Knowledge of the daily growth rate of pigs would enable the stockman to monitor their performance and health, and to predict and control their market weight and date. This paper describes and evaluates the performance of an automatic image collection and analysis system designed to record the weight-related areas of pigs under production conditions. The system successfully logged the growth rates of three groups of pigs of three genetic strains to within 5%, and identified significant differences in the measured area to weight relationships for the three strains, such that linear regression coefficients could be fitted, with the same slope but different intercepts for separate breeds. (1999 Silsoe Research Institute)

1. Introduction

Computer-controlled systems for the remote monitoring of livestock have the potential to increase production efficiency and improve animal health and welfare, as reported by Frost et al. and Van der Stuyft et al. Examples of potential applications for image analysis based systems in pig husbandry were suggested by Schofield, and include recording animal weight, growth rate, quality and conformation, control of diet, monitoring behavioural vices and providing management decision support. Schofield describes how remote monitoring systems have the greatest value where continuous observation of intermittent events is essential, and where data collection is tedious and labour intensive, e.g. monitoring weight gain, feeding behaviour and breeding processes including heat detection and farrowing.

Research reported by DeShazer et al. identified over 90 potential applications for image analysis in pig production, many of which are purely observational and some of which require actual measurements to be made from images. Of these, estimation of pig weight was identified as a primary application for the development of image analysis techniques for use in livestock production. This has led to the research reported here. Weight can be measured by moving the pig(s) from the pen and passing through a conventional weigh crate. This is labour-intensive and stressful to both pig and stockman, and in practice this means that pigs are seldom weighed more than once, if at all, during production. Alternative techniques for weighing pigs in the pen have been considered. These include electronic weigh pads for the whole pig or for just the front legs. Although these can provide accurate and continuous measurements of weight, they require considerable stockman attention to maintain cleanliness. The steady accumulation of dirt on and below the weigh platform results in inaccurate weight readings which are difficult to detect. The image analysis technique used in the prototype system described here does not require the pigs to be moved nor stockman input during the period of the trial. As the only equipment within the pen is the camera and a light for illumination, cost and maintenance are minimized. The ability of the system to capture large numbers of images and relate them to pig weight on a daily basis enables statistical processing to be applied to determine accurate daily changes in measured parameters.

Improving the stockman’s knowledge of pig weight and growth rate is a vital aid to the maintenance of health and maximization of production efficiency. An imaging system for weighing pigs under experimental conditions has been developed, evaluated and reported by Schofield. The system was used to analyse video recordings of the plan view area for each of a group of 15 pigs as they attended a drinker over a 24 h period. The imaging system measured the apparent plan view area of each pig, recorded the duration and frequency of drinking, and could estimate the weight of pigs in the range 50–75 kg to within 5%.

This report describes and evaluates a development of this imaging system for on-farm weighing of pigs. The
prototype system measured the plan view areas of pigs kept under production conditions, and analysed the video images of each pig in a group. Novel analytical computer algorithms were developed for processing the images and extracting the results, from algorithms reported by Marchant and Schofield.\textsuperscript{7,8} The system is self-contained, and once running, requires no operator input. Similar research has been undertaken in Japan by Minagawa \textit{et al.}.\textsuperscript{9} but with only nine pigs, and with a basic thresholding technique for detecting the outlines of each pig. In Denmark, Brandl and Jorgensen\textsuperscript{10} monitored the growth of over 400 pigs, but their analysis was performed off-line using a manual technique for detecting the pig outline.

The ability of the prototype system to continuously monitor and observe the growth and performance of pigs, its potential to work continuously in the piggery environment, errors in measurement and processing of results as well as installation and pig behaviour problems, are discussed.

2. Experimental details

2.1. Pigs

Three groups of male pigs were monitored over 47 days in each of two consecutive trials, during which their average weights increased from 47 to 90 kg. The pigs were loose-housed in partly slatted pens measuring approximately 2 m by 5 m. They had \textit{ad lib} access to pelleted food from one single space feed station for each pen. The groups of pigs were of three genetic strains taken as having the typical conformation of the Landrace, Large White and Meishan breeds. Eight Landrace pigs and seven Meishan pigs in one pen were continuously monitored in trial 1. In trial 2 each of two groups of pigs were monitored on alternate weeks. Group 1 contained 14 Landrace and 2 Large White pigs, and group 2 contained 14 Large White pigs.

