Preface

Precision Livestock Farming and precision technologies in companion animal care are upcoming and in some cases almost mainstream. Just as we are depending more and more on data and technology, with smartphones, smartwatches, smart homes and smart cities, so is the livestock and companion animal sector. Many of our dairy cows have activity meters, cameras are being installed in pig and poultry farms, activity meters are used for horses and GPS trackers for dogs and cats. For all these technologies, context and domain knowledge are extremely important. If you do not know about the biology and management of the animals you are working with or designing technology for, I believe that your project will not succeed. At the same time, working in livestock production or companion animal care is difficult, if not impossible, without some knowledge of data and technology. There are not many study books available that combine precision technology and animal knowledge. With this book, we aim to combine these knowledge areas. We describe the main animal sectors in livestock, companion animals and horses, and we give an overview of the application of technology and sensors for these sectors. We also describe the main trends and concerns in each sector, since these are important drivers of the technology. Separate chapters focus on the working mechanism of sensors and the data science applications. The purpose of this book is to help students understand the cross-over field between technology and biology. The book is meant for students from an animal science or biology background that want to work with data and technology, but also for students from a business, technology or IT background that are venturing into the animal sector.

The writing of this book was a team effort. It was a great pleasure to work with colleagues from HAS University in Den Bosch, from Aeres University in Dronten, from the Universidad de Córdoba (ETSIAM) in Spain and Harper Adams University in the UK. Together we worked hard to produce this book, we learned a lot on the way, and we cannot wait to implement the book in our teaching modules and beyond. We hope that this book will inspire students and lecturers alike, and introduce them to, as well as win them over for, this very interesting field.

We are grateful to the students and farmers that provided photos for the book. Furthermore, we want to thank the reviewers that helped improve the text: Karl Behrendt, Marc Cox, Rick van Emous, Jeroen de Haas, Bart Houx, Judith Roelofs, Mark Rutter and Menke Steenbergen.

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Lenny van Erp

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1. Introduction to precision technology and sensors

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1.1 Precision agriculture

Precision Agriculture has quickly become a well-known term. In arable farming, GPS is being used to drive straight with the tractor, and to irrigate, fertilise or spray in the right place at the right time. To do this, sensors are used on an increasing scale to make operations more efficient. A sensor can be described as a device that receives and responds to a signal or stimulus. Sensors can be extra eyes, ears and nose for the farmer, and these artificial senses provide the farmer with extra data. These data are translated into information, and with this information, the farmer can make better decisions. In precision farming, moisture sensors control irrigation, drones with cameras use vision techniques to recognise diseases in crops or predict yields. Satellites, weather stations and sensors provide data and information to optimise business operations. Greenhouses can be operated without human presence, and the best decisions are based on data (Hemming, 2020). Precision farming is using data to make decisions. Data-driven farming not only is more efficient, but it is also an opportunity for more sustainable crop production. Precision Farming is a way to handle resources sustainably and to work towards sustainable global food production: a food production using fewer resources, fewer pesticides and less water, because of more precise sowing, spraying and watering (Auernhammer, 2001; Fresco and Poppe, 2016).

1.2 Precision livestock farming and companion animal care

Precision agriculture in the livestock industry is also known as 'Precision Livestock Farming' (PLF); this term was introduced at the start of the 21st century, with the first conference on PLF held in 2003 (Werner *et al.*, 2003). As defined by professor Daniël

Berckmans (University of Leuven): PLF is the use of technology to automatically monitor livestock, their products and the farming environment in real-time, to aid farm management, by supplying the farmer with relevant information on which to base management decisions. The development and practice of PLF require interdisciplinary engineering and science including animal science, physiology, veterinary science, ethology, information and computing science, ICT, mechanical engineering, electronic engineering, and others. The purpose of this automatic monitoring is to detect deviations at an early stage and improve animal health, welfare and efficiency. The expected result is an improvement in overall production sustainability (Berckmans, 2014, 2017; Van Erp-van der Kooij, 2016).

There are many different technologies developed for monitoring farm and companion animals and their environment. For instance, sensors installed on an animal or in the nearby environment can detect a sudden change in animals' behaviour, such as in feeding, drinking, rumination, moving, vocalisation or productivity. Moreover, the physical state of the animal can be monitored with specific devices. Examples are monitoring body temperature, progesterone level in milk or rumen pH with thermal cameras, sensors in automatic milking stations or rumen boluses for dairy cows (ClearFarm, 2020), or monitoring body temperature and activity with sensors in the girth for horses or in the neck collar for dogs and cats.

