PRECISION LIVESTOCK FARMING FOR ANIMAL HEALTH, WELFARE AND PRODUCTION

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SUMMARY

Precision livestock farming, PLF, is an embryonic technology that applies the principles of process engineering to livestock farming. PLF requires a sensing system for outputs; a mathematical model of input/output relationships; a target and trajectory for controlled processes; and a model-based controller with actuators for process inputs. PLF has great potential to transform livestock production by efficient utilisation of nutrients, early warning of ill health, and reduction in pollutant emissions. While the current focus of PLF should be livestock monitoring, the ultimate goal is to employ PLF as the farmer's aid to automatic management of intensive and extensive livestock production.

Keywords: precision livestock farming, monitoring, welfare, health, production, environment

INTRODUCTION

Precision livestock farming (PLF) is an infant technology that is found in the scientist's and engineer's laboratory; there are few examples – yet – of its routine use on the farm. Its premise is simple: given the many technical, economic and regulatory demands that are complex, exacting and sometimes conflicting, then livestock farming will have to employ automated systems to monitor and manage the main processes involved to remain sustainable. Thus, the European farmer may have to adopt PLF in order to survive in a global market by substituting technology for skilled labour, a trend that has been relentless since modern European agriculture started to develop in the 18th century.

This paper reviews the technology of PLF, outlines its potential advantages in European countries (and other developed countries that face the same economic forces), considers some of the hurdles to be cleared by innovative farmers, manufacturers and scientists working together, and suggests how PLF should – and by implication should not – be used in the production of food from livestock. The perspective is that of livestock farming in the U.K.

The underlying assumption behind the adoption of PLF is that the interests of both the farmer and the consumer have to be satisfied if PLF is to be useful and be commercially viable. From the farmer's perspective, sustainable livestock production requires tight product specifications to be met profitably by skilled stockmen with minimal adverse environmental impact and a high standard of animal health and welfare; from the consumer's viewpoint, (s)he has only a scant knowledge of livestock farming and its practices, is becoming increasingly concerned about the provenance of his (or her) animal products, and requires his (or her) food to be safe, nutritious and affordable.

In the early days of its development, PLF was also known as integrated management systems but the latter term has fallen by the wayside to ensure that PLF is more closely aligned with precision agriculture (for crop production), its larger cousin. The first conference covering PLF was held in 2001 in Cambridge, U.K. (Wathes et al. 2001) and was noteworthy for the multidisciplinary cast of speakers and delegates. Subsequently, the 1st and 2nd European Conferences on PLF (ECPLF) were held in Berlin and Uppsala in 2003 and 2005 respectively (Cox 2003; Cox 2005), while the 3rd ECPLF will be held in Skiathos, Greece, in 2007.

THE BASIC CONCEPTS OF PLF

The definition of precision livestock farming used in this paper is *'the application of the principles and techniques of process engineering to livestock farming to monitor, model and manage animal production'*. Most commonly, closed loop, model-based control systems are used to provide automatic management to meet a specific target. The basic concept of PLF is shown in Figure 1 and is described in detail elsewhere, (e.g. Aerts et al. 2000; Aerts et al. 2003b; Wathes et al. 2005). PLF requires (i) continuous sensing of the process responses (or outputs in the terminology of the process engineer) at an appropriate frequency and scale with information fed back to the process controller; (ii) a compact, mathematical model, which predicts the dynamic responses of each process output to variation of the inputs and can be – and is best – estimated on-line in real time; (iii) a target value and/or trajectory for each process output, e.g. a behavioural pattern, pollutant emission or growth rate; and (iv) actuators and a model-based predictive controller for the process inputs, e.g. feed or the environment.

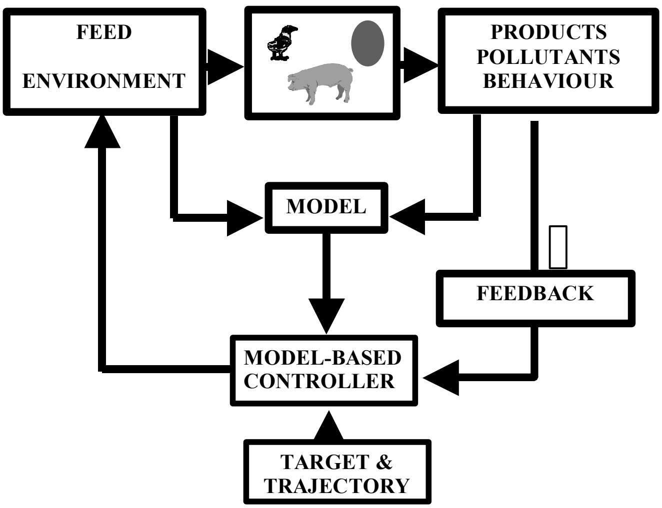

Figure 1. PLF concepts

Although perhaps a semantic point, it seems as if any application of advanced agricultural engineering in livestock farming, e.g. automatic or robotic milking, is considered to be an example of PLF. This is evidently not the case if the formal definition of PLF given above is used.

