Precision Livestock Farming: An international review of scientific and commercial aspects†

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Abstract: Precision Livestock Farming (PLF) is potentially one of the most powerful developments amongst a number of interesting new and upcoming technologies that have the potential to revolutionise the livestock farming industries. If properly implemented, PLF or Smart Farming could (1) improve or at least objectively document animal welfare on farms; (2) reduce greenhouse gas (GHG) emission and improve environmental performance of farms; (3) facilitate product segmentation and better marketing of livestock products; (4) reduce illegal trading of livestock products; and (5) improve the economic stability of rural areas. However, there are only a few examples of successful commercialisation of PLF technologies introduced by a small number of commercial companies which are actively involved in the PLF commercialisation process. To ensure that the potential of PLF is taken to the industry, it is recommended to: (1) establish a new service industry; (2) verify, demonstrate and publicise the benefits of PLF; (3) better coordinate the efforts of different industry and academic organisations interested in the development and implementation of PLF technologies on farms; and (4) encourage the commercial sectors to assist with professionally managed product development.

Keywords: Precision Livestock Farming(PLF), smart farming, commercialisation, scientific issue, animal welfare, efficiency
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1 Introduction

Efficient information management is very much part of profitable livestock production[1,2]. The main purpose of Precision Livestock Farming (PLF) is to improve the

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efficiency of production, while increasing animal and human welfare, via applying advanced information and communication technologies (ICT), targeted resource use and precise control of the production process[3,4]. The main purpose of this article is to briefly review the current scientific state of art and, more importantly, the commercialisation aspects of PLF technologies with the view to facilitate more effective technology transfer between scientific and commercial organisations. By doing so, we hope that PLF will not remain simply "the engineers' daydream" but become the "animals' friend and the farmers' panacea"[5], as predicted by previous authors.

2 Scientific issues

2.1 Scientific concepts and principles of PLF

Through the adoption of electronic data collection, processing and application, precision farming has the potential to improve production efficiency and reduce costs[6-8], as well as increase animal and human welfare. There is currently an abundance of information available to livestock managers, but it is not generally structured in a way that can be applied readily. For example, a survey of producers raising beef from pastures in southern Australia showed that over 400 pieces of information could be relevant for their farms. The information comes from many sources including academic organisations, government advisors, producer magazines, media sources, technical advisers and other producers. Consequently, farm managers tend to adopt procedures in areas where they have most interest or in which they believe they have most expertise and neglect many other areas that are also essential to drive productivity and profitability.

Furthermore, many producers perceive that adopting high productive management systems involves increased risk. The perceived risks include financial failure because of unforseen environment or market circumstances, damage to the farm infrastructure such as soils and pasture, compromises to animal health and welfare, and increased stress on farmers from managing an intensified system. These risks are real. Thus, it is important to develop a management system that ensures only the most essential procedures are carried out, they are all carried out correctly and consistently, and in a way that controls risk. Such a system, based on the Hazard Analysis Critical Control Point (HACCP) method, has been developed for grazing beef enterprises in Australia[9] and forms a model that can be applied to any other animal industry. The principles behind the system are given as follows:

(1) Identify those processes which truly have a major effect on productivity, profitability and/or sustainability. These include actions that, if not carried out correctly, will substantially reduce the viability of the enterprise. These processes should cover every aspect of the enterprise from strategic planning of the business structure through all aspects of production to sale of the product. It is important to reduce the number of "essential processes" to only those that will have a major impact on the enterprise if not carried out correctly. The number must be manageable because all are to be consistently applied over time. In the example with grazing beef enterprises in southern Australia, only 29 processes across the entire enterprise were considered to be essential for maximising profitability and sustainability.

(2) Identify, for each essential process, the farm or market variables that must be measured to ensure that each essential process is being carried out correctly. Establish the frequency at which each measurement must be made and set maximum and minimum limits for each measured variable to ensure that the process will continually remain within the optimum range and will not get out of control.

(3) Apply the most profitable pre-determined corrective action whenever measurements are outside of these limits. The process of having predetermined actions when the measurement limits are breached substantially reduces the stress level for the manager because the plan of action and when to apply it has already been established and the consequences are known. Partial or whole enterprise budgets are an important tool for selecting the most economically viable corrective action.

