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Improved image analysis based system to reliably predict the live weight of pigs on farm: Preliminary results*

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ABSTRACT: *A computer vision system was developed to automatically measure the live weight of pigs without human intervention. The system was trialled on both research and commercial farms to demonstrate the ability of the system to cope with different conditions and non-uniform lighting conditions. Early results demonstrate that the system can achieve sufficient practical accuracy. The results of the initial trials demonstrated that weight of the pigs can be predicted with an average error of 1.18 kg. Precision, reliability and repeatability are likely to be increased in future through improved weight prediction models, increased image resolution and algorithm enhancement.*

1 INTRODUCTION

It is desirable to monitor the weight of domesticated animals regularly as it gives an indication of the animals' rate of growth. An animal's growth rate is important as it ultimately determines the profitability of the farming enterprise (Schofield, 1990). The weight of the livestock can also be associated with size, shape and condition of the animal (Brandl & Jorgensen, 1996). Therefore, it is desirable to monitor the weight of domesticated animals regularly (Schofield et al, 2002). Traditionally, weighing of livestock is performed manually on-farm using mechanical or electronic scales. This practice is labour intensive, time consuming and potentially dangerous (Kollis et al, 2007). Furthermore, the procedures associated with manual weighing are stressful for the animals (Kollis et al, 2007). As a result of these difficulties several research groups around the world are exploring alternative weighing methods with the aim of overcoming the previously mentioned problems on commercial farms. One non-contact animal weighing method that research groups are currently exploring is video image analysis (VIA). This weighing method predicts a live animals weight based on body measurements extracted from a video frame (Doeschl-Wilson et al, 2005; Schofield et al, 1999; Whittemore & Schofield, 2000; Wouters et al, 1990). The body measurements can then be modelled to predict the weight, size and body composition of the animal to reasonable accuracy (Wang et al, 2006; Schofield et al, 1999; Doeschl-Wilson et al, 2005).

Two of the earliest applications of computer vision in the area of live weight analysis were conducted in the UK and Denmark. Research performed at the Silsoe Institute (UK) in the late eighties demonstrated that IA can be used to predict the weight of pigs within 5% accuracy based on a pigs body area (Schofield, 1990; Schofield et al, 1999). Subsequently the VIA-based weighing system developed at the institute was used as part of a prototype closed-loop, model-based control system of pig growth. The core of the system was a mechanistic growth model which monitored environmental and animal variables as inputs for control, such as room ammonia levels and the pigs' growth. A trial demonstrated that the system has the potential to control the growth rate and condition of a group of pigs (Parsons et al, 2007). A similar model based control system is currently being developed for the Australian pig industry (Banhazi et al, 2007a; 2007b; Banhazi & Black, 2009).

Another VIA-related experiment was conducted in the mid-1990s in Denmark. In this experiment 416 crossbred pigs were weighed and captured on video. Samples were taken five times during their life time between approximately 25 and 100 kg live-weight.

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The aim of the experiment was to estimate the live weight of pigs based on their body measurements. The study found that the relationship between body area and live weight was almost linear on a logarithmic scale and the residual standard deviation was constant. Differences in the size of the residuals were demonstrated for pigs from different breed combinations, but the feeding methods had only a minor influence on the "relationship" between body area and weight (Brandl & Jorgensen, 1996). More recent experiments conducted in the USA and Japan also confirmed that a strong correlation exists between the body area of a pig extracted from an image and the weight of the same pig. The study conducted in the Unites States involved a sample of 187 pigs that were imaged from above while walking through a walkway. Body features, such as rear area, body length and centre-width were extracted from the images using standard VIA techniques. Results indicated that the best correlation was found between the body area and the pig weight (r = 0.96), but a good correlation also existed with the centre width of the pigs body r = 0.95 (Wang et al, 2006). In the Japanese study (Minagawa, 1997) pig weights were estimated based on a multiple regression equation. The animals' body area and height were obtained using VIA techniques and used as the equations input variables. In a trial the estimated weight of pigs resulted in a mean relative error of 2.1% with 1.8% standard deviation. The difference between estimated and measured mean group weights was only +0.3 kg, or 0.8% in relative error demonstrating that the equipment preformed with acceptable practical accuracy (Minagawa & Murakami, 2001). Preliminary studies conducted in South Australia also indicated the potential of VIA systems ability to non-evasively predict the weight of pigs on farms with an acceptable error using additional statistical modelling of the data obtained from the images of pigs (Banhazi et al, 2007b; Kollis et al, 2007).

These studies demonstrate the potential benefits that VIA methodology can contribute when incorporated into animal production. Therefore the specific aims of this study were to build upon previous research, and (i) improve weight prediction accuracy and (ii) improve the estimation reliability by enhancing feature extraction and segmentation methods. This article is reporting on the results of an on-going investigation, so some of the results can be classified as preliminary.

2 MATERIALS AND METHODS

The specific target group of pigs for weight analysis in this study were grower/finisher pigs in the weight range from 20 to 100 kg live weight. Initially the system was designed solely for indoor use and thresholding techniques were used to identify the pig from the background (segmentation). Complications, such as decreased accuracy and speed arouse when using this method under varying lighting conditions. Due to these complications a more reliable method was developed based on the gradient in the image. The specific application of the system was to be able to predict the weight of a pig as it walked under a camera. It was also noted that the system could be used in a group-pen situation, increasing the systems functionality.

