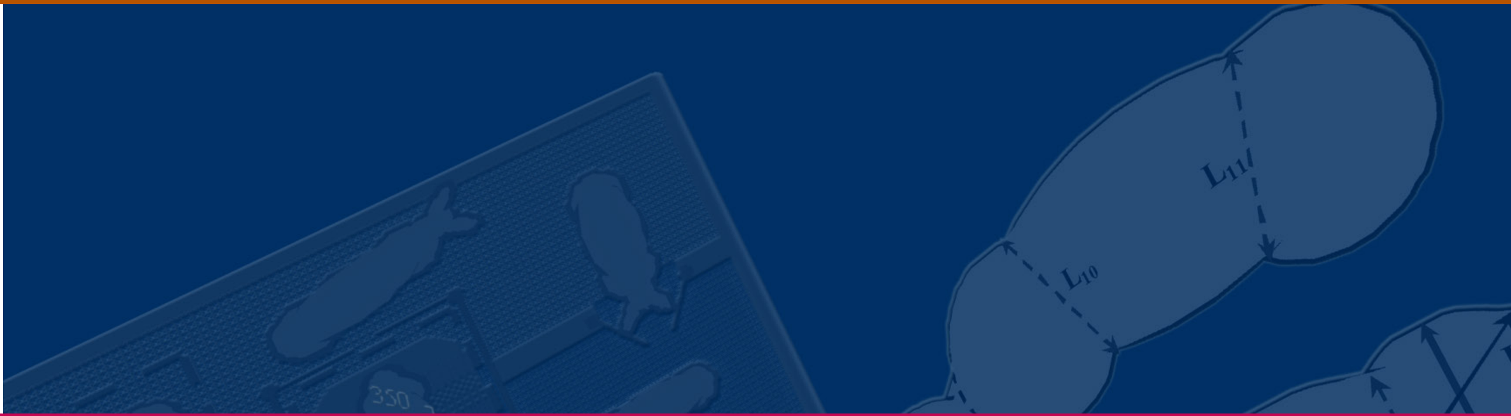

DEVELOPMENT OF A SMART LIVESTOCK FARMING TOOL FOR IDENTIFYING ANIMAL GROWTH USING ARTIFICIAL INTELLIGENCE

A dissertation submitted by

Matthew J Tscharke, M Eng

For the Award of

Doctor of Philosophy

Engineering and Surveying • 2012

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ABSTRACT

Affordable tools with the ability to continuously monitor the growth rate of livestock animals are highly sought after by the livestock industries. This demand is driven by the potential for these tools to assist in improving animal welfare and production efficiency. In a rapidly growing population the demand for meat is escalating, especially in Asia, where the middle class is currently expanding. Meanwhile in the western world there is growing consumer concern surrounding animal husbandry, with certain organisations labelling some of the current husbandry practices cruel or sub-standard. The environmental impacts of livestock farming are also increasingly becoming scrutinised, pressuring researchers to find new methods to increase the efficiency of livestock nutrition, and improve health (disease prevention), reproductive and waste management practices. At the centre of these problems is the ever-changing individual animal as it continuously adapts to its surrounding environment and available resources.

Livestock growth is a fundamental measure which can be used for diagnostic purposes in these areas, therefore the main objective of this study was to develop a system to automatically determine the growth of individual and groups of livestock animals (pigs) using welfare friendly and non-invasive methods. A machine vision system was selected to undertake this weight estimation task, whereby pigs' body measurements are extracted from images and used to estimate their weight without physical interference.