(4) Establish Standard Operating Procedures for

individual enterprises for each essential process to ensure that, under normal circumstances, the critical measured values will remain within the set limits. Such a process is important so the manager can "go on leave" knowing that each critical process in the enterprise will be measured and carried out correctly by staff. Both high level (annual calendar and daily actions) and low level (how to do a specific task) procedures are essential.

(5) Provide the tools necessary for making the essential measurements, interpreting the measurements and deciding on the most profitable corrective action. These tools are essential components of the "package" and must be provided as part of any adoption package. There is a need also to train staff with these tools.

The fact that humans tend to become lax with the application of repetitive tasks is one of the main reasons for failure of systems like the one outlined above. Recording and checks of measurements and actions by other people is one way to help overcome the problem. The difficulty faced by many rural industries in industrialised countries is obtaining and retaining adequately trained and motivated staff. The lack of good staff frequently contributes to the failure of well-planned adoption programs.

The major role for PLF is to simplify this process of collecting, processing and analysing data so that the farm manager is presented with solutions, not problems[10-12]. Advances in the application of the outlined procedure for adoption of essential enterprise processes will depend more and more on the automated measurement, interpretation and control of these processes. The procedure should include automation of all measurement systems, interpretation of the measurements, identifying when critical measurement limits are breached and built-in automatic control systems for each essential process to bring it back inside the acceptable limits. A useful example of the type of change needed within the animal industries comes from the international steel industry. In the 1950's, all tasks were undertaken by humans compared with today when the whole process is controlled electronically, almost all manual work tasks are automated and monitored centrally. This is a vision for PLF, where animal welfare, environmental sustainability, productivity and profitability are all maintained at an optimum using electronic measurement, interpretation and control systems.

2.2 Integration of traceability with PLF

Traceability within livestock management has largely been limited to movement and disease control applications such as the European passport system for cattle, the PigPass for pigs in Australia and the movement permit across state/provincial borders in Malaysia and Vietnam. Virtually no attempt has been made to unlock the economic benefit that traceability can offer for livestock enterprises. There are a number of objective reasons why the integration of traceability and PLF has not progressed further, which include (1) availability of easy to implement and affordable automated identification systems, (2) overemphasised privacy concerns related to data captured on-farm, (3) inconsistent offering of traceability products to farmers, and (4) too much focus on particular numbering technologies (simple numbering, barcode, radio-frequency identification (RFID)).

The most interesting example of the integration of traceability with PLF in our opinion is the exchange of information along the feed-animal-food chain. This information exchange (Figure 1) has a number of benefits: (1) Feed and feed input providers can greatly improve the composition of their products if they have access to slaughterhouse statistics resulting from the feeding profiles applied on the farm; (2) Farms can use such a system for the selection of the right feed (or right feed provider). They can also optimise their feed use/intake from the statistics of other farms on the network; (3) Abattoirs can use the system as a basis for cooperation with farms to produce and source more animals on weight and conformation specification; (4) Industry statistics are a very important tool for both governments and the industry itself to steer the sector. Reliable statistics can be used for political decision making, benchmarking, lobbying and business decision making.

