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APPLICABLE TECHNOLOGIES FOR CONTROLLED ENVIRONMENT SYSTEMS (CES) IN LIVESTOCK PRODUCTION

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SUMMARY
Controlled environment systems (CES) include such diverse applications as buildings for indoor aquaculture, intensive livestock and laboratory animals. The challenges of pushing the design envelope for CES include our ability to quantify important engineering aspects of the surrounding environment such as external loads which affect design and operation, and the development of information gathering, information processing and dynamic control systems to enable the proper functioning and management of a CES. Perhaps more challenging, is the continued need for current, relevant design data for how occupants of CES react with, and to, their environment. There is a range of diverse technologies available, developed in many instances by other industries, which can be readily incorporated and utilised in CES. In this paper two potential technologies which can be used as components of CES are discussed; 1) economical optimisation of livestock production, and 2) 'fuzzy logic' control systems. Integration of such tools into a precision livestock farming methodology, which we characterise as "information rich CES", is critically needed. Precision livestock farming principles need to be incorporated into information rich CES systems, if livestock industries aim to remain economically viable, socially responsible and ecologically sustainable.

Keywords: precision farming, fuzzy logic, environmental management, engineering

INTRODUCTION
Engineering methodologies for design, implementation, control and management of Controlled Environment Systems (CES) have undergone extensive changes in the past few decades. Process engineering and system research principles have been applied with great success (Gates *et al*., 1997), and there have been marked developments in information systems, measurement and control technologies (Frost 2001). Improving CES engineering has also been possible because we continue to develop a more complete understanding of interactions between biological systems and their environment. As engineers and scientists, we have aimed to better quantify these interactions. Yet, surprisingly, design information on biological and physiological responses at the organism or population level, is sorely outdated. The scientific community has embraced biotechnology and sub-organism biology and has been rewarded well, leaving behind whole-organism based biological research.

Despite our progress and funding problems, exciting future tasks, such as the development of more information rich livestock management systems and CES, remains to be accomplished. Such intelligent systems will lead to a futuristic animal production that optimises profit within constraints that include animal welfare and environmental concerns (Wathes *et al*. 2001; Banhazi *et al*. 2000). The main tasks of developing information rich CES may be broken into at least three groups, ie. the development of automated: 1) information gathering, 2) information processing, and 3) of more responsive and autonomous control systems. Each task presents tremendous challenges. The first example discussed in this paper fits into the second and third groups of tasks, namely the development of information processing systems, and their real-time implementation. A second example discussed, (fuzzy logic control) is a good example of a control technology designed to be more precise and responsive to dynamically changing inputs.

INFORMATION-RICH CONTROLLED ENVIRONMENT SYSTEMS
All of us involved in, or exposed to the practical aspects of farm management are familiar with the typical office arrangements and desktop of poultry or piggery managers. Although, computers are increasingly part of the 'landscape' these sometimes million dollar worth of CES systems' management is based on a relatively small amount of manually collected information, compared to what could be achieved if modern IT tools are used. The information management and processing of

many farms is quite inadequate, despite the fact that technologies which can be used to greater effect are readily available.

A conceptual model for how an information-rich CES can be expected to benefit producers is demonstrated in Figure 1.