Reviews prompted the development of a methodology to determine the weight-estimation equations as a function of not just the animals' body measurements but also their pose. Subsequently equations were generated from shapes that conformed closely to a specified reference template shape. Thus, to enhance precision during weight estimation the template shape was directly linked to the equation and pose validation aspects of the system. Filters were developed to provide recognition via the confirmation of the characteristic template shape and known body measurement and weight relationships. The shape filter ensured that 94% of weight estimates that passed through to output were within ±5 kg of the actual weight of the pig. Using the shape and limit filter in unison ensured that greater than 97% of the samples which passed had an weight estimate within ±5 kg of the actual weight of the pigs and 68% of the total number of samples were within ±2 kg. Statistical modelling was used to determine the importance of different body measurements in estimating weight. Subsequently a multivariate linear weight estimation equation was created to estimate pigs' weight using a stepwise selection of variables. The multivariate linear equation estimated 2% more sample weights within ±2 kg error and 3% less sample weights greater than ±5 kg error than the closest non-linear equation. Software was written to automatically recognise pigs inside the field of view (FOV) of the camera and to extract 16 body measurements from the pigs' body contours. Height was manually recorded from the back of a sample of pigs to determine its strength in weight estimation. Including the pig's height in the weight-estimation equation did improve predictive performance with a 7.34 % improvement in the number of samples estimated within ±2 kg of the pigs' actual weight compared to a multivariate equation without the height parameter. Although, this improvement was not significant enough to justify the additional practical development required to collect the height information automatically during the weight estimation process.

Both off-line simulation and on-farm experiments were undertaken using data collected from commercial facilities. During an off-line simulation, the shape and dimension filters were applied across a dataset containing over 20,000 frame samples of over 500 pigs. Gut fill was used as a guide to determine a practical error margin for measuring the weight of individual pigs across the course of a day. The machine vision system was found to operate within an acceptable error margin of 50 % of the gut fill according to the equation and average shape template used during off-line simulations. As on average pigs in the weight-range of 45 to 115 kg had their live body weight estimated to within 3.16 % and 2.20 % of their actual live body weight, respectively. For pigs less than 45 kg in weight the piGUI system operated, on average, to within 67% of the weight attributed to gut fill (between ±1.07 and ±1.49 kg error). During off-line simulations, the percentage mean-relative error obtained by the piGUI system was between 5.1 and 3.7% for pigs in the weaner to grower weight range (15 to 45 kg) and less than or equal to 2.5% for grower finisher pigs between 45 and 115 kg. Thus, on average, the system was able to estimate the pig's body mass with practical precision.

The system labelled 'piGUI' was installed in pens at commercial facilities which housed pigs in group-sizes of between 10 and 160 pigs. During testing, the system determined the average weight of groups of pigs on a daily basis, tracking the group's growth rate. In some trials, the pig's weights were also estimated along with the weight deviation of the group. During a 22 day trial period the system estimated the average weight of a group of finisher pigs within 2.1%, on the seven days when the actual group weight was recorded from an electronic scale. No information was passed between successive days by the system.

The diagnostic power of the piGUI system was also tested on-farm. A deflection away from the standard growth curve was recorded during two successive batches of grower pigs after reaching weights greater than ~45 kg. These growth deflections were believed to be caused by stress related directly or indirectly to temperature, as the summer temperatures reached over 38°C during these batches. The level of animal activity recorded by the system, the temperatures leading up to the deflection in growth and figures reported in literature support this theory.

The piGUI system was also tested to see whether it could estimate the weight of sows in their early stages of pregnancy and whether it could detect changes in the body measurements of individual sows before and after giving birth. A group of eleven sows between day 71 and day 82 of pregnancy had their group weight estimated to within 0.1 kg of their actual group weight. Eighty-two percent of their individual weights were estimated within a practical range of ±5 kg of their actual weight. The metric body measurements of two Large White × Landrace sows were also recovered by the vision system before and after giving birth. The widths and lengths of the sows' recorded by the vision system were consistent with those found in literature. Indicating that the device may be used to monitor sow weight and body morphology in future.

The developed device was also tested at various locations within the pen environment. Radio Frequency Identification (RFID) was integrated into the system to determine whether bias in group estimates could occur as a result of the sampling region observed within the pen. A layout bias was discovered, caused by certain pigs visiting the FOV (containing the feeder) more frequently or for longer durations than others. Subsequently, feeding behaviour was determined using the RFID information collected and demand for the feeder was calculated for the pigs individually and as a group. The number of social interactions between pigs at the feeder was also determined, thus providing a method to identify social interaction and potentially the competitive nature of pigs automatically.