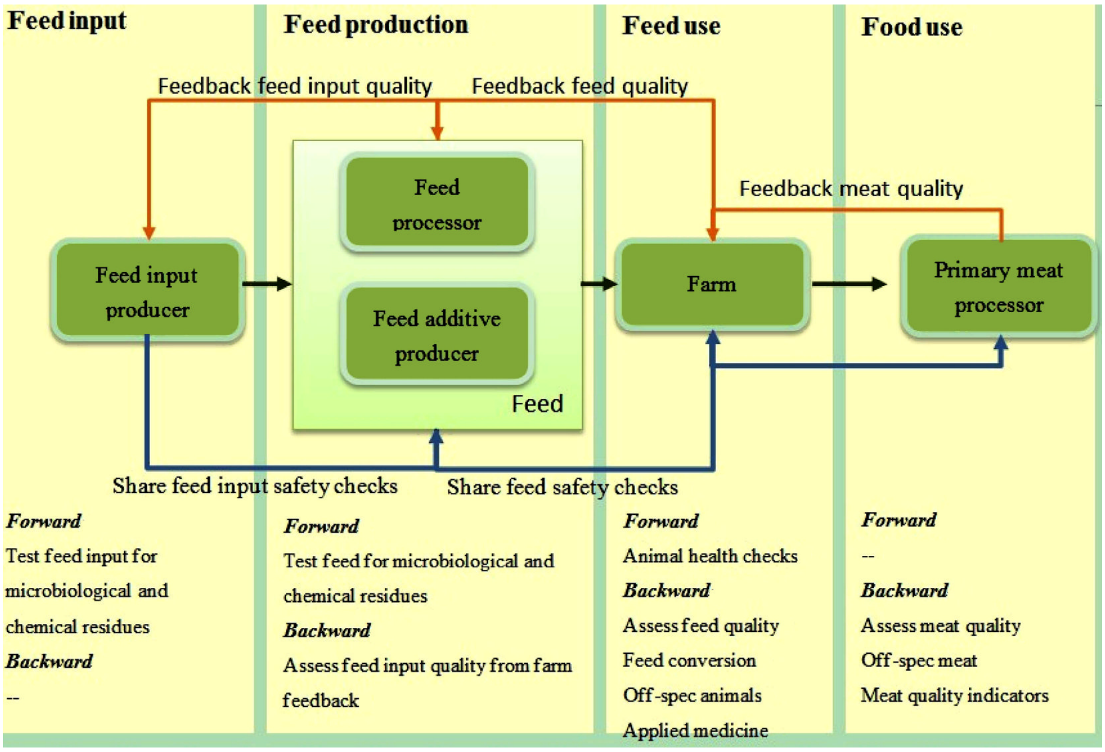

Figure 1 Traceability systems and linkages with PLF[13]

2.3 Scientific and technological developments

Many of the early PLF developments were predominantly instigated in Europe (EU)/UK. Early pioneers of the PLF concept were researchers in the Silsoe Research Institute, UK and Leuven University, Belgium. Additional developments took place in other EU countries, such as Germany, Denmark, the Netherlands, Finland and the Volcani Research Centre, Israel[14,15].

Table 1 Examples of PLF technologies developed over the years

Reference	Technology/tools
[16]	Improved egg incubators via synchronisation of hatching
[17]	Intelligent ventilation control in livestock buildings
[7,18-20]	Weight estimation of pigs via machine vision tools
[21]	Dairy management to maximise profit
[22,23]	Improving profitability via precision feeding for pigs
[24]	Sensor placement robot for pigs
[25,26]	Cattle monitoring system
[27]	Udder health and hygiene monitoring in dairy cattle
[28-30]	Poultry carcass inspection
[31]	Automated egg counting and identification
[32]	Carcass composition prediction for pigs
[33-35]	Automated fish sizing and sorting
[36,37]	Improved thermal control for pigs via machine vision
[38-40]	Cough recognition in pigs

In 2002, Australian PLF developments started with assistance provided by scientists in UK and Belgium[41]. Most pig industry related PLF developments were led by scientists in South Australia[6,42], while researchers in University of Southern Queensland (USQ) developed PLF applications for the beef industry. Researchers at the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) extensively investigated virtual fencing technologies[43,44]. In Table 1, a number of publications and resultant technologies are presented as an example of PLF tools developed over the years without aiming to accurately review all developments over the years.

Recent developments in communication technology through mobile phone technology, telecoms and the internet offer a huge potential benefit to the design, application and value of PLF. Whilst independent applications on individual farms may be desirable to some customers, the advantages of centralised data collection, processing, management and reporting are significant. For example, data collected by sensors on the farm can be sent to a central site for processing, storage and reporting. This could result in considerable time saving for farm managers, with their efforts better allocated for more productive tasks, such as farm and animal husbandry related tasks. The centralised processing should supply managers with only the data pertinent to their daily needs, with more detailed reports available as required, including the comparative performance of their units, for example. In short, the benefits offered by a good PLF system should be obvious to user and ideally should reduce their management workload, not increase it[11].

