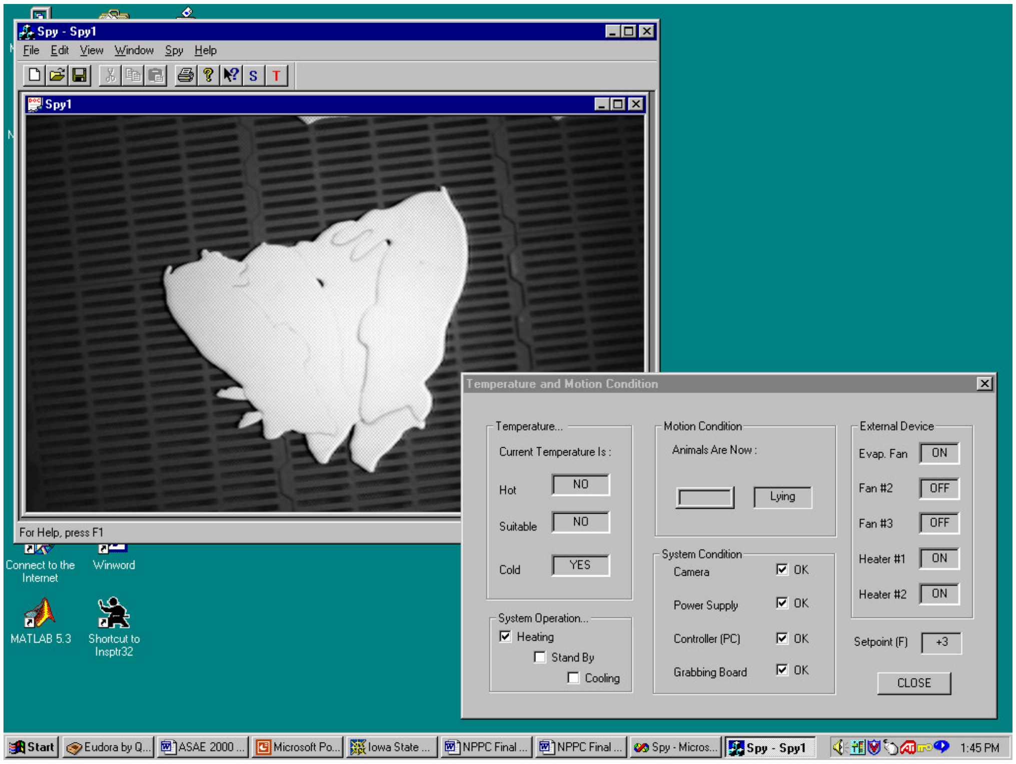
System Operation...
☐ Heating
☑ Stand By
☐ Cooling

Motion Condition
Animals Are Now : Lying

System Condition
Camera ☑ OK
Power Supply ☑ OK
Controller (PC) ☑ OK
Grabbing Board ☑ OK

External Device
Evap. Fan: ON
Fan #2: OFF
Fan #3: OFF
Heater #1: OFF
Heater #2: OFF
Setpoint (F): 0

Figure 6. A snapshot of controller display under comfortable condition.