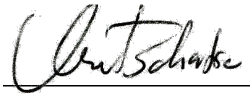
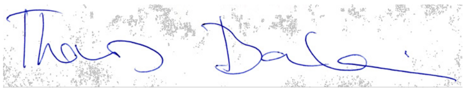
A comparative study was undertaken between a commercial system 'System-A' and the piGUI system. System-A failed to correctly estimate the group average weight of the finisher pigs in the trials. It was apparent that necessary conversions were not taking place within System-A's software to normalise the extracted body measurements to suit weight-estimation equation coefficients. It was found that, System-A's growth data would require a multiplication by a scalar factor to adjust the growth data to valid weight ranges. Code within the piGUI software performed the necessary conversions automatically during initialisation and was not burdened by this limitation. The piGUI system estimated the group average weight to within 2.1% on each of the seven days when the actual weight of the pigs were determined using the electronic scale. On these days, System-A reported group average weight estimates in excess of 16 kg error of the actual group average weight. It was clear that the distribution of weight data recorded daily by the piGUI system was far more concentrated around a mean estimate value than system-A.

The results of this PhD study demonstrate that the average weight of groups of pigs can be calculated with sufficient practical accuracy. The precision achieved during this study was better than reported in the literature and the precision of the system was also favourable compared to a commercially available system. Therefore the developed system can be used for practical purposes on commercial farms to determine the average weight and growth of groups of grower-finisher pigs.

CERTIFICATE OF DISSERTATION

This dissertation is submitted by Matthew J Tscharke (B. Eng - Mechanical) (Honours 2A) for the award of Doctor of Philosophy 2012 at the University of Southern Queensland, Faculty of Engineering and Surveying.

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

		ENDORSEMENT	
Signature of Candidate	Date	Signature of Supervisor/s	Date
	11/7/12		11/7/12

PREFACE

This thesis presents PhD research carried out during the 2/2/09 to the 8/2/12 at both the University of South Australia and the National Centre for Engineering in Agriculture, University of Southern Queensland. Experiments were undertaken at three different commercial facilities during this time Rivalea, Corowa NSW, Riverhaven Enterprises, Morgan SA and PPPI, Roseworthy SA. Early development of this work was undertaken as part of a co-operative research centre program "Measuring feed intake and pig weights in commercial situations" under the subprogram "Practical and continuous measurement of feed intake and pig weight (2A-103)" which was funded by the PORK CRC and collaborative partners South Australian Research and Development Institute (SARDI) and Rivalea. This project was concluded in 2009, however, the PORK CRC continued funding the development of a system to estimate the weight of livestock (pigs) for the subsequent 3 years until early 2012.

This thesis presents the combined work from several published journal articles conference papers and submitted manuscripts to academic journals and industry organizations entitled;

1. **Tscharke, M.** & Banhazi, T. M. (2011). Review of methods to determine weight, size and composition of livestock from images. In *The Bi-annual Conference of the Australian Society of Engineering in Agriculture (SEAg 2011)*, 465-483. (Eds C. Saunders and T. Banhazi). Gold Coast, Australia: Australian Society of Engineering in Agriculture.

2. Banhazi, T. M. & **Tscharke, M**. (2011). Review of Image Analysis (IA) technologies for the Australian pig industry. Final report for APL. (54 Pages). Canberra, Australia

3. **Tscharke, M.** & Banhazi, T. M. (2011).Determining animal behaviour using machine vision and artificial intelligence. In *The Bi-annual Conference of the Australian Society of Engineering in Agriculture (SEAg 2011)*, 55 (Eds C. Saunders and T. Banhazi). Gold Coast, Australia: Australian Society of Engineering in Agriculture.

4. **Tscharke, M.** &Banhazi, T. M. (2011).Growth recorded automatically and continuously by a machine vision system for finisher pigs. In *The Bi-annual Conference of the Australian Society of Engineering in Agriculture (SEAg 2011)*, 454-464. (Eds C. Saunders and T. Banhazi). Gold Coast, Australia: Australian Society of Engineering in Agriculture.

