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The prospects for precision livestock farming[1]

C. M. Wathes[2]

Summary
Precision livestock farming, PLF, is an embryonic technology that applies the principles of process engineering to livestock farming. 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 monitoring farm animals as part of surveillance of health and welfare, the ultimate goal is to employ PLF as the farmer's aid to management of intensive and extensive livestock.

Keywords: farm animals, monitoring, environment, precision livestock farming

Introduction

Precision livestock farming, PLF, is an infant technology; 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 to remain sustainable. Thus, the British 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 agriculture started its development in the 18th Century.

My assumption 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 environmental impact and a high standard of animal health and welfare; on the other hand, the consumer, often with a scant knowledge of livestock farming and its practices, is concerned about the provenance of animal products, and requires food to be safe, traceable, nutritious and affordable.

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2 Professor of Animal Welfare, The Royal Veterinary College, University of London, Hatfield, Hertfordshire, AL9 7TA, United Kingdom.
cmwathes@rvc.ac.uk

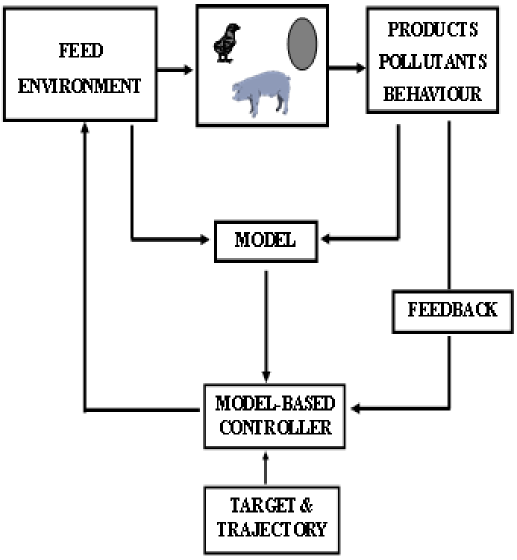
The concept of PLF

PLF is the application of the principles and techniques of process engineering to livestock farming to monitor, model and manage livestock production; closed loop, model-based control systems are used to provide automatic management to meet a specific target. The 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 language 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 online 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.

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 almost any process that is part-and-parcel of livestock farming. PLF can also be applied to both extensive and intensive systems, e.g. in Australia, PLF is used to manage the growth of lambs using automatic shedding gates to diver them to pastures of different nutritional value.

Implicit in the concept of PLF is the scale at which the process is 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. The scale at which products can be traced back to their origin will also be higher. In general, the finer the scale at which PLF is applied, the greater the expense and the higher the return on the 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 it should be applied.

Figure 1. PLF concepts



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. (www.flockman.com), to manage automatically the diet and environment of broilers (Filmer 2001). The key features of Flockman™ were: 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, that is 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 automated (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.; approximately 15 % of U.K. broilers were grown using it a decade ago though current usage is thought to be less. A simplified version, mini-Flockman™, has been developed.

A similar approach to growing broilers using PLF was taken by Aerts in Belgium; his object was to control the growth of broiler chickens along a defined trajectory using an adaptive, compact, dynamic process model (Aerts *et al*. 2003a). Daily food supply was calculated to allow the birds to follow a 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 enabled the broilers to follow different target trajectories with a mean relative error ranging between 3.7 and 6.0 %. With a few exceptions, feed conversion ratio and mortality after the first week were lower and uniformity was higher in the controlled groups compared with *ad libitum* fed animals.

At about the same time as the above developments, a comprehensive research programme to develop PLF to monitor, model and manage the growth of young pigs and sows was undertaken by a team of engineers, mathematicians and animal scientists at the Silsoe Research Institute and the Universities of Edinburgh and Bristol. Their 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 and Whittemore 2003; Green and Whittemore 2005), and control of feed supply according to group or individual requirements (Parsons *et al*. 2007). The advantage of image analysis to monitor growth is that the animals' shape and size (estimated from their plan area) could be measured directly, as well as their weight (Doeschl-Wilson *et al*. 2004; Whittemore and Schofield 2000). The system was tested on a semi-commercial scale but has not yet been taken up in the market place on a substantial scale.

The initial applications of PLF have been the growth of housed pigs and poultry. There are a number of lessons to be learnt from these pioneering attempts. 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-fold. First, the profitability of pig and poultry farming has inhibited capital investment in unproven new technology, even when the expected payback period is only a few years. Secondly, much if not all of the development work that should have been carried out 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 such as most broiler farms, management decisions about feed formulation and supply (according to target) are usually made by the production manager not the stockman.

The penalties of early adoption of a new technology can be severe if the researchers' 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 outstanding teething 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. Given this pessimistic conclusion about the medium term prospects for PLF, the use of the sensing systems - that are an essential component of PLF - to aid the farmer to monitor animal health, welfare and production would appear to be a better goal. Development of automatic monitoring could also help to assure the consumer about certain characteristics of livestock products, such as welfare provenance or traceability.

The electronic stockman: an engineer's pipedream or a genuine prospect?