3 Commercial issues

3.1 Examples and principles of commercialising PLF technologies

In livestock production there are already a few examples of commercialisation of PLF techniques. Good examples of commercial adoption of PLF techniques include the use of robotics in dairying, measurement of water usage, egg counting, bird weighing, better control of environment in poultry houses, computerised feed systems, climate control, automated disease detection, growth measurement and real-time production site data capture in piggeries[38]. The recent EU sponsored BrightAnimal project[13] has looked for evidence of PLF technologies in laying hens, pigs, diary and aquaculture fish used in a commercial environment in a number of countries, including Estonia, Denmark, Norway, United Kingdom, Australia, Malaysia, Vietnam and South Africa. In general, there was limited evidence of commercial PLF products used on farms. As expected, farmers in techno-friendly countries like Estonia, are more inclined to use technology to reduce their dependency on hard-to-get (and expensive) workers and make their life a little more comfortable. However, even on Estonia, the amount of deployed technology is very limited and key aspects of animal welfare or productivity are not monitored in an automated fashion routinely.

The commercialisation principles of PLF technologies need to include (1) a verification of the benefits of the PLF technique being proposed, (2) a clear communication of those verified benefits to customers, (3) identification of principle beneficiaries (i.e. operator vs. owner of the business), (4) provision of appropriate training and technical support, (5) correct specification, installation, commissioning and monitoring of the installed system. Unfortunately, PLF developments have been largely spear-headed by academic organisations so far. In general, there is an inadequate engagement of commercial companies in the PLF technology development process. In order to increase the interest of suitable companies in providing services to farmers, collaboration between smaller specialist firms and larger generalist firms is desirable. Transferring PLF technologies to companies supplying and managing the systems is a significant step towards developing commercial PLF tools/products that are wanted by customers and sold with confidence.

3.2 Limiting factors of commercialisation

The greatest problem of commercialisation is the lack of a consistent service offering for farmers. Farmers are biologist by nature and only technologists occasionally. There is a need for a service sector that will be able to (1) take care of technology components, (2) interpret data captured by sensors, (3) formulate and send simple, relevant advice to farmers on a regular basis, and (4) involve users in technology developments. This service sector would need to use suitable business models that avoid high initial investment costs for farmers. Affordable monthly or annual fees might well be compatible with farmers' cash flow; especially if they are linked to performance improvements or animal sales. Although farmers usually invest part of their gains in technology, it is typically machinery that they would look forward to buying (as opposed to software or sensors).

The food industry in general is a very conservative industry and with good reason. Although it is one of the largest industries world-wide, its margins are very small and its products are usually very delicate. Agriculture is a fragile industry, because it depends directly or indirectly on climatic factors and seasonal demand/supply circles. In addition, even for the more adventurous farmer it is very difficult to judge the applicability of a particular technology and "guesstimate" its benefits. In other words, an important missing element is the absence of clear cost benefit data on PLF that takes into consideration the complexity of farmers' purchase decisions. Demonstrating and verifying the economical, welfare and environmental benefits of these technologies are essential in the commercialisation process.

The other key limiting factor of adoption rate of PLF technologies on farms is the lack of co-ordination between researchers, developers and technology suppliers. Achieving better co-ordination between the developers and suppliers of PLF tools is very difficult, but would result in the development of better integrated systems. That in turn would result in greater commercialisation of PLF systems as integrated systems to serve the farmers better. In addition, many of the PLF "products" actually never have been "productised" (developed into a proper "product"); but they went directly from the lab to the farm. Only some larger firms with enough development funds have taken up PLF as their guiding principle.

4 PLF as a facilitator of progress: likely benefits and motivators of implementation

In the next 10 years, it is very unlikely that PLF will revolutionise the livestock industries. However, in the next 5-10 years, sensors will be deployed routinely around animals that might allow farmers to effectively monitor a range of useful parameters for all livestock species. This will enable a range of new services to be developed and implemented on farms, such as individual feeding, heat detection, health monitoring and animal localisation. Mobile robots will emerge for milking and other tasks both in the shed as well as in the open. Virtual fencing will contribute to better herd and meadow management and improve financial returns for grazing enterprises. Most farms in Europe will be computerised in 10 years and use software tools for their management.

