A review of livestock monitoring and the need for integrated systems

Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS, UK

Abstract

Developments in sensor technology which have taken place, and which are in progress or can be foreseen, will make available increasing amounts of information relevant to monitoring animals and their environment, and hence their production, growth and health. Systems are already available for identifying and weighing animals and it is reasonable to expect that systems will become available for tracking animals; for monitoring basic physiological factors such as body temperature and heart rate; and for assessing body conformation, and some limited aspects of composition. The application of integrated monitoring system techniques, in which information from sensors, databases, mathematical models and knowledge bases are combined and interpreted, will enable the maximum potential of this information to be realised. Several systems containing some of the elements of an integrated monitoring system are already available commercially for pig, broiler and milk production. © 1997 Elsevier Science B.V.

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1. Introduction

Modern, intensive farms make the farmer totally responsible for all livestock under his control. Over the last three decades farming practice has moved away
from self-sustaining mixed livestock enterprises with relatively small numbers of several species, towards large, single species units. Animals now are produced intensively, and maintained under near ideal conditions for growth and production within current technological limits. The majority of animals are constrained within a building or stockyard for most or all of their lives. As they are prevented from foraging for their own food, the farmer takes complete responsibility for all aspects of their husbandry. Monitoring of feeding, environment, reproduction, health, growth, marketing, transport and quality becomes the responsibility of the stockman. This responsibility is not only moral; it is also in the farmer's commercial interest to satisfy these basic needs of his livestock.

The main purpose of most livestock production enterprises is to satisfy the demands of a customer by providing a product which meets the customer's requirements at a price which enables the producer to make a profit. The customer's requirements are becoming increasingly well defined. An example is the meat industry which pays producers more for animals of a particular weight, conformation and composition. Another example is the dairy industry which pays dairy farmers according to milk quality and composition.

For a given group of animals, product quality depends almost entirely on the skill, experience and subjective assessments of the producer in monitoring and controlling the production process. Very little technological assistance is currently available. This means that the producer is frequently unable to monitor and control the variables which will determine the value of the product. Many producers have great expertise, but there is considerable evidence that customers' requirements are frequently not met. For example the beef trade considers animals with particular conformations and fat levels to be more desirable than others, but only about 40% of animals meet this specification (Meat and Livestock Commission, 1994). It seems to be highly likely that this is due, at least in part, to the inability of the producer accurately to assess and control the variables that affect conformation and fat levels.

Sensors are being developed which can gather an increasingly wide range of information. However with the development of these sensors it becomes more important to develop systems which can collect, process and utilise the information. Raw data, on its own, is of limited value. The stockman can maximise the efficiency of a production system only by monitoring all its critical stages and targets and ensuring that they are kept close to the optimum. For example, it may be necessary to assimilate data on the climate within and without a building, the breed, number, age, feed level and weight of animals, their growth rate, activity and health records and market requirements.

The purpose of this paper is to review the current state of monitoring and control systems technology in the context of livestock production and to discuss some overall design concepts for integrated monitoring systems.
2. Integrated monitoring and control system concepts

An integrated monitoring system is one which collects information from a variety of sources, including sensors, databases and knowledge bases, processes the data, and provides outputs, which may be recommendations to the producer, or direct process control actions. Fig. 1 illustrates this general concept as it might be applied to a livestock production process. Inputs to the system would include sensors measuring for example climatic conditions, feed intake, growth rate, animal behaviour and product quality; databases containing past values of these variables; and models to enable future conditions to be predicted, or the values of unmeasurable variables to be deduced. The interpretation routines would use this information to draw conclusions relating to the progress of the production process in areas such as climate and feed control, and the health and reproductive status of the animals. In the final stage a knowledge base would initiate control actions, or report to the user, with recommendations for actions.

To illustrate the power of the integrated approach, consider the information that could be deduced from a knowledge of an animal’s weight, say that of a growing pig. On its own a single measurement is of limited value, except perhaps to determine whether the animal is ready to be sent to market. The weights of each pig within a group are more useful, because they enable animals to be compared, which may enable pigs that are not performing well to be identified. This is made easier still by the construction of growth curves as time histories of the weights of the animals. An actual growth curve can be compared with one predicted from knowledge of how the pig should grow. If the animal is not performing as expected the producer could be alerted to investigate the cause. To implement a basic system such as this would require electronic weighing and animal identification and a computer with a data base and a growth rate model. Further power could be added to the system by adding sensors to measure the amount of food eaten by each animal, and an animal’s pattern of activity. These behavioural indicators, together

Fig. 1. Conceptual integrated monitoring system for livestock production.
with the growth rate information could be used by an expert system to suggest likely causes of poor performance.

The potential benefits of the integrated monitoring system approach for livestock production arise from the opportunity to combine the strengths of the stockman and the computer-based system. The stockman’s ability simultaneously to observe, sense and process the continuously changing conditions in livestock husbandry constitutes a most powerful monitoring system.