2.1 Measurement system and experimental location

A traditional weigh scale was used to measure the weight of individual animals and the corresponding video segments were captured using an off-the-self webcam (Logitech Quickcam Pro 9000, Logitech, Quarry Bay, Hong Kong) set at 320 × 240 resolution and a frame rate of 30 frames per second (fps). Image distortion was minimised by using the built-in feature of the camera selected. The Logitech Quickcam RightLight technology also ensured that the camera automatically readjusted itself to handle variable lighting conditions. Subsequent results demonstrated the camera's ability to perform well under variable lighting conditions. The images were stored on a dedicated PC and later processed using Matlab V6.5.1 (R13) with the Image Processing Toolbox V4.1 (the MathWorks, Inc., Natick, MA). No artificial lighting was projected onto the walkway to ensure that the system can cope with normal lighting conditions. The experiments were conducted in an outside weighing area at the University of Adelaide's, Research Piggery. Figure 1 provides a top view of the experimental setup and location.

The main aspects of the image analysis and weight prediction process are summarised in figure 2 and discussed in detail in the following pages.

2.2 Frame selection

To perform weight prediction in real time the VIA system was required to acquire, analyse, extract features and measurements from the 320 × 240 image and output the corresponding weight within a 1 second interval. The pig was completely within the field of view (FOV) of the camera for approximately 2 seconds as it walked under the camera at a height of 1.68 m. Therefore it was desirable to only completely process frames that contain the entire body of a pig in order to save precious processing time. Consequently a classification between frames containing an entire pig and any other case was required. Two different selection methods were trialed to achieve correct frame classification, but ultimately, the "cross hair method" was chosen due to its speed and measurement capabilities.

Both methods used dimensions such as the pigs back area or length and width to identify and separate the good images that contained an entire pig and

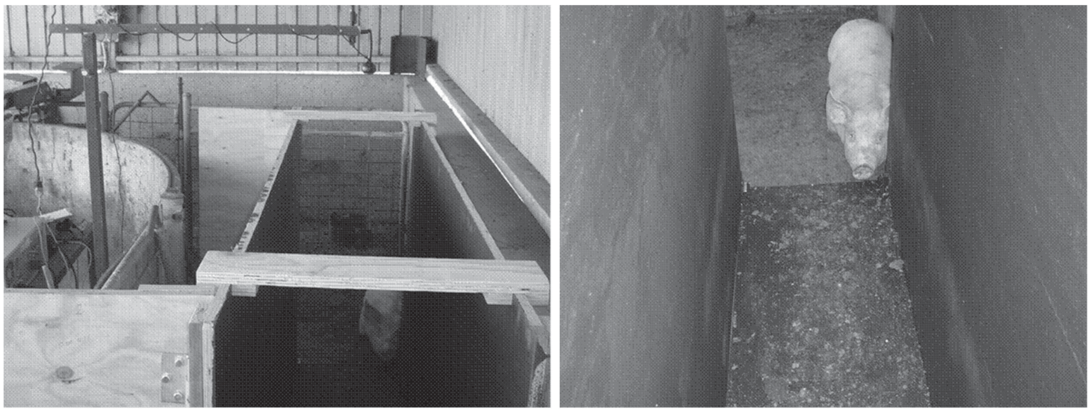


Figure 1: A walkway was constructed and set up at Roseworthy Research Piggery to improve the image quality of samples used to build the weight estimation equations by creating more uniform conditions.

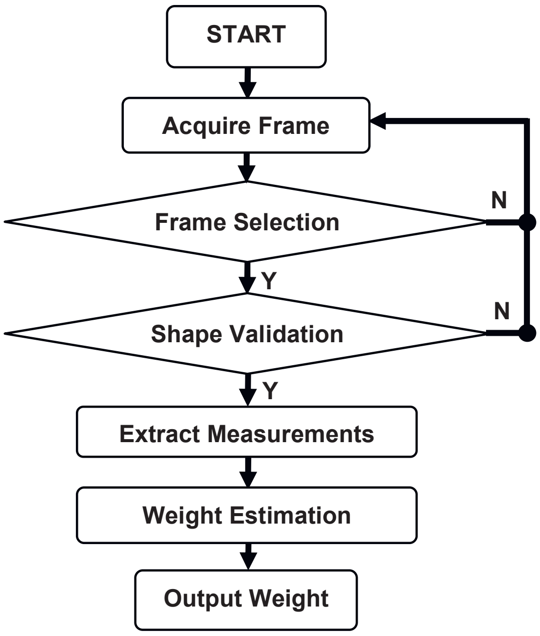


Figure 2: Main steps used during the image analysis and weight prediction process.

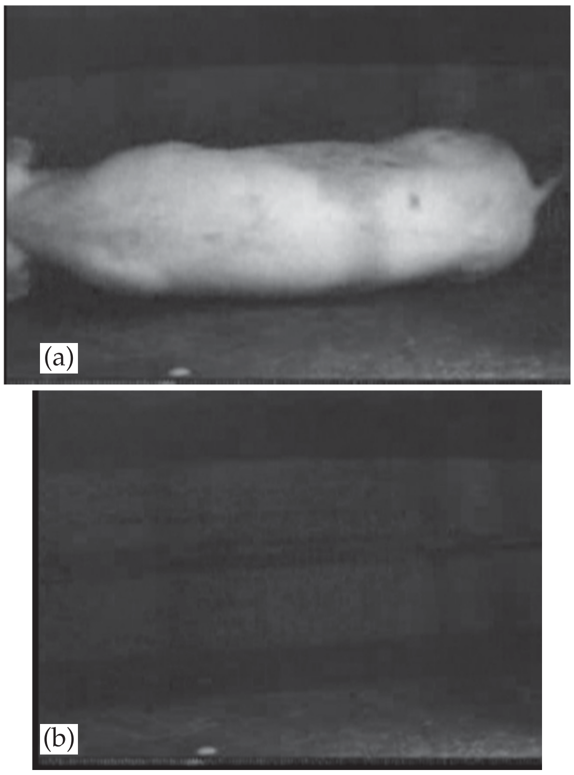


Figure 3: Sample (a) foreground and (b) background.

the bad images containing partial or no pig. The first step in frame selection was acquiring the red colour channel from the sensor. The red channel was chosen as it provides a better representation of high intensity pixels of an object within an image and because processing the incoming frame in all three dimensions (RGB) would contribute to significant additional processing time.

