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Advances in precision livestock farming

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Contents

Introduction

The livestock sector is facing increasing pressure to develop more 'climate-smart' methods that can be used to prevent the onset of major diseases, whilst also monitoring the efficiency and environmental impact of livestock production.

This volume provides a comprehensive review of recent advances in the development of precision livestock technologies to monitor the health and welfare of animals as well as key areas of production such as housing and feed efficiency. The collection is split into two parts: Part 1 includes chapters on data collection and analysis using different techniques to monitor livestock, such as on-animal sensors, thermal imaging and acoustic techniques. Chapters also focus on machine vision techniques and developments in data analysis for decision making. Part 2 chapters review applications in precision livestock farming for monitoring and controlling housing conditions, developments in individual-animal feed efficiency monitoring systems and using automated systems for monitoring mastitis and lameness. Chapters also examine the developments in automated monitoring of livestock fertility and pregnancy, automatic milking systems and monitoring grazing behaviour and automatic grazing management.

Part 1 Data collection and analysis

The book opens with a chapter that reviews the developments in on-animal sensors for monitoring livestock. Chapter 1 begins by exploring the different components of an on-animal sensor system and the challenges and limitations faced by developers trying to make them operational on commercial livestock farms. The chapter then goes on to discuss form factor and the deployment of various sensors such as leg, collar, headstall or halter sensors and ear tag sensors. It also draws attention to tail or tail-head sensors, in-animal sensors as well as novel deployment modes. The chapter moves on discuss four sensor types that provide data on location, activity, movement and physiological characteristics of livestock. Energy management for on-animal sensors is also addressed, followed by sections on communication and data transfer, data management, reduction and analysis as well as the application of on-animal sensors.

The next chapter focuses on developments in thermal imaging techniques to assess livestock health. Chapter 2 begins by examining the use of these techniques to monitor animal health then goes on to discuss how these detection systems must account for key challenges such as ambient environmental conditions. From this, the chapter draws attention to the development of infrared thermography technologies to address these challenges. A section on improving diagnostic accuracy is also provided, which is then followed by a case study highlighting the use of infrared thermography to identify bovine respiratory disease.

The subject of Chapter 3 is developments in acoustic techniques to assess livestock health. The chapter first provides an overview of the different animal vocalisations and sounds produced and how these can be used to identify certain behaviours as well the health status of the animals being monitored. The chapter moves on to analyse how these sounds can be recorded and analysed. Sections on sound applications for monitoring pigs, poultry and cattle are also provided. A critical review on the status of the current technological developments in acoustic techniques is also included in the chapter.

Chapter 4 examines the developments in machine vision techniques to monitor livestock behaviour and health in precision livestock farming. The chapter begins by reviewing advances in computer vision-based technologies for precision livestock farming. It also reviews how automation in image analysis can promote smart management of livestock to improve health and welfare. The chapter discusses the main devices for data acquisition in computer-vision based systems and the range of tasks computer vision (CV) techniques can perform. It reviews key steps such as initialisation, tracking, pose detection and recognition. The chapter includes illustrative case studies of precision livestock farming applications based on existing CV techniques. The chapter concludes by reviewing recent advances in CV techniques based on artificial neural network techniques, as well as future challenges.

The next chapter focuses on the developments in activity and location technologies for monitoring cattle movement and behaviour. Chapter 5 begins by examining the range of options for monitoring cattle location and activity by highlighting the different techniques currently available. The chapter then moves on to discuss the application of these technologies in livestock and how they can also be integrated into the farm system and industry. It concludes by providing an overview on the future development of these technologies and how machine learning techniques are so important in identifying potential issues in livestock.

The final chapter of Part 1 draws attention to the developments in data analysis for decision making in precision livestock farming systems. Chapter 6 first discusses the fundamental concepts in data science and reviews the various techniques that can be used in the data mining process, such as classification, regression and clustering. For each technique, an example has been added for livestock data. The chapter also examines the use of machine learning for supervised learning and unsupervised segmentation. Fitting the model to data and the phenomenon of overfitting are also described. The chapter concludes by providing an overview of why data mining is a useful tool in precision livstock farming and highlights future research areas.

Part 2 Applications

The first chapter of Part 2 focuses on the monitoring and control of livestock housing conditions using precision livestock farming techniques. Chapter 7 discusses the effects of variables such as temperature and humidity on animal productivity, health and welfare. It also shows how environmental conditions affect production of greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) as well as other damaging emissions such as ammonia (NH_3), The chapter reviews ways of measuring and managing these environmental variables in dairy, poultry and pig production to make livestock production more sustainable.

The next chapter examines the developments in individual-animal feed efficiency monitoring systems for livestock. Chapter 8 begins by first reviewing three key literature databases that provided a basis for the chapter's main discussion on the individual feed-intake measurement system. It then goes on to examine how wearable sensors and electronic scales are used to monitor livestock in various settings, which is then followed by a section on the use of camera sensors for the same purpose. The chapter also looks at image analysis algorithms and deep learning, then moves on to discuss how feed-intake measurement systems can be evaluated.