For example, in the case of a pig fattening house, the stockman monitors: sound, indicating illness (coughing), fighting or fright amongst the stock, power failure or mechanical breakdown of ventilation equipment; odour and air quality, e.g., high ammonia emissions or the smell of smoke or overheating electrical equipment; appearance including animal numbers, condition, location, signs of injury (e.g., lameness, fighting, wounds, prolapses), signs of ill health (e.g., stance, unusual behaviour), and inputs such as heating and ventilation rates, and feed and water consumption.

The stockman is and will remain the primary monitor of livestock, but the amount of time available for observing and interacting with his stock has reduced dramatically in post war years as mechanisation has increased and the number of farm workers decreased. While it may be possible to ensure that there are sufficient staff available to feed, inspect and care for all high value animals such as dairy cattle, on an individual basis, it has become impractical with sheep, pigs and poultry. Modern farming techniques, along with the greatly reduced labour availability, have transformed much of the daily routine of caring for livestock. A stockman’s day is largely spent performing manual tasks such as transport and distribution of feed and bedding and removal of waste, milking, and environmental control. It is highly likely that the time available for observation and interaction with animals has declined substantially, although there is no published research in this area.

The disadvantages of the stockman being in total control of the planning, monitoring and running of the livestock unit include: lack of time or opportunity to observe each animal thoroughly; infrequent visits to the unit, often for only a few minutes each day; visits disturb the animals and often coincide with the replenishment of food, so the animals’ behaviour may not be typical of the diurnal rhythms; observations are subjective. The stockman is able to collect and assimilate only fragmented pieces of information on which to make his management decisions. The livestock unit runs continuously, and requires continual monitoring and control to maintain optimum conditions for animal growth, health, welfare and productivity.

The advantages of integrated monitoring systems include: continuous, non-intrusive operation; a very large memory capacity; the ability to detect small but significant changes and complex patterns in data, which may pass unrecognised by the stockman; objective assessments are possible; the ability to integrate data from various sources (sensors, knowledge bases and databases) so that conclusions can be drawn which would not be apparent from the data from a single source.
3. The current state of integrated monitoring system development

Several computer based systems, containing some of the elements of an integrated monitoring system, have been developed for pig production. The one described by Dijkhuizen and Huirne (1990) is for pig breeding herds and consists of a decision support system which identifies and assesses the significance of deviations of performance from standards, and a set of expert systems which attempts to find causes of problems and suggest solutions. The system examines quarterly data from farms, relating to variables such as size of litter, mortality and feed rates and looks for deviations between actual performance and that which would be predicted from historical data for that farm. Performance is also compared with that of other similar farms. Deviations from expected performance are examined for statistical and economic significance. The expert systems, relating to nutrition, health, reproduction, housing, stock movement and prices, are then used to examine the deviations in performance, find causes and suggest solutions. Such a system would be a valuable management and planning tool. However it is not intended to monitor and control rapidly changing variables such as environmental conditions.

Belyavin and Filmer (1990) describe a system for monitoring broiler production. This microprocessor based system operates fans, heaters, feeders, lights, air inlets and bird and feed weighers. It reads sensors in several zones in each house and operates the heating and ventilation systems to control temperature, relative humidity and ammonia levels. Target weights for birds at given ages and target values for all the control variables are set up at the start of each crop of birds. As the crop progresses, actual feed intake and bird weight are compared to the targets. If the manager detects significant deviations he can take corrective action.

The above system relies on the poultry manager to observe and interpret patterns or trends in the data. A difficulty with this approach is that significant trends are often obscured by noise, due to biological variability or the means of measurement, and may not be noticed until it is too late to take remedial action. Roush et al. (1992) have suggested the use of a Kalman filter to detect significant features in data. The filter produces a predicted value of the variable, based on the time history. This is compared with the actual measured value, when that becomes available, and any significant difference is flagged. They developed an algorithm that would generate warnings to the manager when there was a significant change in a monitored variable such as feed consumption. The same principle could be applied to any other relevant variable such as environmental temperature or disease level, or to combinations of variables. Further work is required to determine the practical value of this particular approach, but the use of time series analysis in general has considerable potential and certainly merits further study.

Dairy cows have received considerable attention because they are high value animals. Data base systems for record keeping are well established. The quantity of milk provided by each cow has always been the main item recorded, and the design of milkometers has received a great deal of attention, e.g. Ordolff (1989), but modern databases can accept other information such as cow identity, health, fertility, milk quality, and cow weight. The Dairy Information System (DAISY), developed and
reported by Esslemont et al. (1990), for example, accepts all of these inputs, or a selection chosen by the farmer. There are now also examples of systems under development which have more of the elements of an integrated monitoring system. For example Hogewerf et al. (1992) describe a system for monitoring health and reproduction in dairy cows. Inputs to the system from sensors include milk yield, milk temperature, milk conductivity, cow activity and concentrate intake. Running mean values of these parameters are calculated for each cow and significant deviations from these means are listed in a report which is generated after each milking. Animals showing deviations in more than one parameter are also identified if the deviations conform to a pattern which would be expected for animals with a particular physiological condition. For example, reduced yield, combined with increased milk temperature, and higher milk conductivity would produce a warning of possible mastitis; reduced yield, combined with reduced activity and reduced concentrate intake would indicate possible lameness.