In this book, many examples of sensor applications will be given for livestock and companion animals in Chapters 2-7. Each chapter focuses on a specific sector, and highlights are given at the beginning of each chapter. In Chapter 8, sensors and their working mechanism are described. This rather technical chapter can be used as a reference and be studied if needed. Chapter 9 describes the data science applications in the livestock and companion animal sector and gives examples of techniques used when analysing animal data. In this introduction, sustainability and the relation with the use of sensor technologies are explained in the following section. In Section 1.4 the reliability of sensors will be explained, and in the last section, the factors that influence the willingness to buy sensor technology will be discussed.

1.3 Sensor technologies and sustainability

Sustainability goals on farm level can be described as minimising environmental impact, minimising wasted inputs and thereby maximising economic efficiency, maximising food safety, and maximising animal welfare. PLF technologies facilitate these goals (Werkheiser, 2018). This promise of Precision Livestock Farming was spelled out during the final conference of the EU-PLF project: PLF has the potential to make farming more efficient by better use of resources and to guarantee or improve animal welfare (EU-PLF, 2016).

1.3.1 Minimising environmental impact, minimising wasted inputs and maximising economic efficiency

Precision feeding is a promising feeding technique to reduce the environmental footprint of livestock production systems. With precision feeding, animals within the group can be fed individually, with a feed composition better adapted to the individual animal. For example, a high-quality feed can be provided to animals that are growing faster and thus produce more efficiently, while the low-value feed is given to the animals that do not have that potential. This saves on feed costs. The practical application of individually precision feeding can have a great impact on livestock sustainability. In a study where pigs were fed individually with daily tailored diets, it was found that precision feeding reduced lysine intake by >25%, feeding costs by >8%, nitrogen and phosphorus excretion by almost 40% and greenhouse gases emission by 6% (Pomar and Remus, 2019).

Location systems for dairy cows help the farmer find a cow that needs to be checked on, treated or inseminated. This saves the farmer much time and energy. Integrating this system with other sensor systems that alert the farmer when an animal needs attention will greatly increase efficiency. Labour is an important resource on a farm, that should not be wasted; systems that decrease labour for the farmer make farming more sustainable.

1.3.2 Maximising food safety and animal welfare

Sensor systems can alert the farmer in an early stage when animals deviate from their expected behaviour or performance. This way, clinical disease is detected very early or even prevented. These 'early warning systems' result in fewer ill animals, or fewer animals being treated with antibiotics and less medication used, when the first patients are found quickly before the disease spreads any further. In other words, when farmers are alerted in time to deviations in health and behaviour, medical costs decrease and animal welfare is enhanced. The result is increased sustainability. The better we monitor the animals, the better we can take care of them, and the more sustainable the system (Matthews *et al.*, 2017).

Several sensors can monitor the physiology of individual animals to prevent or detect disease in an early stage. The biological principles of heat production during stress or inflammation can be used by measuring temperatures of certain body parts with a thermographic camera. Stress can be made visible because extremities (ears, tail) become colder and the eye region becomes warmer. An elevated temperature in claws, legs or udder can be made visible to detect lameness or mastitis (Nääs *et al.*, 2014). Temperature sensors are often combined with other sensors in an integrated system, such as in an ear tag or in an internal bolus for dairy cows, where temperature, activity and sometimes pH are combined (Mottram, 2016).

Finally, several measurements to monitor welfare can be automated using PLF systems. Housing conditions such as climate and light, feed and water, health and behaviour can be monitored with sensors, directly, e.g. by measuring body condition or body temperature, or indirectly, by measuring feed and water intake or climate conditions in the farm. Besides these animal-related factors, also to the human-animal relationship can be automatically measured. Although precision livestock technologies monitor several parameters relevant to animal welfare such as feeding and health, none of the systems yet provide the broad, multidimensional integration that is required to give a complete assessment of an animal's welfare. However, data from PLF sensors could potentially be integrated into automated animal welfare assessment systems (Larsen *et al.*, 2021; Randle *et al.*, 2017; Rowe *et al.*, 2019; Van Erp-van der Kooij, 2020)