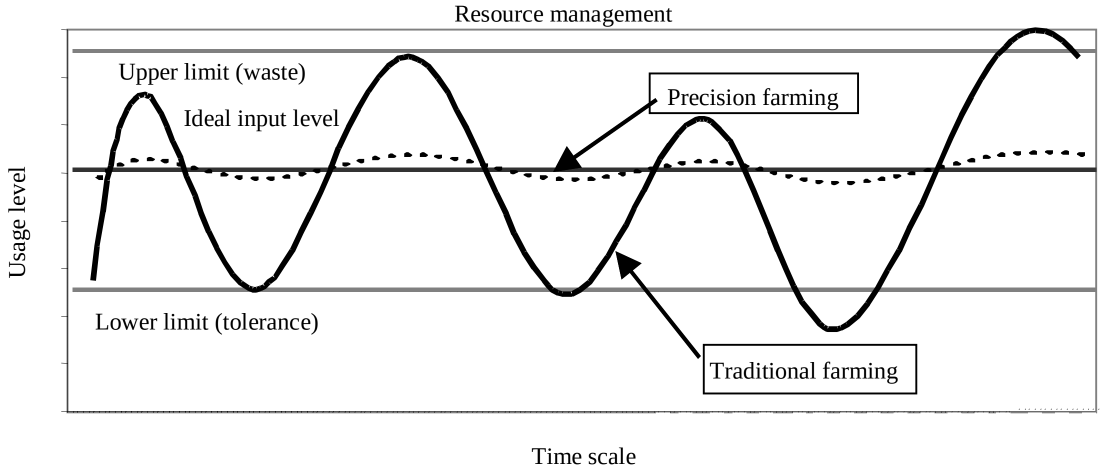

Figure 1. The ability of Precision Farming to closely match the ideal production conditions, will prevent producers to waste (over-supply) and/or under-supply their resources and therefore rely on the tolerance of the livestock to preform under sub-optimal conditions.

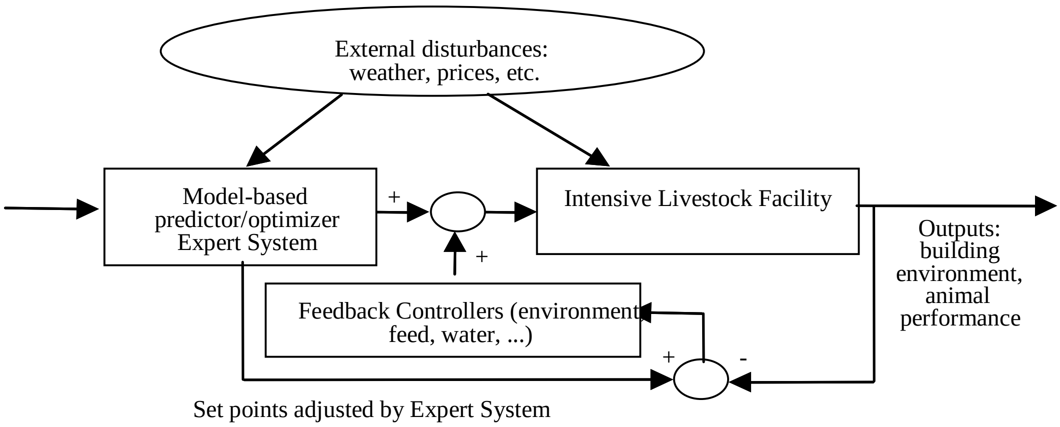

Figure 2. Information-rich control systems can be visualised as a combination of feedback controller (conventional) coupled with one or more feed-forward modules (the model-based control, inference engine, etc).

The main benefits expected from a more information rich system is two fold:

1. Waste will be reduced (costs lowered), as managers do not have to over-specify resource inputs (for example excess amino acids) to ensure that animals will receive their specific requirements. A more intelligent system will be able to assess what resources are being used, what effects they are having on the production process and what else needs to be done to achieve optimal production conditions. Waste will also be reduced by better product specification and delivery. Producers do not have to risk, for example, producing pigs with excessive backfat in order to achieve higher market weights. Ideally, they should be able to monitor backfat and adjust environment and nutrient densities accordingly. The development of such information gathering and information processing systems will obviously take time. The first step, for example, could be to establish a system which will ensure a quicker information transfer from slaughterhouses to producers (via e-mails for example), so producers are able to respond quickly to problems identified during slaughter, such as excessive backfat or sub-

clinical diseases (Pointon and Banhazi 1995). A next step would be to install automated backfat testing equipment on farms, a development which is still a fair way away for most producers (Persaud 2001). Finally, it will be necessary to close the loop on the process so that both environment and feed can be adjusted to control to the proper backfat level, while maintaining other constraints.

2. The second benefit will come from the fact that with better information gathering systems producers will not under-supply and under-utilise their resources. Ideally, one of the benefits of readily available, precise and up-to-date information will be that animals will experience significantly less time under sub-optimal conditions. Sub-optimal thermal, environmental, nutritional etc. conditions will be rapidly identified and the remedial action will be automated or streamlined.

ECONOMIC OPTIMISATION TOOL

Vertically integrated poultry operations in a sense have defined the new age of large-scale, commercial animal production. Each broiler house constitutes a unique CES, with no two houses exactly alike. The house environment is controlled based on factors including age and breed of birds, weather pattern, the equipment available for environment control, the costs of feed, electricity and fuel for heating, and the past history of litter, veterinary and dietary management. This past history component often involves subjective decisions by the operator and higher management, and is sufficiently complicated to challenge the best managers.