Chapter 9 analyses developments in automated systems for monitoring livestock health, focusing specifically on mastitis in dairy cattle. The chapter describes the current state of automated mastitis detection systems in dairy cattle and potential new developments in mastitis detection. It first reviews the various components of a mastitis sensor system, then goes on to review the current commercially available sensors. Sections on developing biosensors and combing data sources and improving algorithms are also provided.

Touching on topics previously discussed in Chapter 9, Chapter 10 moves on to review the use of automated systems for monitoring lameness in dairy cattle. The chapter examines existing methods for manual and automated detection of lameness, including approaches that detect changes and abnormalities in the gait or stance of the animal, and methods that directly or indirectly detect changes in individual and social behaviour. It also highlights approaches that use automated technology such as video, accelerometers and spatial positioning systems, and discusses methods to analyse trends and signals in these data.

Chapter 11 focuses on developments in automated monitoring of livestock fertility and pregnancy. The chapter first describes the oestrous cycle in dairy cows, focusing specifically on oestrus-associated changes in dairy cows' behaviour as well as the physiological parameters that can be affected. A section on oestrus detection, pregnancy diagnosis and reproductive performance is also provided, which is then followed by an overview of the various methods currently in use for oestrus detection in cows. The chapter concludes by emphasising the importance of developing oestrus detection methods in future research in order to ensure that any potential issues are detected early on.

The subject of Chapter 12 is advances in automatic milking (AM) systems. The chapter provides comprehensive information on the different aspects of AM to ensure that the potential benefits of the system are available to dairy farmers. It begins by highlighting the importance of identifying which breeds of dairy cow are most suited to automatic milking systems. The chapter moves on to review the effects of AM systems on milk yield and quality, feeding concentrate supplementation in AM systems as well as grazing and grassland management. A section on benchmarking and optimising performance using key performance indicators is also provided. Cow behaviour, training of cows and the transition to AM is also addressed, which is followed by an analysis of health and welfare management. The chapter also analyses how people are involved in AM systems, the impact of these systems on labour requirements, the economics of AM and the possibility of mobile AM systems. The chapter concludes by providing an overview of the current and future focus of AM research.

The final chapter of the book provides an overview of the development and use of information technology to improve the management and welfare of grazing livestock under extensive systems. Chapter 13 discusses the evolution of grazing management through the animal/pasture interface, and the development and application of grazing management technologies, including, on-animal managements though virtual fencing technology and on-animal monitoring of pasture intake, location, health and activity. Technological examples will focus on the Australian beef industry as a potential early adopter of PLF solutions. A case-study is also presented on the commercial implementation of the eShepherd® virtual fencing system for protection of an environmentally sensitive area. The chapter concludes with a summary of developments to date, discussion of future research trends, and where to look for additional information.

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Chapter 1

Developments in on-animal sensors for monitoring livestock

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1 Introduction

Since the very beginning of animal domestication, humans have sought to understand several key attributes of the livestock under their care. Very simply, these questions can be summarised as: Where are they (location)? What are they doing or experiencing (behaviour)? Are they in a biological state that will meet my needs in terms of the purpose for which I manage them (state)?

Traditionally, these attributes have been discerned by closely watching the animals, in some cases through almost constant human association (e.g. early shepherding practices) or through observations undertaken at critical times (e.g. dairy farmers observing their cows as they are moved into the milking parlour). This resolution of monitoring, aligned with the highly trained eye of the manager, meant that any problems or challenges to the health and productivity of individual animals could be quickly identified and ameliorated.

Unfortunately, the same degree of intensity in monitoring is no longer achievable in modern livestock production systems, particularly in remote and extensive areas, as the costs of labour preclude the ability to have trained staff

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monitoring animals at similar temporal resolutions. While much has changed in terms of the characteristics of modern animal production compared to early subsistence husbandry, modern livestock managers still seek the same information as their historic counterparts: location, behaviour and state. Given the ever-increasing pressure to reduce costs (particularly time) and the decreasing skill of farm labourers to interpret animal behaviour, producers are increasingly turning to automated remote monitoring systems to provide this key information. Sensors have been developed for a variety of purposes and come in many shapes, sizes and means of interaction with an animal. Sensors can be broadly divided into two categories: on-animal sensors (OASs) – which are attached to, or inserted into, the animal in some manner and which are the focus of this chapter – and off-animal sensors, which collect data by observing the animal without maintaining a permanent attachment. Off-animal sensors include systems that automatically weigh, collect imagery or record vocalisations of livestock. Off-animal sensors provide valuable information, and a brief discussion of the benefits of integration between the two platforms is provided in the applications section (Section 8).