1.4 Performance of sensors

1.4.1 Accuracy, precision, validity and reliability

Sensors are used to measure and quantify observations. For example, activity sensors are used to quantify behaviour, temperature sensors give information on the body temperature of an animal, and location sensors indicate where the animal is. Sensors provide the user with data and information to be used in the management of the farm and care of the animals. Therefore, reliable results of the measurements are essential. Only then will the results lead to good advice and possibly an improvement in animal production or animal care. Important features are accuracy (systematic error), precision (random error), validity and reliability. Accuracy is the degree of closeness to the true value and precision is the degree to which an instrument or process will repeat the same value. Validity is defined by how well the measuring

3. Precision beef and sheep farming

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Highlights

- Beef cattle and sheep are important livestock sectors in Europe, especially in vulnerable areas, where they provide high-quality products and numerous ecosystem services.
- There are few PLF solutions specifically designed for beef cattle and sheep, but they benefit from technology developments for other sectors, such as dairy farming.
- PLF solutions can be classified as wearable and non-wearable, according to their physical relationship to the animal. Wearable devices are normally used with large and high-value animals, while non-wearable options are chosen when technologies are large, complex, or expensive.
- The most common PLF solutions for beef cattle and sheep are focused on location, especially in extensive farming systems, and weight monitoring, because producing meat is the primary aim.
- Radio Frequency Identification is mandatory for sheep, posing a great opportunity to make them readable by different PLF tools.
- PLF solutions to monitor the fields, based on proximal or remote sensors, are promising tools to increase production efficiency and system sustainability.

3.1 Background of beef cattle farming in Europe

The European cattle sector consists of the bovine meat sub-sector, which produces and processes beef and veal, and the dairy sector, which produces and processes cow milk. It is important to clarify that meat production comes both from beef cows (also known as suckler cows) and dairy cows, being the production systems of both sub-sectors quite different. In this chapter, the focus is on beef cattle production systems, as dairy farming systems are addressed in Chapter 2.

Nowadays, the European Union (EU) is the world's third producer of beef with 7,844 million tons of meat in 2019 (EUROSTAT, 2021), behind the United States of America (USA) and Brazil. In 2019, there were over 86.5 million bovine animals in the EU. This figure comprises all types of bovine animals, i.e. beef and dairy herds, and animals of different ages. Specifically, the number of cows was 34.8 million, being 22.6 million dairy cows and the rest suckler cows (EUROSTAT, 2021). The EU cattle sector is biased toward dairy production. Therefore, beef production is divided into two main types or subsectors: dairy-beef production, which is a primary driver of the EU beef production sector, and beef breed production, focused on cow-calf systems. The EU dairy cattle production is concentrated mainly in six countries, accounting for almost 70% of total heads (Germany, France, Poland, Italy, United Kingdom (UK), and the Netherlands). On the other hand, France, Spain, UK, and Ireland hold over 70% of the EU suckler cows, which are normally used to valorise less-favoured areas (Lherm *et al.*, 2017). The highest number of fattening farms corresponds to Ireland, followed by Spain, the regions in or around the Alps, Eastern Poland, and Slovenia. Fattening farms in those regions have a small average size, while the largest farms are in Germany and the Benelux (Hocquette *et al.*, 2018).

Beef consumption in Europe is about 16 kg per capita (20% of total meat consumption), far below other countries, such as Argentina, Brazil, or the USA, with annual consumptions per capita between 37 and 54 kg (Ihle *et al.*, 2017). Although a small reduction in domestic beef demand has been observed in the last years, the overall beef production in the EU is expected to maintain stable, due to the increasing demand of developing countries, such as China.

The heterogeneity of the EU cattle sector at the regional level is very pronounced. Beef cattle farms under extensive, semi-extensive or intensive regimes can be found, depending on the region and the production phase. Beef farming practices and farm structures vary largely throughout the EU because of climatic factors and the large variety of ecological zones in Europe. Beef production systems in the EU also differ regarding the age and weight at which animals are slaughtered, the feeding regime and the type of accommodation. Nevertheless, in general, two production phases can be distinguished:

1. Breeding, also referred to as cow-calf systems, which are dedicated to the production of calves from suckler cows. It also includes heifer rearing for the replacement of the herd.
2. Finishing, which refers to the fattening of calves produced in breeding farms and dairy farms, prior to the slaughterhouse.