A subtraction method was implemented. An image without pigs was stored in the memory as a background image before running the system (figure 3(b)). A subtraction was performed between the background frame and any subsequent frame. If a frame contained a large difference between the subtracted frames it was deemed to have an object in it and was analysed further. If there was no significant difference between the frames it was stored as the new background frame. An adaptive global threshold was then applied to the subtracted image to convert it into a binary image. A white pixel (value 1) in the binary image represented a pig pixel and a black pixel (value 0) represented the background.

Problems were encountered in this pre-selection process as it was prone to errors from differences in light intensity and the systems real time capabilities were restricted due to some of the algorithms processing requirements. It was noted that this subtraction method had potential to work in strict lighting conditions with a constant background and a relatively clean and white animal. However from an application perspective the requirement for the animal to be clean and background to be uniform was not practical as it is often not the case under commercial farming conditions. In addition the implementation of additional hardware components such as structured lighting was undesirable and would lead to additional system maintenance and cost so an improved method for selecting frames was developed.

A new method called the "cross hair method" (due to its targeting approach) was developed resulting in much simpler and faster means of classification between frames that contained pigs and frames that did not. Firstly the image was divided into vertical and horizontal sections. Then large peaks in intensity across sections were identified indicating the presence of an object in the image (figure 4, top right). Finally the same intensity profile was used to determine whether the object was completely in the frame.

Figure 4 is an intensity profile plot of various sections of an image containing half a pig. The top three axes illustrate the RGB intensity levels along different vertical sections of the image and the bottom one illustrates the intensity profile along the length of the pig.

2.3 Image enhancement and segmentation

The pig had to be separated from the background (segmented) before extracting the body measurements from the image. First a median filter was applied to reduce any background noise in the image and the images contrast was enhanced. The image was divided into quadrants for thresholding. Each quadrant was thresholded adaptively based on Otsu's method (Otsu, 1979). Often the edge of the pig appeared rough after thresholding and non-pig