4. Sensor developments

Sensors are crucial to the development of integrated monitoring systems for livestock production. There are many types of sensor which are either in current use, or are likely to become available in the foreseeable future.

4.1. Animal identity

Electronic identification devices have been available for 7 years, and have recently been reviewed by Geers (1994). They are used in the dairy industry, where the value of both the cow and the monitoring and control which the identification offers, is high compared with the cost of implementation. For cows they usually consist of transponders mounted on neck collars (Street, 1979), and are used to identify animals as they feed or are milked.

Considerable progress has been made in the development of injectable identity transponders (Eradus and Rossing, 1994). Optimism regarding their use as an international method for identifying all large farm animals was high in the late eighties. One of the main targets for commercial application so far has been growing pigs, with the intention of identifying them throughout the growing, marketing and slaughter processes. There appear to be no problems of biocompatibility (Gruys et al., 1993). However the problem of locating the implant for removal at slaughter has not yet been completely solved. In a recently reported trial (Lammers et al., 1995), transponders were injected into the auricles of pigs of various ages, and the pigs were slaughtered at various intervals after injection. Of the 204 transponders that were injected, six were either lost or failed to respond by the time the pigs were slaughtered. In most cases this was due to the transponder having been broken. Finding and removing every device is fundamental to their acceptability for use with meat animals. Transponder failure is likely to make this more difficult, and this may account for the meat industry's apparent lack of confidence in the system.
4.2. Animal weight

The weight of an animal is an important indicator of the wellbeing and value of an animal. However, very few livestock producers weigh their animals frequently. This is often due to the lack of convenient weighing equipment.

For poultry, an automatic broiler weighing system has been developed (Turner et al., 1984). This consists of a perch for individual birds, suspended on a strain gauge link. The perch is monitored by a computer which tares the weight between each record, stores and processes each reading to eliminate false data, and provides the stockman with a weight distribution for the flock. An abnormal change in the weight of the birds can provide an early warning of health problems, or of problems with feeding or ventilation equipment. A further enhancement allows the birds in the flock to be split into separate groups according to weight, by automatically directing them to a ‘heavy’ or a ‘light’ pen as they leave the weigher. The weighing perch system is commercially available (Belyavin and Filmer, 1990). A difficulty with any system that operates on a sample of the population is ensuring that the sample is representative of the population.

Knowledge of the growth rate of pigs provides valuable information on health, productivity, and yield. A growth rate curve, for example, shows up deviations from the ideal, indicating checks in growth which require investigation, or delays in starting growing following weaning. In order to gain enough readings to be able to follow the growth rate of individual pigs, it is necessary to weigh them at least weekly. This is impractical if done conventionally, due to the large labour input it requires, and the stress it causes to man and animal. If pigs were weighed automatically and frequently, each time they attended a feeder for instance, then it would be possible to produce a growth curve, provided that each animal was identified using electronic tags, for example. Load platforms are available for weighing pigs attending feed stations, but have been found to be unreliable due to mechanical interference by the pigs and dirt building up under the platform (Turner et al., 1985).

It has been found that there is a strong correlation between the weight of a pig and its plan view area (Schofield, 1990). This has led to the development of systems in which images from a video camera, suspended over a pig, are analysed to extract the plan view area and estimate the weight of the animal (Schofield and Marchant, 1991). Pig weights have been determined to within 5% accuracy by this method (Schofield, 1993; Minagawa et al., 1993). The image analysis problems involved in this procedure are discussed below (Section 4.7). This type of system has the advantages of not interfering with the animal or requiring equipment to be installed at pig level where it is vulnerable to attack. It also has no moving parts which should benefit reliability. Disadvantages are that the performance of the system depends on the quality of the images, which can be affected by lighting conditions, and that the relationship between weight and plan view area has to be established for each different breed of pig; it is not yet known how many relationships will be required to cover all breeds of pig that are currently being grown.
An automatic weighing machine for cows has been reported (Filby et al., 1979; Laycock and Street, 1984). It consisted of a load cell connected to a platform across which cows walked as they left the milking parlour. One of the main difficulties was that of filtering the highly variable signal that was produced as the cow walked across the platform. It was also necessary to ensure that weights were recorded only when a single cow had all of its weight on the platform, and that spurious readings due to more than one cow at a time being on the platform, or a cow not having all of its feet on the platform, were rejected. In practice it was found that about 80% of a herd of 270 cows could be weighed on exit from a conventional 16 place herringbone parlour, which meant that weekly mean weights for about 90% of the herd could be obtained. The error associated with each weight was found to be greater than that from a manual weighing but it was estimated that the accuracy of a mean weekly weight of an animal measured by such a system was equal to that which would result from three manual weighings per week. This type of device has not been widely adopted, probably because of the technical problems mentioned above, and because the economic justification for weighing dairy cows frequently has not been established to the satisfaction of the farmer.