One clear benefit of OASs over off-animal systems is that the former collect information wherever the animal is located. While it is true that some off-animal imaging systems can monitor animals almost constantly in confined areas (e.g. cattle feedlots and pig barns), OASs provide the unique capability of being able to monitor individual livestock in larger areas and more extensive landscapes. As a result, the animal is monitored 24 hours a day and 7 days a week. It is this feature that has proven to be one of the key strengths of these systems, as this degree of intense monitoring could never be achieved using human labour. Most livestock are essentially herbivorous prey animals, which have evolved to hide signs of pain and weakness when observed. It is this tendency for resilience that makes detecting health and welfare problems, through occasional human inspection, a challenge (McLennan, 2018). OASs provide an opportunity to overcome this challenge as they allow for changes in location and movement to be detected while the animal goes about its daily activity without interference. This provides insights that have never been available to animal managers. Remotely detecting the location of an animal also provides an additional key benefit of enabling the animal to be easily found. This simple application is valuable, especially in extensive rangeland systems, where simply finding livestock is a time-consuming and expensive process.

OASs are not the product of the digital age; they have been used, at least in a rudimentary form, for centuries. The simple cow bell collar (Fig. 1) could be described as the earliest version of a remote animal monitoring device. The gentle ringing of the bell as the animal walks enables a manager to remotely locate the animal in difficult landscapes (usually terrain or vegetation related). The sound provided by the bell also provides a clue as to the behaviour of

Figure 1 The 'original' on-animal sensor, a bell on a cow in the Italian Alps North of Torino and a current commercially developed GNSS tracking collar, the Smart Paddock Blue Bell™. The original cow bell provides the livestock manager with the ability to remotely detect the location of the animal using an audible signal. The new technology enables the producer to remotely locate the cow using their smart phone. While digital technologies are transforming the livestock sector, the principle of on-animal sensing has been used for centuries (photo: Bailey and Wolchyn).

an animal; a rapidly ringing bell indicates that the cow is running, either from a predator or from the manager as they attempt to round up the herd. While the cow bell can be considered the original OASs, the digital revolution has delivered a range of new sensor platforms that have significantly advanced this concept. The development of sensors has primarily been driven by other industries, particularly the mobile phone and human wearable platforms. At first glance, it appears a simple translation to take the technology in a FitBit™ and attach it to a cow; however, in reality, there are a number of challenges that make on-animal sensing a far more complex problem.

The objective of this chapter is to provide the reader with a broad understanding of how OASs work, how they are deployed, how data from them are managed and what the data can be used for. It will also provide insights into the challenges of developing and deploying these devices in commercial livestock management operations.

2 Components of an on-animal sensor system

OASs systems have four broad functional components: (1) the device, which is attached to the animal and collects data; (2) the communication system, which transfers the data off the device; (3) the data handling and analytical system, which turns raw data into meaningful information; and (4) the data visualisation platform, which presents the information to the end user to enable decision making (Fig. 2). However, not all on-animal systems follow this simple linear

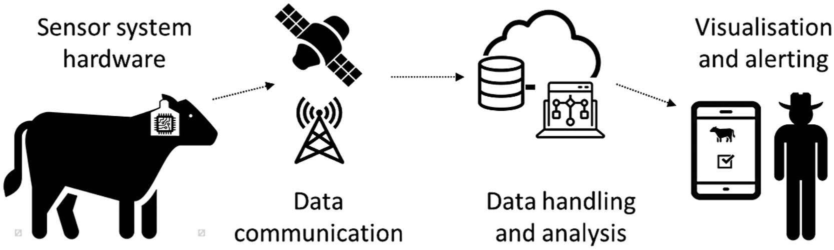

Figure 2 Components of an on-animal sensor system. It is worth noting that not all systems follow this simple design. Many undertake data reduction or preliminary analysis on the device, some even providing alerts (e.g. a coloured light may flash to indicate a problem).

model. Some systems undertake preliminary processing or data reduction on the device while others incorporate a warning system on the device itself, such as a flashing light, to signal an issue with an individual animal. These design specifications are dictated by the specific application and environment in which the system is deployed.

The on-animal device usually consists of several key components: the sensor technology that detects the desired attribute (common sensors include accelerometers, Global Navigation Satellite Systems (GNSS) and proximity loggers); a power source that may include either an energy storage system or energy harvesting system or more commonly both; a transmitting and potentially receiving radio to communicate the data with a receiver; data storage and/or processing capability; and the packaging that contains all the elements, protects them from the external environment and attaches the entire system to the animal.

3 Form factor and deployment mode

Key challenges in the deployment of OASs include attaching the device to the animal (i.e. form factor) and keeping it attached (i.e. device retention). For some species this is relatively easy, and for others the development of an industry-acceptable form factor remains a considerable challenge. There have been numerous options explored over the years, from the traditional collar-borne sensor systems to more novel subcutaneous implantable sensors. A full discussion of the various deployment modes follows.

3.1 Leg sensors

Sensors have been deployed on the legs of dairy cattle for over 40 years, initially as a research tool (Kiddy, 1977) and subsequently as commercially available systems. The earliest leg deployed sensors were simple pedometers, and

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