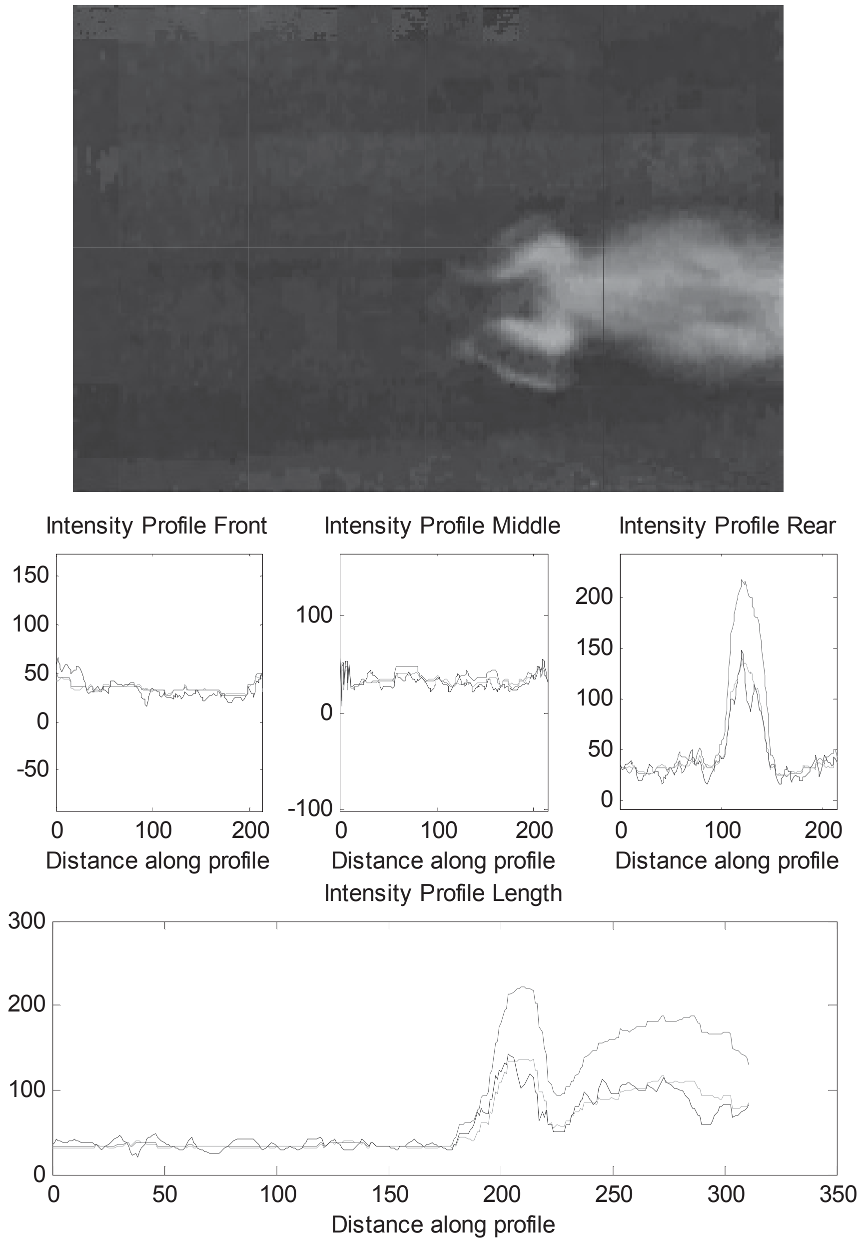


Figure 4: Intensity profile of different colour components (red, green, blue) of image sections.

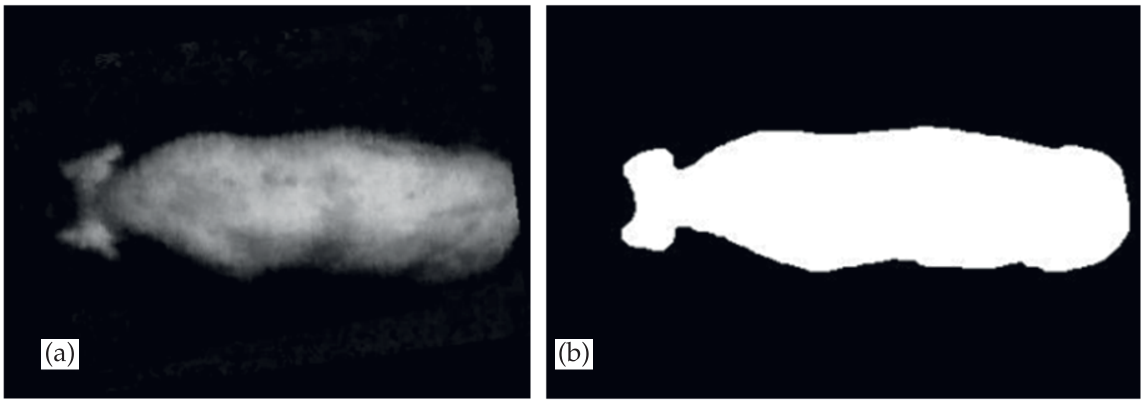


Figure 5: Greyscale image after noise filtering and contrast enhancement (a) and the resulting binary image after removing all isolated non pig pixels (b).

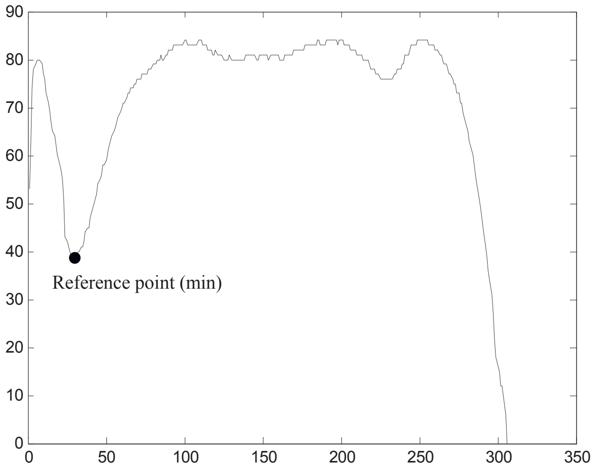
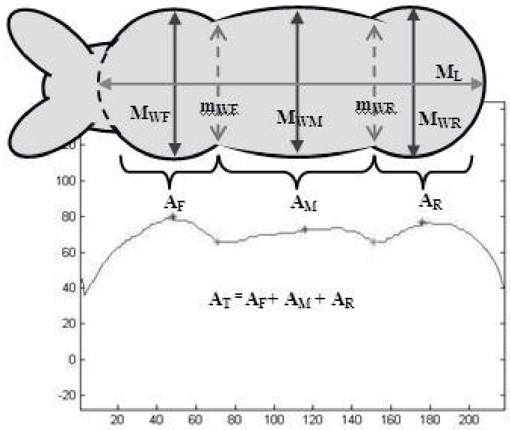


Figure 6: Identifying a reference point on the pigs neck for trimming.



Variable	Colour	Description
Max Length	M_L	Maximum length
Max Width	M_W	Maximum Width
Min Width Rear	m_{WF}	Minimum width of the front section
Min Width Front	m_{WR}	Minimum width of the rear section
Max Width Front	M_{WF}	Maximum width of the front section
Max Width Middle	M_{WM}	Maximum width of the mid section
Max Width Rear	M_{WR}	Maximum width of the rear section
Area Front	A_F	Total pixels between m_{WF} and far left
Area Middle	A_M	Total pixels between m_{WF} and m_{WR}
Area Rear	A_R	Total pixels between m_{WR} and far right
Area Total	A_T	Total pixels A_F+ A_M+A_T

Figure 7: Locating maximum and minimum points and defining measurement variables.

objects were present in the image so morphological opening and closing operations were used to smooth and eliminate unwanted pixels.

Figure 5(a) illustrates a greyscale image and figure 5(b) is its binary image after performing all enhancement and segmentation operations.

2.4 Removing head and tail

In order to obtain accurate measurements the head is required to be removed from the image (Brandl & Jorgensen, 1996). A reference point on the neck of the pig had to be found so that the head could be cropped from the image. First, the width of pig was calculated in every column of the image (figure 6). The neck reference point can be observed in figure 6 as the minimum value on the left of the curve. After finding the reference point all pixel values in front of the reference point were converted to zero, effectively cropping the head area (Wang et al, 2008).