The PLF can greatly contribute to an objective discussion on animal welfare by providing real data to the otherwise very subjective (and sometimes emotional) discussion process. While PLF will not be able to necessarily resolve all welfare related questions, it will allow interested parties to detect and act upon time periods when animals are kept under sub-optimal conditions.

Greenhouse gas (GHG) emissions are going to be very important in the future and PLF can contribute to the reduction of such emissions by measuring emission and potentially adjusting feeding, temperature and other parameters that influence the emission of gases[45]. Farm enterprises in the supply chain are making a concentrated effort to keep animals under optimal conditions, to keep emissions down and to provide the best livestock product at the lowest possible price. PLF can assist in transporting this information to other parties within the supply chain, and ultimately to the consumer. It can facilitate more informed choices by consumers and can be the base for other business models, such as selling meat by protein contents, emitted GHG gases, food miles, or other concepts. The exchange of information on the feed-animal-food chain has a great potential for optimising livestock production. Feed producers could extract very important information from carcass composition data. Farmers could improve their feeding regime and choose the feed provider with the "best" feed for their animals. Traceability and PLF are the basis for such an information exchange. If there is a continued decline in the profitability of farms in Europe, perhaps retailers will start buying farms and require data exchange along with the supply chain.

Environmental control will be much improved within 10 years and most farmers will know how much GHG they are emitting. Driven by consumers and retailers, they are striving to reduce their emissions by capturing gases, adapting their feed and dealing better with waste. The PLF will have its role in feeding strategies; perhaps will link to gas and waste production.

The PLF can also contribute to the avoidance of illegal trading of livestock and livestock products. Smuggling animals is a major problem (health and financial) in countries like Malaysia. Illegal and unregistered fishing is a billion dollar enterprise and cuts deeply into our fish banks. Misusing the available fish stock could be significantly reduced if the information chain was quicker to react.

5 Conclusions and recommendations

(1) The principles of PLF are well established and the routine use of PLF technologies could certainly contribute to the improved livestock management on

farms.

(2) Integrating traceability with PLF would be a positive step forward and would improve the usefulness of PLF systems.

(3) A number of interesting PLF developments has occurred over the past years, which have great potential to revolutionise livestock management. The PLF/smart farming technologies, (if properly implemented), could (a) improve or at least objectively document the level of animal welfare on farms, (b) reduce GHG emission and improve environmental performance of farms, (c) improve product segmentation and facilitate better marketing of livestock products, and (d) improve rural economy and stabilise rural populations.

(4) However, when it comes to commercial technologies, (a) there are only a few good examples of successful PLF technology commercialisation exist, and (b) only a small number of commercial companies are involved actively in the PLF commercialisation process.

(5) Thus, to facilitate the proper development and implementation of PLF products on farms, (a) a new service industry needs to be established to be responsible for maintenance of hardware tools and management of collected data, (b) benefits provided by PLF technologies need to be independently verified under commercial farm conditions, (c) development and marketing efforts of different industrial and academic partners need to be better coordinated, and (d) the involvement of commercial sector in the process of professional product development needs to be facilitated.

(6) In addition, a “Federation of PLF focused companies” might be created aiming at developing a “road map” document, highlighting the critical steps that need to be taken to stimulate the commercial uptake of PLF/Smart Farming technologies. Such document should be based on the outcomes of international PLF project and might be developed as part of a commercially focused PLF conference/meeting. PLF participants also need to engage their respective governments in order to secure public funds required for verification studies that would be unlikely to be financed by private companies.

[References]

[1] Thysen I. Agriculture in the information society. Journal of Agricultural Engineering Research, 2000; 76(3): 297-303.

[2] Lewis T. Evolution of farm management information systems. Computers and Electronics in Agriculture, 1998; 19(3): 233-248.

[3] Chamberlain-Ward S L. Continuous ambient air monitoring systems. in 14th International Clean Air & Environment Conference, 1998; Melbourne, Australia.

[4] Cumby T R, Phillips V R. Environmental impacts of livestock production. in Integrated Management Systems for Livestock, 2001; Selwyn College, Cambridge, UK. BSAS, Edinburgh.