Individual farms can be dedicated to breeding, finishing or both (complete cycle farms), although specialisation is the most common option in the EU beef cattle sector, i.e. production phases tend to be separated in different farms and even in different regions.

Normally, cow-calf farms and complete cycle farms are pasture-based systems, where animals have permanent access to pasture. In some warm regions, mostly in Mediterranean countries, where grass production can be 5 to 10 times lower than in Northern Europe, animals require significant feeding supplementation during several months of the year. It is worth highlighting the case of Southwestern Spain, where beef production is linked to a very specific agroforestry system, named 'dehesa', where cattle, sheep and Iberian pigs are raised together under predominantly oak trees. Agroforestry refers to the land management systems combining the growing of trees, crops and livestock in the same place (Allen *et al.*, 2011). In drylands, agroforestry systems play crucial economic, social, and environmental roles, reaching high levels of sustainability.

During the breeding phase, calves from suckler cows remain with their mothers for a four-to-eight-month period before they are weaned. This is a very important difference with calves coming from dairy farms, which are separated from their mothers when they are one or two days old and artificially reared on milk or milk replacer plus solid feed for a two-to-three-month period. The life cycle of animals in cow-calf farms is represented in Figure 3.1.

In breeding farms, reproductive efficiency is essential to obtain a satisfactory economic return for the farmer. Thus, some indicators, such as the percentage of pregnant cows, the proportion of born alive and weaned calves, and the calving

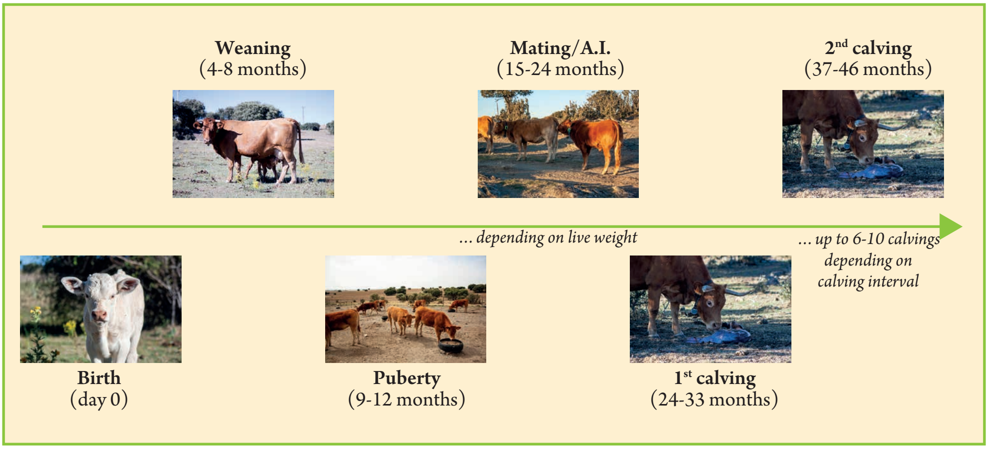

Figure 3.1. Timeline for beef cattle from birth to first and second time calving (photos: Rubén Blanco Carrera, farm La Blaquería).

interval are used. One of the most important management decisions is to establish controlled calving seasons. Despite the widespread adoption of artificial insemination (AI) worldwide, natural service is the most frequent breeding method in beef cattle farms, mainly due to the management constraints associated with the extensive or semi-extensive conditions under which these animals are reared. Besides, extensive production systems make it difficult to gather information on animal behaviour, feeding status or health that allow the making of timely decisions. Closer monitoring of animals and timely interventions could greatly reduce the number of cows failing to become pregnant and the number of calves lost during the calving season. This is an area of research for many Precision Livestock Farming (PLF) applications, as explained later in this chapter.

Feeding optimisation, which is needed to maintain animal health and productivity, is another field of interest for beef cattle farming. In pasture-based systems, most feed comes from grass, so monitoring grass growth and consumption is as crucial as monitoring cows. Grass production and utilisation are below optimum in most farms. Grass underutilisation, as well as overgrazing, should be avoided, improving grazing efficiency and saving significant costs for the farmer through the minimisation of supplementary feed. Stocking rate (number of livestock units per area unit) is the indicator most widely used in this field and fences are the main management tool.

Regarding the fattening phase, production systems may be divided into extensive (grass-based), or intensive (indoor), the latter being the most common in Europe.