A problem encountered with this method was that occasionally a pigs' ear or neck appeared "attached" to the side of its body if it was looking downward or its head was twisted at the time the frame was grabbed. In addition often the head was bent which resulted in a width curve where there was no minimum reference point.

2.5 Feature extraction

After completing all operations mentioned above the image was ready for feature extraction. The length of the pig was found as the maximum length of the body. The pig length was then used to separate the pigs' body into three regions of interest, namely the front, middle and rear areas. All maximum and minimum width values were found using the width curve (figure 7).

The vertical measurements extracted from the contour appear in figure 8.

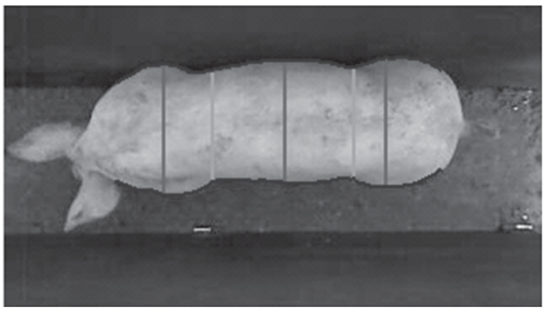


Figure 8: Vertical measurements.

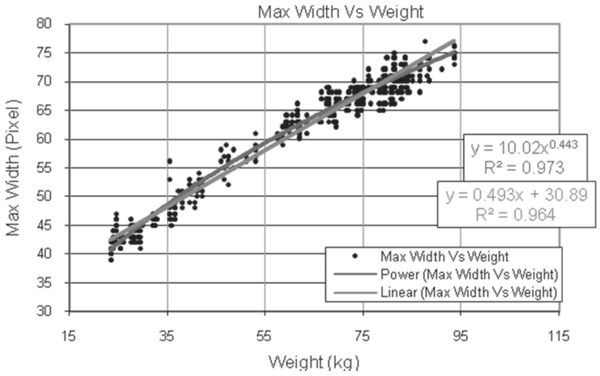


Figure 9: Max width versus weight sample data.

2.6 Statistical analysis and model development

The explanatory variables (maximum length; minimum width of the front, rear and mid sections; minimum width of the front, rear and mid sections; total areas of the front, rear and mid sections) were analysed to explain as much of the variation in the weight of the animals as possible and to construct descriptive model for pig live weight. A general linear model procedure (PROC GLM) was used (SAS, 2005) to build a comprehensive model that could be used for predicting the live weight of pigs. The models were developed from the maximum model tested by sequentially removing (in a stepwise manner) non-significant effects ($p < 0.05$, based on type III estimable functions) until only significant effects remained. This process was undertaken while ensuring that all marginality requirements of the model were met (Nelder, 1994).

3 RESULT AND DISCUSSION

More than 10,000 images of 500 pigs were investigated in this study, which is significantly more than the images used in previous studies. Table 1 shows sample data of the main features extracted from the images and statistical correlations found between the features and corresponding scale weight. The R^2 values in table 1 are calculated from a linear relationship however the width R^2 values improve slightly using a power model such as in figure 9. The ability for the system to yield accurate results was also assessed and is discussed further in the following sections.

Different frames of the same pig were used in the analysis and were taken as independent data points. Initially dimensional variation within these samples indicated that there was either an inaccuracy in our process to repeat the dimensional measurements or the variation was a result of the pigs' natural body movement. An observation of the results indicated both these cases had occurred. Notably the environmental conditions had an impact on the analysis of particular sample frames which was either a direct result or combination of (i) the speed of animal movement under the camera, (ii) the pose of the animal and (iii) the colour or cleanliness of the animal's body or surroundings. All of these erroneous samples frames were excluded to accurately depict the correlation to weight between the different dimensions and to give a preliminary indication of acceptable variation for each dimension. In future these errors are required to be identified and handled automatically. The statistical analysis proved that several of the measurements had excellent correlation to weight (table 1).

3.1 Results of farm trials

A number of preliminary farm tests were undertaken at the Roseworthy research piggery and other commercial piggeries to assess the precision of the program developed. The results of system evaluation trial are presented in figure 10 and 11 and table 2.

3.1.1 Trial 1

The first experiment yielded promising results. Table 2 shows the raw data that was used to develop the graph presented in figure 10.

Several pigs had multiple weight readings as a result of them slowly moving across the FOV of the camera. Very good predictions were generated if the frames were visually chosen based on the performance of the algorithm out of all available frames. However, some frames of pigs were processed poorly leading to a decrease in precision (highlighted cells in table 2).

Table 1: Correlation coefficients found between extracted features and animal weight.

Measure	ML	MW	MWF	MWMid	MWR	mWF	mWR	AF	AMid	AR	AT
R^2	0.899	0.965	0.935	0.921	0.964	0.925	0.894	0.69	0.478	0.735	0.974
M = max; m = min; W = width; L = length; F = front; R = rear; Mid = middle; A = area; T = total (head trimmed)											

Table 2: Weight prediction data (kg) obtained from images that coincide with figure 10.