[5] Wathes C M, Kristensen H H, Aerts J M, Berckmans D. Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall? Computers and Electronics in Agriculture, 2008; 64(1): 2-10.

[6] Banhazi T M, Black J L. Precision livestock farming: a suite of electronic systems to ensure the application of best practice management on livestock farms. Australian Journal of Multi-disciplinary Engineering, 2009; 7(1): 1-14.

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

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

[9] Black J L, Scott L. More beef from pastures: current knowledge, adoption and research opportunities. 2002, Meat and Livestock Australia Limited: Sydney, Australia.

[10] Berckmans D. What can we expect from Precision Livestock Farming and why? in Acceptable and Practical Precision Livestock Farming, Smith I G and Lehr H, Editors. 2011, European Commission Halifax, UK. pp. 7-10.

[11] Lehr H. General conclusions and recommendations, in Multidisciplinary Approach to Acceptable and Practical Precision Livestock Farming for SMEs in Europe and Worldwide, Smith I G and Lehr H, Editors. 2011, European Commission: Halifax, UK. pp. 179-188.

[12] Berckmans D. Precision livestock farming (PLF). Computers and Electronics in Agriculture, 2008; 62(1): 1.

[13] Lehr H. Food information management and advanced traceability in Multidisciplinary Approach to Acceptable and Practical Precision Livestock Farming for SMEs in Europe and Worldwide, Smith I G and Lehr H, Editors. 2011,

European Commission Halifax, UK. pp. 84-111.

[14] Devir S, Maltz E, Metz J H M. Strategic management planning and implementation at the milking robot dairy farm. Computers and Electronics in Agriculture, 1997; 17(1): 95-110.

[15] Halachmi I, Edan Y, Maltz E, Peiper U M, Moallem U, Brukental I. A real-time control system for individual dairy cow food intake. Computers and Electronics in Agriculture, 1998; 20(2): 131-144.

[16] Exadaktylos V, Silva M, Berckmans D. Real-time analysis of chicken embryo sounds to monitor different incubation stages. Computers and Electronics in Agriculture, 2011; 75(2): 321-326.

[17] Gates R S, Chao K, Sigrimis N. Identifying design parameters for fuzzy control of staged ventilation control systems. Computers and Electronics in Agriculture, 2001; 31(1): 61-74.

[18] Brandl N, Jorgensen E. Determination of live weight of pigs from dimensions measured using image analysis. Computers and Electronics in Agriculture, 1996; 15(1): 57-72.

[19] Schofield C P. Evaluation of image analysis as a means of estimating the weight of pigs. Journal of Agricultural Engineering Research, 1990; 47: 287-296.

[20] Wang Y, Yang W, Winter P, Walker L. Walk-through weighing of pigs using machine vision and an artificial neural network. Biosystems Engineering, 2008; 100(1): 117-125.

[21] Maltz E, Livshin N, Antler A, Edan Y, Matza S, Antman A. Variable milking frequency in large dairies: performance and economic analysis - models and experiments. in 1st European Precision Livestock Farming. 2003. Berlin, Germany: Wageningen Academic Publisher.

[22] Niemi J K, Sevón-Aimonen M, Pietola K, Stalder K J. The value of precision feeding technologies for grow-finish swine. Livestock Science, 2010; 129: 13-23.

[23] Banhazi T M, Rutley D, Parkin B, Lewis B M. Field evaluation of a prototype sensor for measuring feed disappearance in livestock buildings. Australian Journal of Multi-disciplinary Engineering, 2009; 7(1): 27-38.

[24] Frost A R, Tillett R D, Welch S K. The development and evaluation of image analysis procedures for guiding a livestock monitoring sensor placement robot. Computers and Electronics in Agriculture, 2000; 28(3): 229-242.

[25] Mottram T T. Automatic monitoring of the health and metabolic status of dairy cows. Livestock Production Science, 1997; 48(3): 209-217.

[26] Stewart M, Stewart M, Webster J R, Verkerk G A, Schaefer A L, Colyn J J, et al. Non-invasive measurement of stress in dairy cows using infrared thermography. Physiology & Behavior, 2007; 92(3): 520-525.