4.3. Animal behaviour

The behaviour of an animal can be a clear indicator of its physiological state. For example a diseased animal may be more, or less, active than a healthy one; animals suffering from a cold environment may huddle together for warmth; an animal’s activity level may be linked to its stage in the reproductive cycle.

However, despite its importance, the only commercially available method of measuring any aspect of behaviour is the pedometer, which is used as an aid to detecting oestrus in dairy cows. It consists of an inertial switch which is attached to a collar around the neck or to the cow’s leg. Oestrus is associated with an increase in activity and therefore significant changes in the number of movements over a given period, as registered by the switch, are brought to the attention of the herdsman. Eradus et al. (1994) report that many data processing algorithms have been studied in attempts to optimise oestrus detection. The difficulty is that generally any attempt to make the system more sensitive, i.e. to increase detection rate, will increase the number of false positives. Typical results achieved by Eradus et al., using techniques based on signal thresholding, were 70% of heats detected, with 40% false positives. They also compared the effectiveness of neck and foreleg mounted pedometers. They found that the movements registered at the neck led to far more false positives than did those from the foreleg.

de Mol et al. (1996) have suggested that more reliable oestrus detection would result from including measurements of other variables. They propose a qualitative relationship in which reduced yield, increased milk temperature and reduced feed intake, combined with increased activity, is indicative of oestrus. They propose similar models for lameness, mastitis (see Section 4.4), and other diseases. de Mol et al. (1996) used a Kalman filter based approach to analyse data from cows on experimental farms. They generated low, medium or high level alerts, based on the
confidence with which a prediction was made (95, 99 and 99.9%, respectively). The results are presented in terms of sensitivity (i.e. true positives as a percentage of the sum of true positives and false negatives) and specificity (i.e. true negatives as a percentage of the sum of false positive and true negatives). For example, for oestrus detection (based on 537 cases) a high level alert corresponded to a sensitivity of 83% and a specificity 98%, whereas a low level alert corresponded to a sensitivity of 94% and a specificity of 95%.

Some systems have been developed for monitoring animal behaviour for research purposes. Rutter et al. (1997) have shown that the Global Positioning System can be used for tracking grazing sheep. Image analysis has been used for tracking animals within a building, this is discussed below in Section 4.7.

Howell and Paice (1989) used an accelerometer strapped to the leg of an ox to measure its stepping rate. The dominant acceleration per step was detected and converted into a square pulse so that the rate could be counted. The use of an accelerometer, rather than a switch as in the pedometer, allows greater sophistication in data processing, which should lead to more reliable results.

Various devices to monitor animal jaw movements have been developed and used particularly in studies of grazing behaviour. A silicone tube, filled with carbon granules, has been fixed to the side of the lower jaw of cattle so that movements of the jaw caused a change in the electrical resistance of the device (Matsui, 1994); similarly Rutter et al. (1997) used conductive rubber sensor; and a water filled tube in which jaw movements caused changes in pressure has also been used (Dado and Allen, 1993).

Wouters and Puers (1993) report the development of an implantable telemetry device for activity monitoring. The device was developed for laboratory use and incorporates identification, and body temperature measurement. Commercially available piezoresistive accelerometers or specially developed capacitive accelerometers were used for activity monitoring. The stated long term aim of the project was to develop an injectable device to perform these functions and, in this context, Puers (1993) describes a capacitive accelerometer with dimensions 1.2 x 1.2 x 1 mm.

Pedersen and Pedersen (1995) report the use of passive infrared detectors (PID’s) to measure animal activity. These were commercially available devices intended for security alarms. Using a laboratory rig with a moving heat source as a simulated animal, it was found that the output signal from a PID could be processed to provide a voltage which was proportional to the velocity of the simulated animal and the difference between the temperatures of the simulated animal and the environment. However there was a non-linear response to the addition of a second heat source. A complex pattern of spatial sensitivity was observed. Despite these limitations it was concluded that a PID could provide a measure of activity. As a practical example a PID was positioned above a group of 60 pigs, distributed over six pens, and it was possible to detect diurnal activity rhythms in the PID output. It is difficult to see how PID’s in their current form could be calibrated to provide reliable absolute measurements of activity, but they may be useful for detecting gross changes in behaviour patterns.
4.4. Physiological factors

There are many known relationships between basic physiological factors such as heart rate, body temperature and respiration and the state of health and metabolism of an animal. Despite this, there is no monitoring system in routine commercial use that is capable of monitoring any of these factors.