5. Banhazi, T. M., **Tscharke, M.**, Ferdous, W. M., Saunders, C. &Lee, S.-H. (2011). Improved image analysis based system to reliably predict the live weight of pigs on farm: Preliminary results. *Australian Journal of Multi-disciplinary Engineering* 8 (2): 107-119.

6. Banhazi, T. M., **Tscharke, M.**, Ferdous, W. M., Saunders, C. &Lee, S.-H. (2009).Using image analysis and statistical modelling to achieve improved pig weight predictions. In *The Bi-annual Conference of the Australian Society*

of Engineering in Agriculture (SEAg 2009), p. CD publication. (Eds T. M. Banhazi and C. Saunders). Brisbane, Australia: Australian Society of Engineering in Agriculture.

7. Ferdous, W. **M., Tscharke**, M., Saunders, C., Lee, S.-H. &Banhazi, T. M. (2011).Digital image processing methods for the identification of pigs posture during weight estimation. In *5th European PLF Conference*, 422-432. Prague.

8. Banhazi, T. M., **Tscharke, M.**, Lewis, B. &Broek, D. (2009). Practical and continuous measurement of feed intake and pig weight. Final report for the PORK CRC. (108 pages). Adelaide, Australia.

9. Banhazi, T. M., Lehr, H., Black, J. L., Crabtree, H., Schofield, P., **Tscharke, M.** &Berckmans, D. (2011).Precision livestock farming: scientific concepts and commercial reality. In *ISAH conference proceedings*, p:137-143.

A patent has also been submitted:

Banhazi. T. and **Tscharke, M**. *Image analysis for size estimation*. **(Provisional patent application number: 61346310)**

During this time I attended four conferences on subjects directly related to this PhD study and made two oral and one poster presentation. During this PhD study I was also involved in the data collection and analysis of a sister component in the project (2A-103) involving the development of an apparatus to determine the dispensed weight of feed which is detailed in the following publication;

10. Banhazi, T. M., Lewis, B. &**Tscharke, M.** (2011). The development and commercialisation aspects of a practical feed intake measurement instrumentation to be used in livestock buildings. *Australian Journal of Multi-disciplinary Engineering* 8(2): 131-138.

AIMS AND THESIS OVERVIEW

The Chapters found in this thesis provide supporting evidence that relates to the general hypothesis of this PhD study which aims to determine whether the live weight of groups of livestock can be estimated reliably, efficiently, accurately and automatically using two dimensional image analysis techniques.

These chapters aim to answer the following key questions.

- What methodical approaches could be used to tackle this problem?
- What equipment could be considered in the system design?
- How can an animal be identified and tracked reliably within images?
- How accurately and reliably can an animal's weight be determined from its appearance in two dimensional images?