[27] Bull C R, McFarlane N J B, Zwiggelaar R, Allen C J, Mottram T T. Inspection of teats by colour image analysis for automatic milking systems. Computers and Electronics in Agriculture, 1996; 15(1): 15-26.

[28] Chao K, Park B, Chen Y R, Hruschka W R, Wheaton F W. Design of a dual-camera system for poultry carcasses inspection. Applied Engineering in Agriculture, 2000; 16(5): 581-587.

[29] Park B, Chen Y R, Nguyen M. Multi-spectral Image Analysis using Neural Network Algorithm for Inspection of Poultry Carcasses. Journal of Agricultural Engineering Research, 1998; 69(4): 351-363.

[30] Park B, Windham W R, Lawrence K C, Smith D P. Contaminant classification of poultry hyperspectral imagery using a spectral angle mapper algorithm. Biosystems Engineering, 2007; 96(3): 323-333.

[31] Cronin, G M, Borg S S, Dunn M T. Using video image analysis to count hens in cages and reduce egg breakage on collection belts. Australian Journal of Experimental Agriculture, 2008; 48: 768-772.

[32] Doeschl-Wilson A B, Green D M, Fisher A V, Carroll S M, Schofield C P, Whittemore C T. The relationship between body dimensions of living pigs and their carcass composition. Meat Science, 2005; 70(2): 229-240.

[33] Hsieh C L, Chen F H, Liou J H, Chang S K, Lin T T. A simple and effective digital imaging approach for tuna fish length measurement compatible with fishing operations. Computers and Electronics in Agriculture, 2011; 75(1): 44-51.

[34] Ruff B P, Marchant J A, Frost A R. Fish sizing and monitoring using a stereo image analysis system applied to fish farming. Aquacultural Engineering, 1995; 14(2): 155-173.

[35] Zion B, Alchanatis V, Ostrovsky V, Barki A, Karplus L. Real-time underwater sorting of edible fish species. Computers and Electronics in Agriculture, 2007; 56(1): 34-45.

[36] Shao B, Xin H. A real-time computer vision assessment and control of thermal comfort for group-housed pigs. Computers and Electronics in Agriculture, 2008; 62(1): 15-21.

[37] Wouters P, Wouters P, Geers R, Parduyns G, Goossens K, Truyen B, et al. Image-analysis parameters as inputs for automatic environmental temperature control in piglet houses. Computers and Electronics in Agriculture, 1990; 5(3): 233-246.

[38] Guarino M, Guarino M, Jans P, Costa A, Aerts J M, Berckmans D. Field test of algorithm for automatic cough detection in pig houses. Computers and Electronics in Agriculture, 2008; 62(1): 22-28.

[39] Chedad A, Chedad A, Moshou D, Aerts J M, Hirtum A V, Ramon H, et al. Recognition system for pig cough based on probabilistic neural networks. Journal of Agricultural Engineering Research, 2001; 79(4): 449-457.

[40] Moshou D, Moshou D, Chedad A, Hirtum A V, De Baerdemaeker J, Berckmans D, et al. Neural recognition system for swine cough. Mathematics and Computers in Simulation, 2001; 56(4-5): 475-487.

[41] Banhazi T, Black J L, Durack M. Australian Precision Livestock Farming workshops. in Joint Conference of ECPA-ECPLF. 2003. Berlin, Germany: Wageningen Academic Publisher.

[42] Banhazi T., et al. Development of precision livestock farming (PLF) technologies for the Australian pig industry. in 3rd European Precision Livestock farming Conference. 2007. Skiathos, Greece: University of Thessaly.

[43] Bishop-Hurley G L, Swain D L, Anderson D M, Sikka P, Crossman C, Corke P. Virtual fencing applications: Implementing and testing an automated cattle control system. Computers and Electronics in Agriculture, 2007; 56(1): 14-22.

[44] Umstatter C. The evolution of virtual fences: a review. Computers and Electronics in Agriculture, 2011; 75(1): 10-22.

[45] Frost A R, Parsons D J, Stacey K F, Robertson A P, Welch S K, Filmer D, et al. Progress towards the development of an integrated management system for broiler chicken production. Computers and Electronics in Agriculture, 2003; 39(3): 227-240.