The essence of PLF is an integrated systems approach to livestock farming with automatic monitoring, modelling and management to drive processes along defined trajectories to meet specified targets. Nor does PLF have to be restricted to saleable products, such as eggs, meat or milk. The concept is general and can be equally well applied to animal behaviour, certain diseases or pollutants, in fact any process that is part and parcel of livestock farming. PLF can also be applied to both extensive and intensive systems of livestock farming.

Implicit in the concept of PLF is the scale at which the approach is to be used, i.e. the unit to be managed. This may be an individual animal, a pen, a building, the animals' bedding or a flock or herd outdoors at pasture. It is quite feasible to use PLF with unidentified individuals; however, the accuracy of their management will be greater if they are identified electronically to allow individual monitoring and management to take place. In general, the finer the scale at which PLF is applied, the greater the expense and the higher the return on the extra capital investment needed to justify the more accurate, finer control of the enterprise. Given the embryonic nature of PLF, there are no studies that address the question of the optimum scale at which PLF should be applied.

LESSONS TO BE LEARNT FROM CURRENT APPLICATIONS OF PLF

The earliest example of PLF is the Flockman™ technology, developed by David Filmer Ltd, U.K., to manage automatically the diet and environment of broilers (Filmer 2001) The key components of Flockman™ are: i) real time monitoring of feed intake and live bird weight; ii) novel feed provision using a blend of regular concentrate and whole grain cereals fed in meals; iii) environmental management, including dawn and dusk lighting, integrated with the feeding system; and iv) automatic adjustment of daily feed supply according to deviation of growth from target. Latterly, decision-making in Flockman™ was automatic (Stacey et al. 2004), according to real-time measurements of growth rate and food intake. Flockman™ was a pioneering example of PLF and, as such, was prone to many of the pitfalls of all new technology. It achieved early success in the U.K. market; approximately 15 percent of U.K. broilers were grown using it several years ago (www.flockman.com), though current usage is thought to be much less.

A similar approach to growing broilers using PLF was taken by Aerts where the objective was to control the growth trajectory of broiler chickens using an adaptive, compact, dynamic process model (Aerts et al. 2003a). Daily food supply was calculated to allow the birds to follow a defined target growth trajectory. Parameters of the growth model, which predicted the response to the control input (food supply), were estimated on-line. This adapted the model to the actual response of weight to feed intake and was the basis for efficient control. The control algorithm developed enabled the broilers to follow different target trajectories with a mean relative error ranging between 3.7 and 6.0%. With a few exceptions, the numerical values of feed conversion ratio and mortality after week 1 were lower and the values of uniformity index were higher in the controlled groups compared with *ad libitum* fed animals.

About the same time as the above developments, a comprehensive research programme to develop PLF to monitor, model and manage the growth of pigs and sows was undertaken by a team of engineers, mathematicians and animal scientists at Silsoe Research Institute and the Universities of Edinburgh and Bristol in the U.K. The PLF system comprised an imaging system for non-invasive monitoring of growth of pigs in a pen (Schofield et al. 1999; White et al. 2004), mathematical models of growth, food intake and carcase composition (Green & Whittemore 2003; Green & Whittemore 2005), and control of feed supply according to group or individual requirements (Parsons et al. 2007).The novelty of image analysis to monitor growth meant that the animals' shape and size could be measured directly, as well as their weight (Doeschl-Wilson et al. 2004; Whittemore & Schofield 2000), which was estimated from their plan area. The system was tested on a semi-commercial scale but has not been taken to the market.

The initial applications of PLF have been the growth of housed pigs and poultry though, in principle, the PLF approach could be applied to any farmed species, including those animals farmed extensively. There are a number of lessons to be learnt from these pioneering attempts by a few groups to develop PLF. Given the importance of the efficient management of growth and feed, the difficulties and tedium of manual weighing and the need to match nutrient supply to demand, it is not unsurprising that growth was the initial focus. Needless to say, the commercial success of these applications has been poor. The reasons for this are several folds. Firstly, the poor profitability of pig and poultry farming has inhibited capital investment on unproven new technology, even when the expected payback period is only several years. Secondly, much if not all of the development work that should have been carried out and paid for by the technology developers was not done, in which case the first customers (unwittingly) acted as guinea pigs to identify and resolve any shortfalls or problems in the technology. Thirdly, the sophistication of the computer hardware was too great for the skills and knowledge of many stockmen; in integrated operations, e.g. broiler farms; management decisions on feed formulation and supply (according to target) are not made by the stockman but instead by the production director/manager.