Of the 15 pigs observed in trial 1, two lost their electronic ID tags. The results processed and presented below are for the remaining 13 pigs, of which six were Landrace type, and seven were Meishan type. Results from all 30 pigs in trial 2 are included.

2.2. Pig identification and weighing

Each pig was fitted with an electronic ear tag. The tag reader was fitted into the side wall of the feed trough, so that each pig was identified as it attended the feed station. The identity number was stored with the time and date on the feed station computer. Every pig was weighed manually each week using a conventional weigh crate fitted with an electronic readout. McCarthy\textsuperscript{11} demonstrated that this type of weigher is accurate to $\pm 1\%$ or $\pm 1$ kg (whichever is the greatest), for pigs weighing up to 100 kg, under ideal conditions. The weigher was calibrated prior to the trials, and used by farm staff under production conditions throughout the trial period.

2.3. Image capture

Image and manual weighing data were collected and analysed during each trial. An imaging system was developed to perform automatically all image gathering, processing and timing operations, and store selected data to file. Images for analysis were collected using a low light (4 lux) monochrome CCD video camera fitted with a wide angle lens (4 mm), mounted directly over the feed station (see \textit{Fig. 1}). The camera was connected to an
image analysis system consisting of a 486DX/33 PC fitted with a frame grabber capable of capturing a $512 \times 512$ pixel image, and analysis software developed at Silsoe Research Institute. The ambient lighting levels inside the piggery were variable, since they were due to a mixture of natural and artificial light, so additional low-level illumination was required in the feed station area to obtain images of appropriate quality. This was provided by two tungsten filament lamps, providing average daytime luminance levels within the feed station of $2.2 \text{ cd/m}^2$, as measured using a Macon model L.103 digital photometer.

2.4. Image processing

The image analysis software was designed to capture and process each image using the following tests.

Test 1: presence of pig. The grey level of pixels in the area of the image where the pig’s shoulder was expected, was measured, and the image was accepted if the level was above 60% of the predicted value for the grey level of the body of a pig. This assumed that the feeder floor area was dark (low grey level) and the illuminated pig was light (high grey level). A pass indicated that a pig was present and that the lighting was acceptable.

Test 2: visibility of pig. If the measured area was less than the predicted minimum possible value, the identified area could not represent a pig shape, and so this test failed.

Test 3: acceptability of aspect ratio. The length-to-width ratio of the outlined area was measured and compared with the predicted value. If it was found to be below that expected, the test failed.

Each image was tested to identify its quality (test 1), prior to processing it to locate the outline of the plan view of each pig, and measure the relevant areas. Only if it passed tests 2 and 3 in turn, were these areas stored along with the time and date. The predicted values mentioned in the above tests were determined from analysis of pre-trial test images gathered under conditions similar to those in the main trials, and are relevant only to the specific installation used at that time. If any of the tests failed, a new image was captured and the tests repeated.

In practice, the system captured an image on average once every 26 s during a typical 24 h period, and the tests removed 32% of the images. The processing time needed for each image was approximately 12 s. Discarding captured images which failed the tests listed above, resulted in one satisfactory set of image data being stored on average, every 40 s. This resulted in the system collecting the equivalent of over 140 sets of measurements per pig for each day of the trial.

3. Analysis of results

3.1. Preparation of data

The data files from the image analysis and the feedstation computers were combined by matching the time information for each data set. This produced a single data file containing results for each of the six dates in Trial 1 and the seven dates in Trial 2 for which manual weight information had been gathered. The file contained manual weight data as well as daily average, median and standard deviations for the area data measured from each pig.

The image analysis programme produced two area measurements from each processed image ($A_1$ and $A_2$). The image area $A_1$ represented the whole visible plan view area of the pig. The image area $A_2$ represented the visible area $A_1$, minus the area to the front of a perpendicular line 25% of the distance from the front end of the long axis centreline of the plan view. The head of each pig was not visible when the images were captured as it was hidden inside the feeder. Knowledge of the expected shape of the plan view area gained from test measurements on good quality images, determined that the ratio $A_2/A_1$ should lie between 0.79 and 0.9, allowing for variation in individual pig position and apparent shape. Only data which satisfied this condition were used in producing the average, median and standard deviation values.