Various systems have been developed for research purposes. Kettlewell et al. (1997), describe an implanted system for monitoring heart rate and deep body temperature in poultry. This requires surgical implantation of a package incorporating ECG electrodes which are attached to muscles, a thermistor and a transmitter. This is a relatively large device, and is not likely to be developed into anything which could be used in commercial practice. Geers et al. (1997) report the use of telemetric devices which were injected into bases of pigs' ears for measuring body temperature. It is feasible that devices such as these could become farm management tools. Implanted devices are either active and have an internal power source, or passive and are energised by an external transmitter. Geers (1994) discussed the relative merits of these operating principles.

Howell and Paice (1989) report a system for experimental monitoring of draught animals. The physiological factors monitored included heart rate, breathing rate and body temperature. Heart rate was measured by a device which detected changes in the infrared transmissivity of the ear. The unit clamped onto the ear so that light from infrared emitters passed through the ear to an array of receivers. At each heart beat the surge of blood attenuated the light passing through the ear. Breathing rate was detected using a device which was clipped to the animal's nose. The device included a tube contained two thermistors, either side of a small heating element, so that, depending on the direction of airflow, one or other thermistor was warmed. Body temperature was measured with a thermistor.

So far the only reported sensors designed specifically for the diagnosis of a particular disease are those aimed at detecting mastitis in dairy cows. It has been known for some time that there is a relationship between the electrical conductivity of milk and the presence of mastitis (Linzell et al., 1974) and devices have accordingly been developed to measure conductivity in the milk flow during milking (Onyango et al., 1988). However it is also known that the relationship between conductivity and mastitis is not direct, and there has been a great deal of research aimed at improving the accuracy of diagnosis by measuring extra parameters, for example milk temperature and yield (Maatje et al., 1992), and using neural networks to process conductivity data (Nielen et al., 1992).

de Mol et al. (1996) developed a model with which measurements of milk temperature and yield, conductivity and feed intake were combined to produce a prediction of various stages of mastitis. This was tested on cows on experimental farms. As for oestrus detection (see Section 4.3) the system generated a low, medium or high level of alert, depending on the confidence with which the prediction was made, and the results were presented in terms of sensitivity and specificity. It was found that a high level alert for sub-clinical mastitis was associated with a sensitivity of 57% (for 21 cases) and a specificity of 99% (for 21 cases).
Conductivity sensors are commercially available for mastitis detection although, on the basis of published research, none is likely to be capable of producing a totally reliable diagnosis.

4.5. Environmental factors

Livestock housing in temperate climates falls into two types, controlled environment and climatic buildings in which the physical environment mirrors that outdoors. This distinction is based on the desirability of control or modification of the physical environment. In general, the former type is suitable for pigs and poultry while the latter suits ruminants and horses. In reality, manipulation within controlled environment buildings refers almost exclusively to dry bulb air temperature via variation of ventilation rate. Typically air temperature is measured with thermistors, compared against a set target, and the rate of (mechanical) ventilation is adjusted to raise or lower ventilation heat losses and thereby cool or warm the building (Randall and Boon, 1994). The lack of control of other factors, such as air quality arises either from an inability to engineer a workable system through lack of sensors or control mechanisms, or from ignorance of the effects of each factor on animal health and performance and hence of control targets.

4.6. Body conformation and composition

The value and condition of a meat animal depends on the conformation and composition of its body. It is important that these should be accurately assessed during growth and prior to slaughter, so that ideally sized animals can be produced as economically as possible and marketed at the quality required to achieve the highest slaughter grade.

Currently conformation is assessed by eye, by the stockman, with the attendant problems of subjectivity. Image analysis offers the prospect of objective assessment of conformation. This is discussed below in Section 4.7.

The composition of the live animal, in terms particularly of fat levels, is also commonly assessed subjectively by the stockman, by eye and by palpation, but ultrasonic devices are available. There are three basic devices for ultrasonic measurement: the probe, the scanner and the velocity of sound (VOS) device. The probe is usually a cylindrical device, about 20 mm diameter and 50 mm long, which is held in contact surface with the animal, and produces a graphical representation of the positions of the fat layers beneath the probe. It requires a skilled operator to position the probe at the appropriate places on the body and to interpret the output. It is occasionally used on farms, usually by advisory staff and mainly on pigs.

The scanner is also used occasionally on farms by advisory staff, either on cattle or on sheep for pregnancy scanning. It is the same type of device as is used in hospitals. It displays the location of body parts, effectively giving a cross-sectional image. Analysis of the image is subjective, and calls for a skilled operator. The device has been used successfully to locate subcutaneous fat, but is not good for quantifying inter-muscular and internal fats.
The VOS device (Fisher, 1997) measures the time for sound to travel through an object (animal), and can measure subcutaneous and intermuscular fat simultaneously. It senses the total proportion of fat, but not its thickness or location in the body. VOS techniques are fast and inexpensive, and do not require direct physical contact, so are more suited to automation, and for use with live animals. They are not yet in routine use on the farm.