Electronic monitoring of livestock is at the heart of PLF. Currently, electronic monitoring is used to identify livestock, detect oestrus, and measure milk yield and composition. 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 integral to controllers. These applications have been extremely successful in helping a farmer to manage his herds or flocks but the question remains as to why has more use not been made of electronics to monitor livestock?

In the mid 1990s, Frost and others forecast that automatic monitoring systems for farm animals would soon be developed that would integrate information from multiple sensors with mathematical models and knowledge bases to aid the farmer in decision-making (Frost *et al*. 1997). Even then, sensors were available that were suitable for electronic monitoring of animal weight, behaviour, and physiological parameters. 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*". Thirteen years later, is this conclusion 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 developments in monitoring systems for livestock. At the most recent workshop (SMART 2006, Italy; www.smart2006.eu), papers were presented on electronic monitoring of rumen pH; blood and milk fat; vocalisations and activity; calving behaviour; temperature: rumen, vulva; lameness and location in cattle; farrowing behaviour; growth and body composition in pigs; and liveweight in poultry and temperature, pH, albumen, nitric oxide in eggs.

Clearly, there has been significant investment in research in Europe on the application of sensors and sensing systems over the past decade and longer. However, most reports refer to experimental situations, with few dealing with commercial use on livestock farms. Electronic monitoring of livestock is uncommon on commercial farms for three 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 a market analysis has been carried out, the results are not widely known amongst 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.

Of course, it would be foolish to argue that electronic monitoring should supplant the stockman. Instead, automatic or semi-automatic monitoring should be viewed as an aid to the busy farmer. Machines have advantages over humans and *vice versa*. For example, they do not tire, have an almost inexhaustible memory, are logical and will work in hazardous or unpleasant environments; humans, on the other hand, are flexible, imaginative and adaptable. My argument is that both will be needed in the future; it would be very poor economy to pay a stockman to count the number of pigs at play while it would be impossible to design a robot to assist a cow having difficulty in calving. The consumer's views about electronic monitoring also matter; the case for the introduction of CCTV and similar technology on the livestock farm will have to be well argued and presented carefully.

The new, BBSRC-funded, welfare barn at the Royal Veterinary College. It comprises two full-sized sections of a typical livestock building and ten environmentally-controlled rooms, each holding about 250 broiler chickens or 20 finishing pigs. It was built in 2005 at a cost of £600k and is currently being used for research on PLF.

The prospects for PLF – the need for automatic monitoring in livestock farming

The commercial climate in which British livestock farmers operate has changed markedly over the past decade. From a position of strength in which many sectors of livestock farming were ‘price setters’, most livestock farmers are now ‘price takers’. Over the past decade, net farm income has fluctuated widely, reflecting substantial changes in the profitability of livestock farming. Furthermore, the regulatory burden has increased, particularly in terms of the allowable environmental impact owing to the introduction of the EU’s Integrated Pollution Prevention and Control directive. Concurrently, compliance with public and private standards of animal welfare has led to regular inspection. In essence, livestock farmers effectively require explicit or implicit permits to operate in order to satisfy the consumer that his or her food is safe, traceable and compliant with Government regulations for environmental impact, welfare and nutritious value. Many of these demands 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 food and 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 incessant demand for information – including full traceability - about animal-based products and farming methods, thereby meeting a current need that should be much simpler to achieve than 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 via traceability of livestock products will be of equal, if not greater, importance.

An obvious example of a product that should sell well 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), they are uncommon. Since pig and poultry farmers are paid by live weight, a means to determine the efficient conversion of feed into saleable meat should be essential if the processor's strict requirements are to be met. The reasons for the absence of automatic weighers 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 arguably the most important determinant of profitability is astonishing. It is as if Henry Ford estimated the output of his factories by counting the number of Model T automobiles in showrooms and scrap yards.

Automatic monitoring in livestock farming should therefore be developed for environmental emissions, zoonoses, organoleptic properties of meat, traceability 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 (Table 1). After all, if the farmer cannot guarantee to the consumer, processor or regulatory authorities that his animals have been produced to their specifications and satisfaction then his produce will be unmarketable.

Table 1. Processes in livestock farming that are suitable for automatic monitoring
Emissions of ammonia, methane, nitrous oxide and other aerial pollutants from livestock buildings
Presence of salmonella, campylobacter and other zoonoses in pigs, cattle, broilers and laying hens
Predictive markers of meat quality
Identity of the animal, herd/flock and farm, allowing products to be traced back to source
Welfare
Meat texture and tenderness

Undoubtedly, there are technical difficulties to be overcome in developing sensing systems for livestock monitoring. The requirement for low cost may be met using sensors developed for other industries, e.g. cameras used in mobile phones. Deployment of a sensing system will undoubtedly raise questions relating to the number and location of sensors, their robustness, reliability and data capture. However, perhaps the most difficult challenge will arise when 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, 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 processes; and iii) development and demonstration must be at a commercial scale to show that investment will generate a reasonable return and that the technology is reliable. Given the scale of these challenges and the timescale needed to overcome them, 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 traceable farm animals of guaranteed standard of welfare within acceptable limits of environmental emissions.

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