An economic optimisation requires the following key components:

- Physiological model of the animal or bird population, including sensitivities to environmental and nutritional constraints (e.g. temperature-dependent heat and moisture production data, feed intake, etc.)
- Housing model to predict real-time energy fluxes as weather patterns and internal loads vary
- Interaction module that negotiates between the physiological model and the housing model, to find valid equilibrium states
- Economic model that evaluates costs and benefits for each possible equilibrium state
- Optimisation model to select the environment which maximises income for current conditions, given past history and possible future trends

The ability to provide model-based control of each individual broiler house, using an economic optimisation technique to maximise profit, has been available for nearly two decades (Timmons and Gates 1986). Yet this process (which maximises profit, not production) has never been commercially implemented. Economics of the technique are clear, and demonstrations (both simulations and field experiments) have validated the approach. But this technology remains to be transferred. Perhaps as the poultry industry matures in developed countries, becoming less concerned with cost-cutting and more concerned with value-added profits, economic optimisation will be recognised by industry leaders and adopted. Recent advances in online optimisation and adaptive intelligent control may improve its likelihood of adoption (Sigrimis *et al*. 2000)

FUZZY-LOGIC CONTROL AND ENVIRONMENTAL MANAGEMENT

A promising new technology that is capable of contributing to the development of a better managed and controlled CES is "Fuzzy-logic" control (FLC). Principles of environment controller design that incorporates fuzzy logic have recently been presented elsewhere in detail (Chao *et al*, 2000; Gates *et al.* 2001*)* and thus an overview of the idea is presented here to demonstrate the usefulness of the technology for CES.

Greenhouse and livestock heating, ventilation and air-conditioning (HVAC) systems have evolved as these agricultural facilities have become large-scale production units. Modern control systems for these facilities include fully integrated process controllers, often with centralised monitoring systems that communicate with local zone controllers. These types of systems are robust, and have been designed and installed with the unique requirements of the agricultural production facilities. Environment control system design for greenhouse and livestock facilities entails requirements that are significantly different from classical control system design. The majority of large scale systems utilise on/off type equipment and are characterised as "discrete stage controllers"; thus controller design evolved from multiple staged thermostat systems, with each stage corresponding to an increased amount of heating or ventilation. Guidelines for selection and design of stage increments, which are sensitive to climate and occupancy, are available (Gates *et al*. 2001) and constitute the primary design input to many of these systems. Conventional control systems are designed to satisfy constraints on limiting interior environment fluctuations, with preference given to lower energy costs rather than precise temperature control. A key difficulty is that such designs cannot scale well amongst different building designs and applications, e.g. poultry broilers vs. layers and pig grower/finisher houses vs. farrowing or gestation units.

In contrast, a FLC can incorporate reasoning and memory into current control decisions. Two examples of FLC application to livestock and poultry CES are 1) use of fuzzy reasoning to determine the degree to which birds are acclimatised to heat stress, and to adjust night-time ventilation setback control points accordingly (Gates *et al*. 1997) and 2) a means of providing users with the "look and feel" of a control system they are familiar with while incorporating a user-specified balance between control precision and energy consumption (Chao *et al.* 2000; Gates *et al*. 2001). This latter approach demonstrates how the use of fuzzy reasoning can easily incorporate conflicting control constraints and allow an experienced operator to set the desired trajectory, which may vary with external factors on a management time horizon rather than on the more dynamic time horizon needed for real-time environment control. A key feature of this application is the ability of the same controller (and control logic) to be utilised in the full range of CES facilities.

CONCLUSIONS AND FUTURE OF R&D NEEDS

Development of a "Precision Farming" concept to CES involves integration of the scientific method with an integration of production and environment processes (Wathes *et al*. 2001), which include the unique needs of different livestock species. In a sense, this is an articulation of a path many researchers have taken. An example of this approach is the incorporation of animal welfare needs and environmental constraints in new CES designs. For example, Armstrong and Pajor (2001) argue for new solutions that maximise profit with added constraints of satisfying an animal's need for normal patterns of behaviour. There is a clear need for automated information gathering and processing systems which can enable data collection and automated data management of animal behaviour (Naas *et al*. 2000) and environmental data (Banhazi *et al*. 1999).

CES-based engineering research and development encompasses a tremendous variety of topics and disciplines. Biosystems engineers have traditionally used multidisciplinary teams on CES projects, collaborating across Institutions and on many occasions across different countries. This trend is likely to accelerate with the complexity of systems and projects. We face many new challenges in this exciting new research area.

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