Scale weight	Best-predicted	Additional predictions			
34.5	34.92	35.45			
45.5	45.31				
39.0	38.37	38.24			
38.5	39.09	42.19			
54.0	54.50	50.99	58.01		
38.0	38.32				
48.5	47.06	30.76			
49.5	50.11	54.41	37.79	39.29	
35.0	33.88	33.52	31.06	33.88	33.09
67.0	62.81	60.95	63.64	51.39	
38.5	45.50	45.97	46.44		
53.0	54.60	44.90			
55.0	50.86	49.99			
58.5	58.07	59.60	56.54	58.07	
50.0	48.68	47.08			
47.0	45.59	54.70			
44.5	42.85	41.29	46.88	40.39	42.85

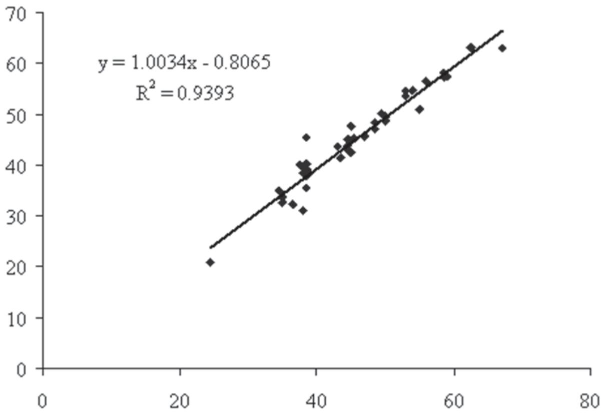


Figure 10: Best results of the farm measurements, trial 1 (kg).

This data demonstrated that the system does have the potential to get the predictions very precise, but the reliable elimination of images from the dataset that lead to inaccurate weight output, such as frames where the pig is in an undesirable posture, will be an important component of any improvement in the future. These principles were not apparent in previous publications. Thus the research team believes that the development reported here has the potential for significantly improving on previously published work.

3.1.2 Trial 2

After some improvements were made a second trial was undertaken to assess the precision of the developed system using the error obtained in relation to individual weighing episodes (figure 11). An average error of 1.18 kg was achieved during the whole trial with as low as 0.02 kg for best prediction and as high as 3.76 kg error for the worst prediction. It can be seen from the data presented in figure 11 that the average precision is remarkably good approaching the ±1 kg desirable range. However, there are still errors derived from inaccurate measurements that result in an unacceptable error margin of up to ±4kg. The main aim of any future development has to be to reliably eliminate any poorly processed video frames.

3.1.3 Trial 3

The results of the previous two trials are based on a predictive equation that consists of only vertical measurements which are immediately prone to inaccuracies if the pig in the image is orientated on an angle. For the third trial angular measurements were incorporated as well as a spline curve to represent the contour of the pig body.

The developed weight monitoring equipment was setup in an Australian commercial piggery located in New South Wales with the main aim of the trial to determine the practicality of the data and durability of the equipment in a commercial setting. The chosen pen contained 168 pigs growing from 30 to 60 kg. The camera was mounted between four bin feeders located in the pen at a height of 1.68 m. The system took a sample of the pig whenever it passed beneath

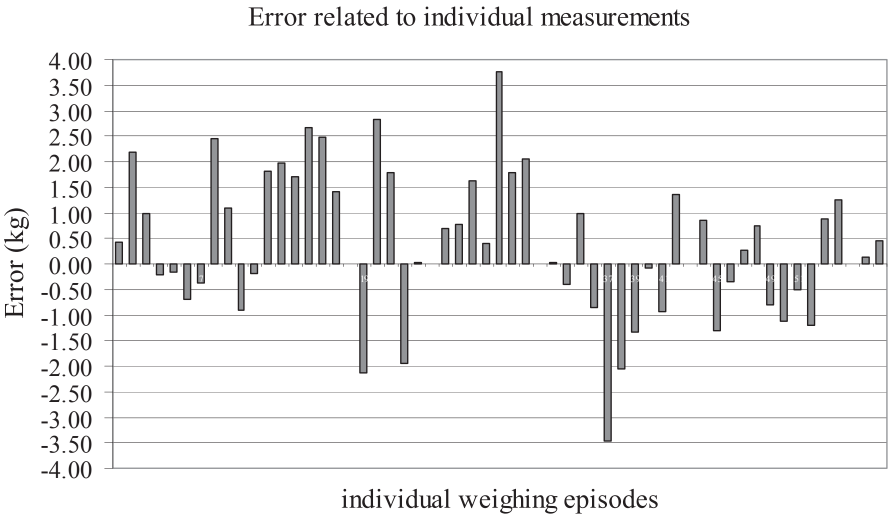


Figure 11: Error associated with individual measurements using the vision system as compared to weight of pigs measured using a traditional scale.