Two literature reviews form *Chapter 1* and *Chapter 2* of this thesis. Chapter 1 involves a comprehensive investigation into the methodologies other researchers have used to tackle the weight estimation problem. From all alternatives image analysis was found to be the most attractive technique to automate the weight estimation process. Subsequently studies using this technique are reviewed and the performance of a number of research based systems involving the weight estimation of several different livestock species is documented. The various modelling methods used to describe the relationship between weight and different body measurements are also determined. In the later part of Chapter 1 the image analysis techniques relevant to identifying and extracting semantic information of the animal out of the image for further analysis are presented, with specific attention given to techniques that complement the systems application environment. Review findings prompt further research related to the posture of the animal during weight estimation. As the animals posture has close ties to behavioural recognition Chapter 2 shifts focus slightly to review machine vision techniques and technologies used in the study of animal behaviour. No behavioural recognition software was available which could extract the required information of the animal out of images reliably. Consequently our own software development was warranted in this study. *Chapter 3* draws on the findings of Chapter 1 and Chapter 2 to identify weak points in existing methodologies for weight estimation using image analysis. Chapter 3 begins with a description of the task at hand, followed by a breakdown of the generic attributes of livestock-scales that provide insight into the various elements required in a livestock-scale design. Potential equipment and the working environment is then reviewed and equipment selection, configuration and installation positioning is justified. The individual software methods that were created in support of a scale's functioning elements are explained and illustrated. These methods identified a pig, its posture and determined its live weight from the body measurements extracted from images. For enhanced control, an integrated equation and shape builder was also formed. This builder configures and outputs a complementary shape and equation pair for weight estimation and shape validation during system operation. After integration, the combined segmentation, extraction, validation and estimation methods formed the 'piGUI' system which was used to test the hypothesis of the project. Simulated results of the performance of the piGUI system can be found at the end of Chapter 3. Various field trials were undertaken during system development. *Chapter 4* presents the first on-farm trial undertaken at a small commercial research piggery housing finisher pigs. The ability of the piGUI system in estimating the live weight of finisher pigs was determined through validations performed both on-farm and off-line. In both validation trials the system estimated the average weight of groups of finisher pigs to practical levels. *Chapter 5* presents trail work undertaken to estimate the weight of grower pigs. Both off-line and on-farm trials at a large Australian commercial piggery were undertaken. In both trials the average weight of groups of grower pigs were estimated to practical levels by the system. The piGUI system's analytical power was also explored in this chapter, with hot summer temperatures appearing to adversely affect the activity level and growth of the grower pigs. In *Chapter 6* the system's ability to estimate the weight of sows' in early pregnancy is determined and the morphological changes recorded before and after giving birth are explored. The system estimated the average weight of a group of sows to practical levels. *Chapter 7* determined whether bias in group weight estimates could occur from certain pigs feeding more frequently and for longer durations than others. The system was installed above a feeder within a group of pigs' pen and Radio Frequency Identification (RFID) was integrated into the piGUI system to detect for any bias. Bias was identified from certain pig's body shapes and the sampling location of the device within the pen. *Chapter 8* contains a comparative study between two systems running in parallel; the piGUI system and an existing commercial image-based weighing system labelled 'System-A'. In *Chapter 9* conclusions are drawn from the results of each chapter and future improvements and directions are discussed. Technical detail can be found in the appendices when prompted.

ACKNOWLEDGEMENTS

My study has involved a combined effort from many individuals which I am forever grateful for.

Firstly I would like to gratefully acknowledge the financial assistance and support of the PORK CRC and APL. In particular I extend my thanks to Roger, Pat, Emalyn, Will, Darryl and Sue who worked behind the scenes to support and guide their students. The workshops, industry events, conferences and meetings I was given the opportunity to attend, gave me great insight into to the pork industry and the livestock industry as a whole. Importantly, these events provided me with background understanding of animal science and continue to allow me to identify areas where engineering may be applicable in agriculture in future. I hope as I move forward in my career I can continue to help the industry with its problems.

I would also like to sincerely thank the professional support received from the staff at the University of Southern Queensland and the National Centre of Engineering in Agriculture (NCEA). In particular I would like to extend a very big thank you to my principal supervisor Associate Professor Thomas Banhazi for the many discussions which have led to the current state of development of the vision system developed as part of this thesis. It was a long and windy road but you have supported me the whole way. Thank you. I hope to continue our work together to develop new PLF systems in the future. I would also like to thank Professor John Billingsley for his insight and Sandra Cochrane for her editorial advice and assistance.

I would also like to thank Kate whom has kept me sane and healthy during what has often been a stressful time of my life and to my parents Brian and Bronwyn who have gone out of their way to ensure that I have had the opportunity to obtain a good education.

Many thanks are owed to Dr Sang-Heon Lee and Dr Chris Saunders for their professionalism and assistance during the early months of this study and especially to Dr Sang-Heon Lee for his mentoring during the final stages of my undergraduate degree.

I would also like to acknowledge staff at the commercial facilities I attended, including Dave, Chris, Paul, Wayne, Mark, Grant and Andre whom at various times during my studies lent me a helping hand or equipment.

Lastly I would like to give a very big thank you to Wahid Ferdous who was a great friend during the early stages of the project and made the unpleasant task of manually weighing pigs, more enjoyable.

Thank you all.

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