Magnetic resonance imaging (MRI) has also been used for determining the body composition of live animals. Baulain (1997) describes the use of an MRI scanner, developed for scanning the human body, to scan pigs. The output from the device is in the form of high contrast, cross-sectional images of any desired plane through the animal. Using image analysis it is possible to determine the amounts of lean and fat tissue and to measure volumes of muscles and organs. MRI is certainly valuable as a reference technique for body composition monitoring, although the cost and complexity of the equipment has so far limited its use to research applications.

4.7. Image analysis

The stockman gains a great deal of information from the appearance of an animal. The purpose of image analysis is to enable some of the available information to be extracted automatically, by connecting a camera to a computer equipped with the appropriate hardware and software. Computer algorithms separate, or segment, the objects of interest and interpret the visual scene. This is particularly difficult when the objects of interest are biological. The visual characteristics of biological objects exhibit a variability that is not generally present in manufactured objects. The mobility and deformability of animals contribute extra visual variability. Further difficulties are due to the relatively uncontrolled conditions in which animals are kept, which mean that it is difficult to arrange for the animal to be presented to the camera under favourable lighting conditions and against a background which makes segmentation easy.

Significant progress has been made in research in these generic problem areas. Algorithms have been developed to enable the outline of an animal to be constructed from an image in which the animal has an indistinct or incomplete boundary. A particularly useful technique is based on the snake algorithm, in which the mechanics of an elastic loop stretched around the image of the animal are simulated. Consideration of the energies involved has enabled a boundary to be located in situations where conventional techniques have failed (Marchant and Schofield, 1993).

An alternative approach to locating an object is to match a model of it with candidate objects in the image. For manufactured items it is usually straightforward to construct the model, since the dimensions are known. Animals however have variable dimensions and can adopt various poses. The model must therefore be deformable. This approach has been demonstrated (Tillett, 1991) by an algorithm in which a model of a pig can be rotated, translated, scaled and bent laterally to find a good match within an image containing a pig.
Progress has also been made in the extraction of three dimensional information from two dimensional images, so that deductions relating to the structure or conformation of the object can be made. One approach has been through the use of stereo imaging. Two cameras are used to produce pairs of images of the object. The cameras are arranged so that points on the object can be identified and located in both images. From a knowledge of the geometrical arrangement of the cameras and the locations of the corresponding points in the pairs of images the three dimensional coordinates of the points can be calculated (Kearfott et al., 1993). An alternative approach involves the analysis of the deformation caused to structured lighting when it is projected onto a three dimensional object (Van der Stuyft et al., 1991).

A further current research topic in image analysis, which has relevance to monitoring animal behaviour, is the segmentation and tracking of moving objects. Tracking animals is difficult, because they are difficult to identify and their movements are often unpredictable. One approach is to use image differencing with respect to a time-averaged background. In this technique the current image is compared with a reference image, based on previous images. This enables areas of change within the image to be differentiated from an invariant background. The areas of change are candidate animals, which can then be confirmed or rejected by model-based algorithms (McFarlane and Schofield, 1995). Tillett et al. (1997) have extended the idea of using a trainable flexible model for locating pigs in images to tracking animal movements through sequences of images. The technique was used to model subtle motions such as bending and head nodding, as well as position and rotation. This approach could be used to characterise animal behaviour over time.

Current applications to animal agriculture in particular include estimating the weights of pigs (Schofield and Marchant, 1991 and Minagawa et al., 1993). It has been found that there is a strong correlation between the weight of a pig and its plan view area, and that pig weights can be determined to within 5% accuracy (Schofield, 1990). Other applications include feather sexing poultry chicks, in which accuracies of up to 89% have so far been achieved (Jones et al., 1991), topographic mapping of live pig shapes, which has been shown to have potential as a predictor of carcass quality (Van der Stuyft et al., 1992), measurement of cattle body surface area (Minagawa, 1988) in which the spatial coordinates of an animal were measured to a mean accuracy of about 7 mm, live fish size determination (Ruff et al., 1995) in which the lengths of swimming fish have been measured with an accuracy of about 10 mm, dead fish weight estimation, to an accuracy of about 5% (Storbeck and Daan, 1991), dead fish species recognition (Strachan et al., 1990), grading meat (Cross et al., 1983) and image based guidance in robotic butchery (Khodabandeelo and Brett, 1990).

Potential applications in animal agriculture include extraction of information relating to the shapes of animals which could be used, for example, in conformation assessment in pigs and cattle, and body condition scoring in dairy cattle. Repeatable quantitative measurements of animal conformation would be valuable on the farm for monitoring production, and will be increasingly valuable in association with electronic marketing of stock. Analysis of the movement of individual animals
could give early warning of abnormal conditions such as lameness and coughing. Tracking individual animals would enable normal patterns of locomotory behaviour to be established and some aberrations detected. Analysis of the movement of groups of animals would enable animal response to be used as a feedback for environmental control; for example pigs huddle when they are below the minimum temperature for maximum production efficiency (Boon, 1984; Wouters et al., 1990). Animal movement analysis would provide evidence of specific conditions such as oestrus and parturition.