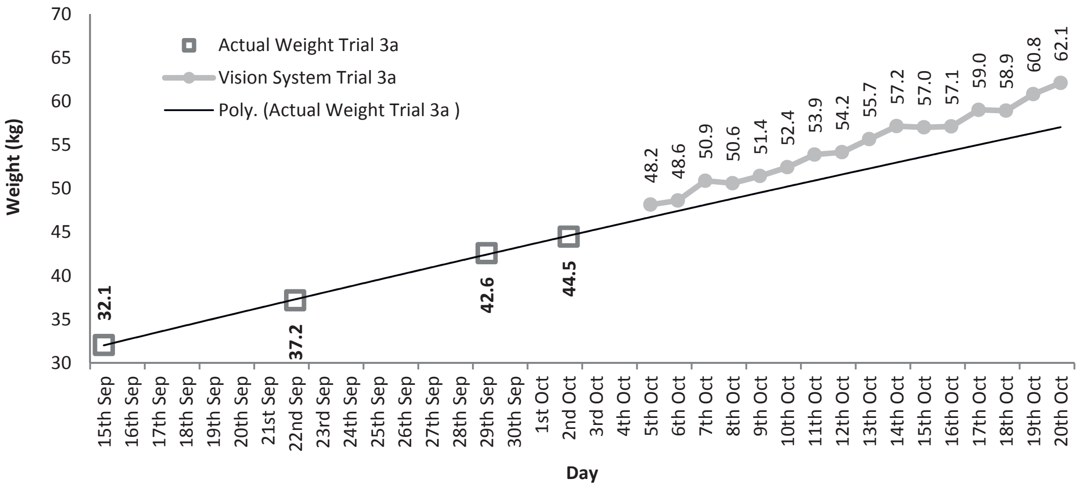


Figure 12: Error associated with individual measurements using the vision system as compared to weight of pigs measured using a traditional scale.

the camera on its way to the feeder and appeared in a pose suitable for weight estimation. The samples were used to determine the average daily weight. Notably it was unknown if all animals were sampled during the course of the day. Future work will involve the integration of RFID to determine (i) if the system discriminates between certain shaped animals in the group and (ii) the number of pigs used within the whole population by the system to predict the daily average weight of the whole group.

The system installed at the commercial farm recorded weight data which was then downloaded remotely from South Australia via a remote access link. Growth was recorded based on the average weight of all samples acquired over the course of the day. A sample weight estimate was based on the average weight estimate of numerous frames acquired of a pig while it was beneath the camera. Three successive batches of pigs were recorded in trial 3a (figure 12), trial 3b (figure 13) and trial 3c (figure 14). No vision-based weight estimates were obtained during the first 20 days of the first trial (3a) due to a software related problem (figure 12). Once the problem was rectified the system recorded the daily sample data and the daily weight estimates. Unfortunately during this 20-day downtime period the actual average group weight measurements for the 168 animals occurred. A total of 4 measurements were taken. Although no direct validation was achieved due to limited labour resources to weigh the animals the slope between the recorded and estimated values indicated that the system was estimating realistic growth curve. The actual weights recorded in trial 3a were then used as a reference in a subsequent trial 3b containing a new batch of animals (figure 13).

A setup variable was inputted to select the weight range at the start of the trial 3a (figure 12) and 3b from 30 to 90 kg (figure 13). As the lower cut off value did not enable results less than 30 kg to be recorded, the first 5 days recorded an incorrect and higher average group-weight due to the fact that pigs less than 30 kg were excluded from the daily average. As the

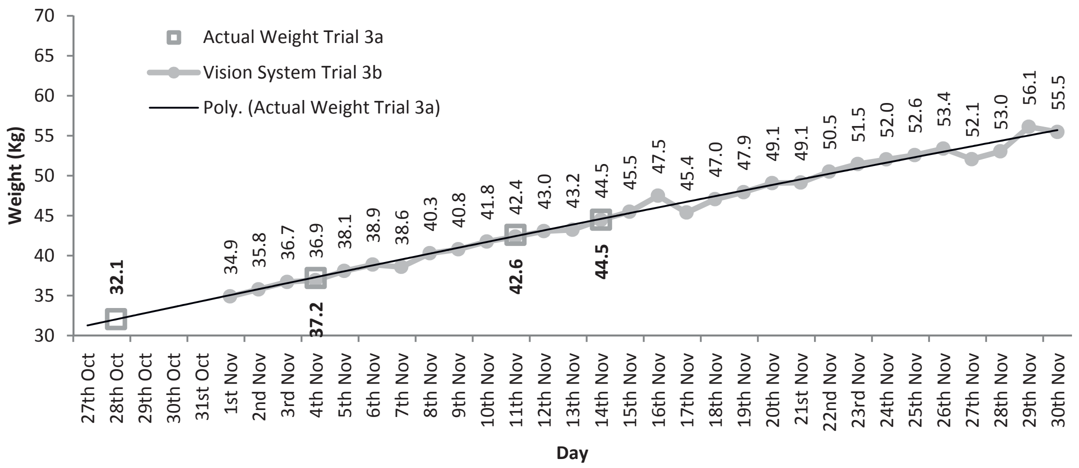


Figure 13: Error associated with individual measurements using the vision system as compared to weight of pigs measured using a traditional scale.

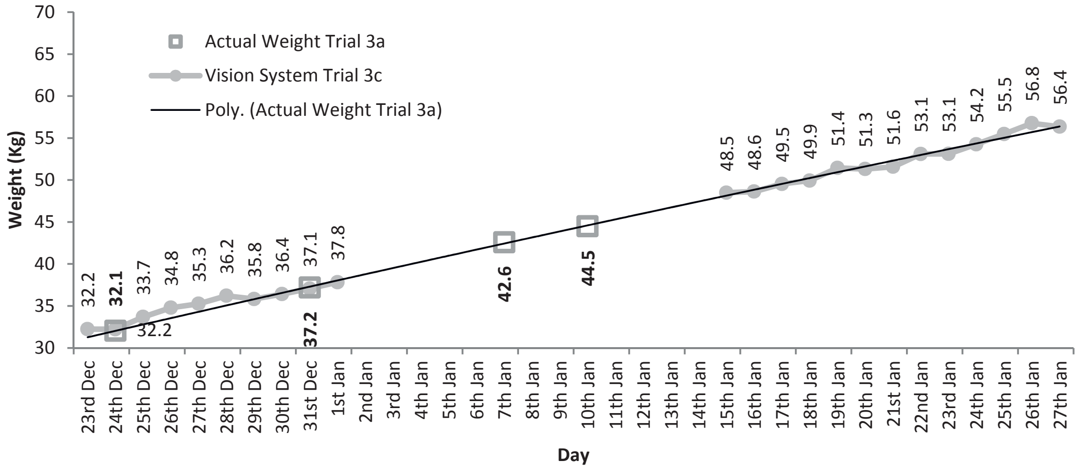


Figure 14: Error associated with individual measurements using the vision system as compared to weight of pigs measured using a traditional scale.