3.2. Results from the trials

The relationship between area $A_1$ and the manual weights for the three genetic strains was compared using three possibilities:

1. a single linear regression, i.e. the same slope and intercept (no difference between genetic strains),
2. separate regression lines with the same slope for each genetic strain, but with different intercepts, representing differences between genetic strains, and
3. separate regression lines with different slopes and intercepts for each genetic strain.

The effects of adding extra terms to the regression model were compared. It was demonstrated that the effect of adding the extra terms required to fit a different slope for each genetic strain was not significant ($P < 0.062$), but that the effect of adding terms to give separate intercepts was significant ($P < 0.001$).
The approximate regression equations for the three genetic strains were as follows:

Landrace: \[ \text{area} = 2182 + 79.54 \times \text{weight} \ (\text{S.E. } = 101) \]

Large White: \[ \text{area} = 2350 + 79.54 \times \text{weight} \ (\text{S.E. } = 51.2) \]

Meishan: \[ \text{area} = 1904 + 79.54 \times \text{weight} \ (\text{S.E. } = 93.0) \]

(Note that the results have been presented using area as the dependent variable because estimates of the variability of area which can be used in the regression analysis are available.)

Figs 2–4 present the median values for areas \( A_1 \) measured for each pig on each day plotted against weight for each of the three genetic strains, with the regression curves overlaid. The prediction capabilities of these linear regression models can be demonstrated by using them to predict weights corresponding to given areas for the three genetic strains. Table 1 demonstrates that under the trial conditions, the mean weight of the group of pigs can be estimated with 95% confidence, to within 5% for live weights above approximately 45 kg. In the 60–90 kg range, this error reduces to below 2% for the Landrace and Large White pigs, and 3% for the Meishan pigs.

### 3.3. Statistical methods

The statistical analysis of the area and weight results was designed to determine the relationship between area and weight, any significant differences in area-to-weight relationships between genetic strains and the accuracy and confidence with which weight could be predicted from area.

In addition to the screening procedure for images outlined above, the measurements relating to each pig were examined by plotting area measurements in ascending order associated with each pig against normal scores to assess the number of outliers and the appropriate normality of the area measurements. Normal scores are

<table>
<thead>
<tr>
<th>Pig strain</th>
<th>Area ((A_1)) pixel</th>
<th>Predicted mean weight, kg</th>
<th>Standard error kg</th>
<th>Error with respect to mean weight ((\pm), %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landrace</td>
<td>4500</td>
<td>29.1</td>
<td>0.789</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>7500</td>
<td>66.8</td>
<td>0.457</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>10000</td>
<td>92.2</td>
<td>0.780</td>
<td>1.6</td>
</tr>
<tr>
<td>Large White</td>
<td>4500</td>
<td>27.0</td>
<td>0.879</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>7500</td>
<td>64.7</td>
<td>0.454</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>10000</td>
<td>96.1</td>
<td>0.694</td>
<td>1.5</td>
</tr>
<tr>
<td>Meishan</td>
<td>4500</td>
<td>32.6</td>
<td>1.256</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>7500</td>
<td>70.3</td>
<td>1.079</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>10000</td>
<td>101.8</td>
<td>1.251</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Table 1

Weights predicted by applying three samples of area \( A_1 \) for each genetic strain (s.e. and % error range within 95% confidence limits)
the order statistics for a given sample size from a standard normal distribution, i.e. with mean = 0 and variance = 1. Fig 5 shows a typical plot of the data collected for one pig over 24 h. To avoid problems of bias in the mean and variance due to outlying values, the data were prepared in the following way. As a first approximation, the data, which are counts of pixels, can be assumed to have a Poisson distribution. The estimate of the variance is then taken from the mean or median without recourse to the usual sum of squares calculation which would be affected by the outliers. Note also that the standard deviation of the sample can be estimated from the slope of the points in Fig. 5. Comparing the standard deviations estimated by the two methods provides a check that the method for estimating outliers is sensible. Note also that the sets of pixel measurements have some temporal correlation and so the slope of the line and hence the estimate of the standard deviation may be slightly too small. Some calculations show that the standard deviation from the Poisson distribution is in fact smaller than that calculated from the slope of the probability plot, as in Fig. 5, for example. This means that the trimming of the outliers accomplished using the standard deviation derived from the Poisson distribution, i.e. the square root of the median, is very conservative since this will remove many more outliers than if the standard deviation had been derived from the slope of the probability plot. It is clear that the selected area measurements are now quite close, and that a standard calculation is possible to obtain an estimate of the variance of the sample. An estimate of variability of the median value for each result was calculated, and each area measurement was weighted in inverse proportion to its variability by applying the reciprocal variance to each pair of area and weight observations.