4.8. Electronic odour sensing

The development of electronic odour sensors (electronic noses) took the mammalian olfactory system as its model (Persaud and Dodd, 1982; Shurmer, 1990). Neurones respond to a wide range of chemicals and it is the pattern of response of the whole array which gives discrimination between different odours. An electronic nose has an array of non-specific sensors linked to a computer-based pattern recognition system.

A large number of sensors with different operating principles for detecting odorous compounds have been reported (Persaud and Travers, 1991). The original devices were of the tin oxide type. These operate by passing an electrical current along a layer of tin oxide heated to 350°C. The hot surface oxidises the odorous compounds, and in doing so draws electrons from the conducting lower layers of tin oxide thereby altering the resistance in the circuit. With suitable interface circuitry tin-oxide sensors have a linear voltage output relative to the concentration of odorous material.

Conducting polymers for odour sensing are a more recent development. They respond to an odour by the diffusion of molecules of the odour compound through the surface. They are attractive because although they are not as sensitive, they can be designed to respond to a range of compounds and they have the potential to be made smaller and cheaper with low power consumption.

The volume of data generated by an array of odour sensors necessitates powerful statistical algorithms to identify the odours present and to assess their relative concentrations. The stage has not yet been reached where it is possible to predict the exact response of an array to a mix of known compounds. Each array is tuned by exposing it to an odour sample and measuring the response. This response is then taken as the standard against which future exposure is measured. The most popular method of measuring the response is principal component analysis (Gardner and Bartlett, 1992), although other techniques have been used successfully (Persaud and Travers, 1991). Byun et al. (1997) present a technique based on a combination of principal component analysis and Sammon mapping to enable complex data sets to be visualised. They used the technique successfully to assess differences in the odours of slurry from pigs fed with different diets.

Electronic noses are available commercially for testing compounds in the laboratory. They have been used to discriminate between odours of different varieties of beer, wine, coffee, tobaccos (Gardner and Bartlett, 1992), and to determine the
freshness of fish (Olafsson et al., 1992). To date, the chief objective has been to discriminate between odours. As yet routine use of an electronic nose in any commercial application has not been reported. In animal agriculture there are some conditions which herdsmen and veterinarians are trained to detect by smell, and these could be a first target for automatic odour sensing research.

Ketosis is a common disorder of high yielding dairy cows. In its clinical form it can cause irreversible liver damage. Diagnosis of ketosis at the sub-clinical stage would be a major benefit. At present there is no method of diagnosing ketosis automatically. A traditional method of diagnosis of ketosis (acetonaemia) is to sniff the breath of the cow for signs of acetone. The ability to monitor the breath of an animal with an electrochemical sensor would provide a useful diagnostic tool for ketosis in any species of farm livestock. There are encouraging signs that this may become possible (Dobbelaar et al., 1995).

Feed inputs are frequently assessed by odour, for example, the palatability of silage and hay is often a more accurate guide to the effect on production than the laboratory analysis. Stetter et al. (1993) reported the use of a sensor array and neural network which classified 83% of samples of grain correctly into the categories good, sour, musty and objectionable odour.

Animals use their olfactory senses extensively. Cattle in oestrus have been shown to secrete distinctive pheromones (Blazquez et al., 1988) and the ability to detect these automatically would allow more timely breeding.

The food output of a livestock system must be free from objectionable odours whether they are taints (caused by external agents such as cleaning chemicals) or off-flavours due to internal agents. Odour sensing may have a role in supplementing or replacing human odour panels in detecting boar-taint at pig meat processing factories, milk taints and off-flavours at creameries and odours in eggs at packing plants. These applications are attractive in that the location of the sensing could be in a controllable environment and so extraneous odours which would complicate the pattern of odours to be analysed could be excluded.

An odour sensing system to detect the presence of manure or other contaminants on cows' teats in preparation for automatic milking has been proposed by Mottram and Wilkin (1994). Work on this application is at an early stage, but the same technique might be used to detect contaminated or diseased animals at the abattoir.