animals grew above 30 kg this cut off value had less effect on the average. The issue was identified on 1 November and the new cut off value was set at 25 kg to include smaller pigs. Notably some animals at this point could have been still less that 25 kg, however it was suspected that these small animals were such an insignificant proportion of the population that at this time that it had little to no effect on the average for 4 November onward.

For trial 3c (figure 14) the lower limit was set to 20 kg and recorded weights continuously until 1 January when the computer hardware failed, moisture and rodents had interfered with the electronics. A new computer was organised and the system resumed on 15 January. Similar results were obtained in comparison to trial 3b (figure 13).

In trials 3b and trial 3c overlaying the initial actual weight estimates in respect to the vision estimates gives a very strong indication that the system is recording the daily estimates accurately. What is unusual is that trial 3a indicates that there is substantial daily growth above the trend of the four actual weight records. Trials 3b and 3c indicate that the pigs grew from 32.1 kg (projected) to 55.5 kg over 34 days and from 32.22 to 55.5 kg over 33 days, respectively. However during trial 3a the system indicated that the animals reached a weight of 55.7 kg in 29 days from the actual recorded weight of 32.1 kg on 15 September. There is therefore, a significant production difference of 4 and 5 days between the second and third batches of animals in trial 3b and 3c, respectively, when compared to that to the first trial 3a. If the actual weight records of trial 3a are each offset backward four days (extending the duration to 33 days) the prediction on the 33rd day of trial3a is 55.7 kg and closely resembles the trend observed during trial 3b and 3c. This indicates that either the date information was recorded incorrectly or there was another reason for the decreased production efficiency during trial 3b and 3c such as the increasing summer temperatures or a diet change. Irrespective of what occurred in trial 3a the system was able to determine near identical rates of growth in respect to the initial actual recorded weight in the same pen at the same facility in both trials 3b and 3c indicating a strong level of repeatability from the systems in relation to daily and independent average group

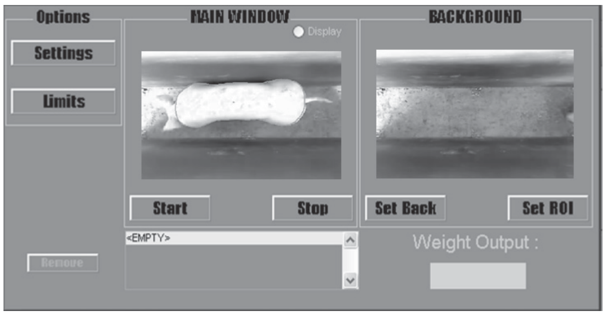


Figure 15: The user interface developed.

weight estimates. Further validation trials will be required with an increased number of actual average group-weight records so that comparisons can be made directly.

3.2 Main shortcomings identified

A poorly processed image was generally the result of a pig being in a suboptimal orientation, dirty or under significantly varying lighting conditions which made edge detection more difficult. The pre-processing stage often correctly identified the pig in the image. However, if the orientation of the pig was not straight and lighting conditions were poor the extracted dimensions of the pigs' body had greater potential to contain errors.

3.3 User interface developed

A graphical user interface called "pigui" has been developed in order to easily and automatically execute image capture, edge and contour detection, feature extraction and record the processed image and weight prediction (figure 15).

4 FUTURE WORK

Currently the system operates with a camera resolution of 320 × 240 pixels and at an operating height of 1.68 m from the camera lens to ground. A setup height increase is required so that it does not interfere with the head height of stock people. Increasing the system resolution is also being considered to assist in the repeatability and reliability of the system. An increase in the resolution is likely to make the system more accurate, however it will also increase the demand on the processor, so an optimal trade-off between the system speed and precision needs to be achieved. Hardware acceleration is also being investigated in the attempt to increase the resolution maintain real-time speed and create more compact dedicated standalone hardware.

The following developments are currently being investigated to improve the vision system or are going to be pursued in the near future:

- improvements in measurement precision of the front and rear portions of the pig
- increase resolution while maintaining processing speed
- collect and analyse another large sample of pigs at a much higher resolutions to define new precise body measurement limits and to permit statistical performance analysis, which have been unable to be deducted for the present results
- predictive methods such as artificial neural networks to increase prediction accuracy and repeatability
- improve the algorithms ability to detect the pig contour at any angle
- determine the optimised limits for all body measurements (define a pig shape set)
- apply same principles to other breeds of pigs
- construct an artificial environment that optimises the vision system.

5 CONCLUSIONS

The potential of obtaining the precise weight of a pig in real time has been demonstrated using image analysis. Several measurements that have not been reported in literature correlated well to weight with R^2 values in excess of 0.90. The developed system has the potential to replace conventional livestock weighing methods in future; however further research into the precision of the measurements of individual animals is required. Future work is likely to increase weight prediction precision and repeatability by classifying good and bad samples based on variables that indicate the estimation integrity of the sample.

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