4. Discussion

The prototype system proved the ability of both the hardware and software to work unattended in a piggery environment for the six months period of the trial. During the 47 d period of interest in trial 1, when the pigs increased in weight from a mean of 47 to 90 kg, the system stored an average of one area measurement every 40 s. A similar rate of image collection was achieved during trial 2.

The trials showed that the mean weight of the group of pigs can be estimated to within 5% and that in the 60–90 kg weight range, the error reduces to below 2% for the Landrace and Large White pigs, and 3% for the Meishan pigs (Table 1). The lower accuracy of weight estimation predicted for the Meishan pigs can be explained by the more variable physical shape (conformation) observed in the Meishan strain, compared with the Landrace and Large White strains. Different breeds may require specific algorithms, as demonstrated by the different regression coefficients identified for the Landrace, Large White and Meishan strains. These algorithms could be developed from field trial results, and adjusted for specific situations using calibration data obtained by conventional weighing.

The accuracy of the manual weighing system used during the experiments and for calibration processes such as those described above should be considered. Under farm conditions, McCarthy\textsuperscript{31} states that it is unlikely that the weigher will be accurate to within ± 1% or ± 1 kg. These error levels can be increased further by operator error, mechanical inaccuracies and poor maintenance. The weigher used during these trials was of good quality and well maintained and had been calibrated regularly, but it should not be assumed that the weights are more accurate than the limits given here. The calculated accuracy of the image system is clearly dependent upon that of the conventional system against which it is compared.

All the checks listed in the data analysis section were simple to implement in the software, and ensured that the stored data was concise and relevant. For those pigs for which a good set of results was obtained, the software provided an average of 89 area measurements per pig each day, of which 56 (63%) satisfied the criteria 0·79 < A_2/A_1 < 0·9. These results were used in the statistical analyses described here. Area records which produced results outside the criteria for the ratio A_2/A_1 could have been obtained from poorly defined images, where the edges were inside or outside the true pig boundaries, or where some of the background had been included in the processed area. It is possible that these errors could be reduced by improving the image quality (better lighting) and by developing better software for

Fig. 5. Normal distribution plot of area measurements (pixels) from observation of one pig over 24 h
edge detection, but as so many good images are already available, the return in improved accuracy of weight prediction would be very small.

The problem presented by coloured and dirty pigs will need to be addressed if they are to be reliably monitored using image analysis techniques. Temporarily poor results may be caused by dirt on a pig, resulting in poor definition of the edge by the measurement algorithm, and so a reduction in the area identified and measured. Permanent dark markings can be due to breeding and genetics, and again cause problems in identifying the correct outline of the pig. These problems need to be considered in further development of the image illumination and capturing techniques, as well as in development of the software for processing the images.

Observation of the feeding behaviour of the group of pigs did reveal occasions where certain pigs stood with their feet in the feeder whilst eating, and so presented a reduced area for image capture and analysis. This behaviour was often observed during the early days of the trial, but reduced significantly as the pigs grew, and so were able to reach further into the feeder without needing to stand in it.

The additional illumination used during the trial was deliberately kept at a low level. This would be desirable in a commercial application for reasons of cost and installation, and to cause minimal disruption to the normal conditions inside the piggery. The camera used was fitted with an automatic shutter and gain control so could cope with diurnal lighting fluctuations. Despite this, there were occasions during the trial when it was observed that a shaft of sunlight was lighting the floor of the feeder race and causing loss of images due to the resulting extreme lighting conditions. Care in positioning the installation to avoid direct sunlight, or the provision of shade to prevent direct sunlight from falling on the observed area, should be considered.

5. Conclusions

The prototype system proved the ability of both the hardware and software to work unattended in a piggery environment.

The mean weight of the group of pigs could be estimated to within 5%. In the 60–90 kg weight range, the errors reduce to below 2% for the Landrace and Large White pigs, and below 3% for the Meishan pigs.

Different breeds may require specific algorithms to relate area measurements to weight, as demonstrated by the different regression coefficients identified for the Landrace, Large White and Meishan strains.

It is more practical to capture many average quality images and process and discard a proportion of them using software techniques, than to increase the complexity and cost of the hardware to attempt to ensure that near perfect images are gathered at all times.

Acknowledgements

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