The penalties of early adoption of a new technology can be severe if the researcher's promises are not met on the farm. The new technology rightly acquires a poor reputation, making it harder for the researchers and commercial manufacturers to secure sufficient funds to overcome the outstanding technological problems or to market it to sceptical farmers. In the light of these lessons, it therefore seems timely to reappraise the technical and commercial prospects for PLF.

THE ELECTRONIC STOCKMAN – AN ENGINEER'S PIPEDREAM OR A GENUINE PROSPECT FOR THE FUTURE?

Electronic monitoring of livestock is at the heart of PLF. Currently the major examples of electronic monitoring of livestock are identification of cows, sows and sheep using RFID tags, detection of oestrus, and measurement of milk yield and composition in dairy herds. The most widespread use of agricultural electronics is to control the thermal environment of housed pigs and poultry where sensors for air temperature, relative humidity and, in some cases, ventilation rate, are integrated in controllers. These applications have been extremely successful in helping a farmer to manage his herds or flocks but the question remains why has not more use been made of electronics to monitor livestock?

In the mid 1990s, Frost forecast that automatic monitoring systems for farm animals would be developed soon that would integrate information from multiple sensors with mathematical models and knowledge bases to aid the farmer in decision-making, i.e. the basics of PLF (Frost et al. 1997). Even then, there was an abundance of sensors that were potentially available for electronic monitoring, e.g. of animal weight, behaviour, and physiological parameters using acoustic, chemical, gravimetric and other sensors. Frost concluded that "monitoring and control in livestock production is relatively undeveloped compared to most major industries. This is largely because most of the factors to be monitored are biological and inherently variable and unpredictable". Ten years after this review, are these conclusions still correct?

European agricultural engineers, in association with leading agricultural engineering companies such as Fancom, De Laval and Petersime, have organised a series of biennial workshops (SMART) since 2000 to oversee the development of monitoring systems for livestock. At the most recent workshop (SMART 2006, Italy; www.smart2006.eu), papers on the following processes were presented; most of the work described was at the experimental stage:

Cattle	Pigs	Poultry
Rumen pH, Blood & Milk fat	Vocalisations & Activity	Birds: Liveweight
Temperature: rumen & vulva	Farrowing behaviour	Eggs: Temperature, albumen,
Lameness & Location	Growth & Body composition	Ph, Nitric oxide release
Calving behaviour		

Clearly, there has been significant investment in research in Europe on the use of sensors and sensing systems over the past decade and more. However, most reports of sensors and sensing systems for livestock refer to their use in experimental situations with few dealing with commercial use on livestock farms. Electronic monitoring of livestock is uncommon on commercial farms for three principal reasons.

i. Most research on electronic monitoring does not involve manufacturing companies from the start, with clear specifications set for commercial success in terms of demand, performance and manufacturing feasibility.
ii. While technical success can be shown under idealised conditions with a few animals in an experimental setting, complete sensing systems do not undergo proving trials on a large scale under semi-commercial conditions, with full-scale demonstration of the proven technology to farmers, consultants and journalists.
iii. The demand by livestock farmers for new monitoring technologies has either not been assessed or, if such a market analysis has been carried out, the results are not widely known within the research community.

It is only once these commercial weaknesses have been addressed that electronic monitoring will realise its potential. Such success would eventually allow PLF to be considered properly by farmers.

THE PROSPECTS FOR PLF – THE NEED FOR AUTOMATIC MONITORING IN LIVESTOCK FARMING

The commercial climate in which European livestock farmers have to operate has changed markedly over the past decade. From a position of strength in which many sectors of livestock farming were ‘price setters’, livestock farmers, with a few exceptions such as organic farmers or niche suppliers, are now ‘price takers’. Over the past decade, the net farm income on farms has fluctuated widely, reflecting substantial changes in the profitability of livestock farming in the U.K (http://statistics.defra.gov.uk/esg/publications/auk/2005/2-5.xls). Furthermore, the regulatory burden has increased, particularly in terms of the allowable environmental impact of livestock farming due to the introduction of the EU’s Integrated Pollution Prevention and Control directive. Concurrently, attention to the acceptable standard of animal welfare has lead to regular inspection of livestock farms by veterinarians and others. Overall, livestock farmers effectively require a number of explicit or implicit permits to operate in order to satisfy the consumer that his or her food is safe, traceable and produced within Government guidelines for environmental impact, welfare and nutritious value. Many of these demands on livestock farming can be met by a farm assurance scheme with independent audit of claims, and labelling at the point of sale to inform the interested purchaser about the environmental, nutritional, or welfare provenance of animal-based food (or other products).

This analysis suggests that the emphasis of researchers and commercial developers over the next decade should be on the use of engineering technology to monitor livestock farming with management decisions left to the farmer, perhaps aided by a full PLF system. The ever-lower costs of technology should be harnessed to satisfy the demand for information about animal-based products and farming methods, thereby meeting a current need that should be much simpler to achieve than in PLF.