4.9. Acoustic monitoring

The stockman extracts much useful information from the sounds in a livestock house. The vocalisations of animals can be particularly helpful and there have been some attempts to analyse these. For example it has been shown that there is a relationship between physical activity and vocalisation for hens (Stone et al., 1984). Examples of vocalisation of pigs describing fear, isolation, pain, greetings, anticipation and frustration have been demonstrated by Wood-Gush (1983). Riley (1972) developed a series of sonographs for 15 different calls for adult pigs. From these sonographs, differences in the acoustical properties of different calls were observed.
Hongwei et al. (1988) showed that pig vocalisations related to selected situations could be segmented from each other, and possibly from background noise, and that stress levels may be related to the duration and frequency of vocalisation. Robertson and Benzie (1989) developed a cough counter for pigs, based on analysis of sound amplitude, but found difficulty in discriminating between coughs and other noises, such as grunting and ear flapping. Van Compernolle et al. (1992) report an overall success rate of 83% in automatic recognition of nine types of pig vocalisation, including alarm calls and coughing, using a multi-stage frequency analysis procedure. Friend et al. (1989) used a commercially available sound-activated device to reduce crushing of piglets by sows. When the system detected the squeal of a piglet, an electric shock was administered to the sow, via a girth belt, to encourage the sow to stand up. Squeals were identified on the basis of sound amplitude and duration. In trials it was found that the system could be effective, but that discrimination between the sounds made by piglets being crushed and piglets fighting was inadequate, and that this resulted in a high incidence of unnecessary shocks.

Automatic systems, capable of analysing and interpreting the sounds in a livestock house, would be very valuable, but considerable difficulties have to be faced. Relevant related areas of research are automatic machine condition monitoring systems, acoustic security alarms, military vehicle identification research and automatic speech recognition, e.g. Nadas and Nahamoo, 1989; Cabell et al., 1992. Analysis techniques and low price hardware have been developed for these applications which could be further developed for monitoring in animal agriculture. In these applications sound signals are monitored continuously and the temporal and spectral characteristics analysed. Algorithms have been developed for examining the change in spectral content over the time of the signal (Refenes and Chan, 1992). Some of the most characteristic patterns of known sounds are compared with the results of this analysis in order to identify the noise.

Probably the most significant problem in livestock monitoring is the high level of background noise. In existing acoustic security alarms, such as break glass detectors, high levels of background noise are overcome by an accurate knowledge of the spectral and temporal characteristics of the sound to be identified. In automatic speech recognition the signature of the signal being identified is more variable, but the signal is very complex so there are many identifiers which can be used simultaneously to enable good discrimination of signal from background. Many important noises in a livestock building have neither of these advantages, hence currently available identification methods will have to be developed further for this application.

5. Discussion

Livestock husbandry is one of the oldest industries in the world, but has benefitted little from the monitoring and processing techniques currently being adopted by other industries. However there is evidence that technology has been
taken on board by the stockman as it becomes available. Buildings have been developed to provide shelter and many incorporate some level of automation in controlling the thermal environment; feeding materials have been improved and rations formulated to provide customised diets; genetics have been used to improve breeding and productivity; vaccines and medicines developed and machinery produced for milking, handling and processing. The stock farmer has not been reluctant to adopt new ideas; it is the research and development of appropriate technology for use in monitoring live animals which has fallen behind that for mechanised industry.

This is, at least partly, because most other industries deal with situations which can be fully controlled; the objects for processing are inanimate, predictable, and can be precisely defined. Objectives can be set independently of time and weather, shape changes or object behaviour. Once a process has been defined and performed, it can be repeated with control of all relevant variables being taken as part of the process. Livestock, on the other hand, even when kept under strictly controlled conditions, are still unpredictable in behaviour, appearance and condition. They move, grow and change shape through age and reproduction; they change colour through cleanliness, hair or wool growth.

The pressure for improved monitoring and control of livestock production will increase as the marketing and retailing of agricultural products becomes more sophisticated, and the demand for control of the quality of produce leaving the farm increases. The farmer will have to provide products to the high quality demanded by the supermarkets. There will also be increasing pressure for livestock products to be supported by a production record to prove that they had been produced in an environmentally acceptable and humane manner.

Sensor developments will enable an increasing number of production factors to be measured. However the value of unprocessed data is limited. The producer does not usually need to know the absolute value of a variable, but does need to know whether the process is proceeding as expected. To provide this type of output an integrated monitoring system approach is required, in which sensor data is integrated with information from databases, mathematical models and knowledge bases. It seems likely that it will be advantageous to adopt a system architecture which will allow extra elements and functions to be added easily as they become available.

6. Conclusions

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.

Developments in sensor technology which have taken place, and which are in progress or can be foreseen, will make available increasing amounts of information relevant to monitoring animals and their environment, and hence their production, growth and health. It is reasonable to expect that systems will become available for
identifying, weighing and tracking animals; for monitoring basic physiological factors such as body temperature and heart rate; and for assessing body conformation, and some limited aspects of composition. It is also possible that methods of providing specific disease diagnosis will be developed, although so far no reliable systems have emerged.

Animal husbandry systems are particularly suited to these new techniques, because of the diversity of relevant information which is becoming available, and the qualitative nature of much of the information.

Several systems containing some of the elements of an integrated monitoring system are already available commercially for pig, broiler and milk production. This suggests that, given a sound economic justification, livestock producers are prepared to adopt new technology.

Integrated monitoring systems have the potential to improve production efficiency and quality control in livestock farming, and so enable producers to respond to the pressure from their customers for products with a given specification and known production history.

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References