Temperature and Motion Condition

Temperature...
Current Temperature Is :
Hot: NO
Suitable: NO
Cold: YES

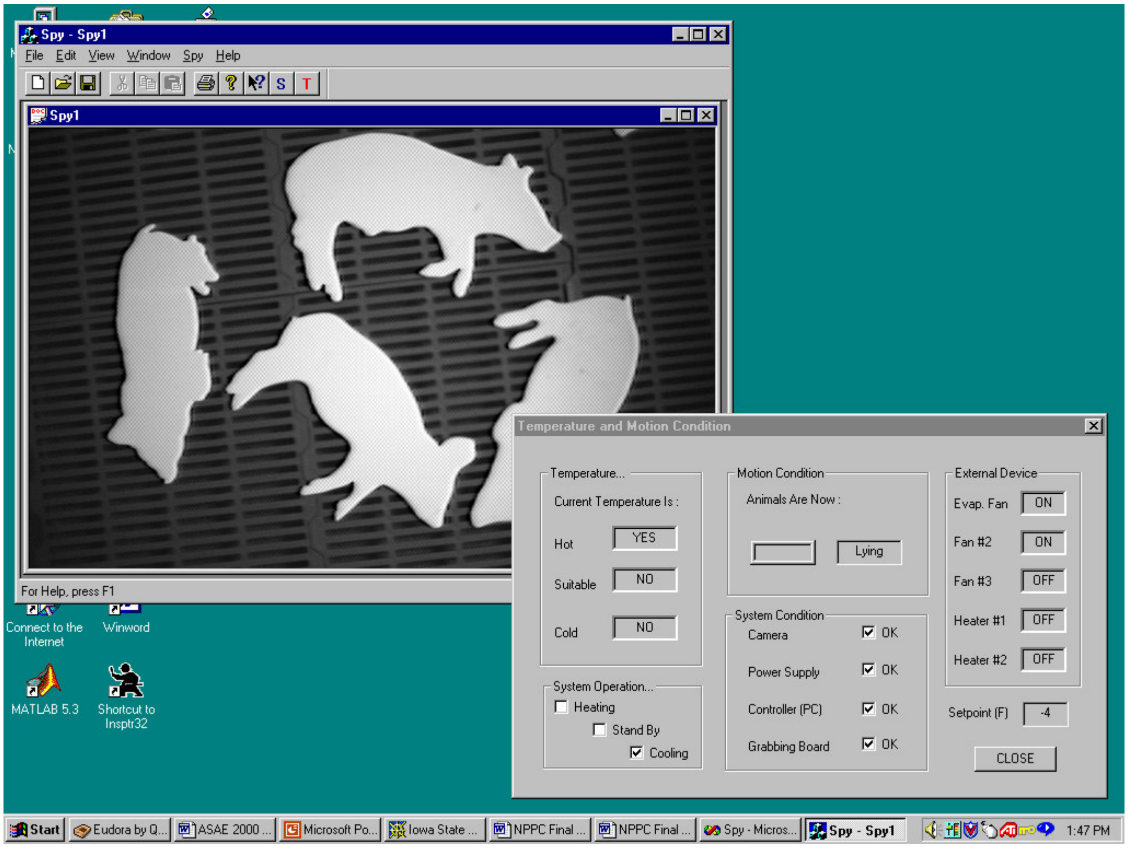
System Operation...
☑ Heating
☐ Stand By
☐ Cooling

Motion Condition
Animals Are Now : Lying

System Condition
Camera ☑ OK
Power Supply ☑ OK
Controller (PC) ☑ OK
Grabbing Board ☑ OK

External Device
Evap. Fan: ON
Fan #2: OFF
Fan #3: OFF
Heater #1: ON
Heater #2: ON
Setpoint (F): +3

Figure 7. A snapshot of the controller display under cold condition.



Temperature and Motion Condition

Temperature...
Current Temperature Is :
Hot: YES
Suitable: NO
Cold: NO

System Operation...
☐ Heating
☐ Stand By
☑ Cooling

Motion Condition
Animals Are Now : Lying

System Condition
Camera ☑ OK
Power Supply ☑ OK
Controller (PC) ☑ OK
Grabbing Board ☑ OK

External Device
Evap. Fan: ON
Fan #2: ON
Fan #3: OFF
Heater #1: OFF
Heater #2: OFF

Setpoint (F): -4

Figure 8. A snapshot of the controller display under hot condition.

Table 1. Feature vectors for different thermal comfort conditions

Image Number Mean & SD	Occupation Ratio (a)	Frequency (f)	Compactness (c)	Moment 1 (ϕ_1)	Moment 2 (ϕ_2)
			Cold Condition, Larger Pigs		
1	0.692	1.520	2.878	0.171	0.000
2	0.681	1.639	3.360	0.171	0.002
3	0.589	1.446	3.039	0.177	0.002
4	0.707	1.475	2.703	0.178	0.004
5	0.631	1.482	3.045	0.188	0.005
Mean	**0.660**	**1.512**	**3.005**	**0.177**	**0.003**
SD	0.049	0.075	0.243	0.007	0.002
			Comfortable Condition, Larger Pigs		
1	0.467	2.047	7.701	0.208	0.011
2	0.527	2.216	8.125	0.222	0.016
3	0.476	2.176	8.629	0.250	0.024
4	0.483	2.153	8.275	0.255	0.023
5	0.670	2.267	6.874	0.219	0.015
Mean	**0.525**	**2.172**	**7.921**	**0.231**	**0.018**
SD	0.084	0.082	0.673	0.021	0.005
			Cold Condition, Smaller Pigs		
1	0.593	1.610	3.819	0.171	0.000
2	0.596	1.591	3.709	0.175	0.001
3	0.593	1.401	2.943	0.179	0.001
4	0.642	1.426	2.762	0.169	0.001
5	0.644	1.387	2.611	0.167	0.000
Mean	**0.613**	**1.483**	**3.169**	**0.172**	**0.001**
SD	0.027	0.108	0.557	0.005	0.001
			Comfortable Condition, Smaller Pigs		
1	0.527	1.635	4.411	0.199	0.009
2	0.551	1.746	4.886	0.208	0.011
3	0.460	1.644	5.194	0.222	0.015
4	0.491	1.835	5.956	0.263	0.027
5	0.408	1.957	8.169	0.284	0.033
Mean	**0.487**	**1.763**	**5.723**	**0.235**	**0.019**
SD	0.057	0.136	1.478	0.037	0.011

SD = standard deviation