Experience over the last decade therefore shows that although there is no shortage of engineers clamouring to develop a large armoury of sensors and sensing systems that could be used to monitor livestock farming, suitable applications of the highest priority have rarely been identified. In this sense, agricultural engineers have failed society. Historically the main influence on the suitability of an application of livestock monitoring has been its potential impact on profitability, but increasingly the need to demonstrate regulatory compliance and/or provide consumer assurance will be at least, if not more, important.

An obvious example of a product that should sell well to livestock farmers is an automatic weigher for pigs or broiler chickens and yet, although various technologies have been developed and marketed, (e.g. Schofield et al. 1999; Turner et al. 1984)), automatic weighers are not in common use. Since pig and poultry farmers are paid by live weight, then a means to determine the efficient conversion of animal feed into saleable meat should be essential if the processor's strict requirements are to be met. The reasons for this are not well understood but could include the ability of the expert farmer to estimate weight by eye or the poor reliability of automatic weighers. This apparent failure to monitor perhaps the most important determinant of profitability is astonishing. It is as if Henry Ford calculated the performance of his factories by counting the number of Model T automobiles in the dealer's showroom or scrap yard.

Automatic monitoring in livestock farming should therefore be developed for environmental emissions, zoonoses, organoleptic properties of meat, and welfare since it is these credence characteristics of animal products that are valued by the consumer, and hence are of value to the producer. After all, if the farmer cannot guarantee to the consumer, processor or the regulatory authorities that his animals have been produced to their specifications and satisfaction then his animals will be unmarketable. Suggestions for suitable processes in livestock farming to be monitored are given in Table 1.

Table 1. Processes in livestock farming that are suitable for automatic monitoring

On the farm:	**Reasons for monitoring**
Emissions of ammonia, methane and carbon dioxide from livestock buildings	Legislation, e.g. IPPC directive
Presence of salmonella, campylobacter and other zoonoses in pigs, cattle, broilers and laying hens, as appropriate	Legislation on food safety
Predictive markers of meat quality	Consumer demand
During transport and at the abattoir:	
Welfare	Consumer demand & legislation
Meat texture and tenderness	Consumer demand

The primary justification for monitoring these processes is either legislation or consumer demand. If monitoring was widespread, then the information could be used as part of a national surveillance scheme for environmental emissions, animal welfare or zoonoses. For example, there is much interest at present in the development of indicators of welfare so that consumers and regulators can be assured that their demands are being satisfied or that there is compliance with the legislation, respectively. Once the basis of a scheme for surveillance monitoring of welfare has been developed, then it will be feasible to determine whether improvements are being made. Discussion of welfare indicators in general is outwith this paper's remit, but is quite apposite in the context of welfare during transport or while the animals are at the abattoir. Monitoring welfare in the lairage and abattoir could be as straightforward as continuously measuring levels of mechanical and animal noise, the number of cattle or sheep that baulk in a race or require a second stun (perhaps using image analysis), the electrical current or gas concentration experienced by poultry during stunning, the dirtiness of the hide or fleece, or the prevalence of hock burn in broiler chickens. All of these are indicators of welfare at various stages in the animal's life and would require limited research and development before use.

Undoubtedly there are technical difficulties to be overcome in developing sensing systems for livestock monitoring. The requirement for low cost may be met by using sensors developed for other industries, e.g. cameras in mobile phones. Deployment of a sensing system will produce questions relating to the number and location of sensors, and their robustness, reliability and data transfer. However, perhaps the most difficult challenge will arise when the data are analysed and interpreted. How will the key findings be communicated to the farmer, consumer and regulator? Finally, successful commercialisation will require researchers to work closely with manufacturing companies to avoid the problems highlighted earlier. Given formation of a suitable partnership then a monitoring system for any one of the processes listed in Table 1 could be marketed within three to five years.

CONCLUSIONS

Some elements of PLF are already commonplace on livestock farms, i.e. sensing systems for milk yield in dairying, and their use should be part of livestock production irrespective of the greater potential of PLF to manage livestock automatically. If the promise of PLF is to be realised then three barriers need to be overcome before commercial uptake occurs: i) PLF technology needs to be developed that is based upon robust, low cost sensing systems and data-based models with meaningful parameters that enable control of two or more interacting physical and/or biological processes; ii) appropriate applications must be identified with targets and trajectories specified for the main candidate processes; and iii) development and demonstration must be completed at a commercial scale to demonstrate that any investment will have a reasonable return and that the technology is reliable. Given the scale of these challenges and the timescale needed to overcome them, then current effort should focus on the development of monitoring systems for livestock that satisfy the demands of consumers and regulators for safe, nutritious food produced from farm animals of guaranteed standard of welfare within acceptable limits of environmental emissions.

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