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Review article

Implementation of machine vision for detecting behaviour of cattle and pigs

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ABSTRACT

Livestock production to provide food for a growing world population, with increasing demand for meat and milk products, has led to a rapid growth in the scale of cattle and pig enterprises globally. However, consumers and the wider society are also increasingly concerned about the welfare, health and living conditions of farm animals. Awareness of animal needs underpins new production standards for animal health and welfare. Pig and cattle behaviour can provide information about their barn environmental situation, food and water adequacy, health, welfare and production efficiency. Real-time scoring of cattle and pig behaviours is challenging, but the increasing availability and sophistication of technology makes automated monitoring of animal behaviour practicable. Machine vision techniques, as novel technologies, can provide an automated, non-contact, non-stress and cost-effective way to achieve animal behaviour monitoring requirements. This review describes the state of the art in 3D imaging systems (i.e. depth sensor and time of flight cameras) along with 2D cameras for effectively identifying livestock behaviours, and presents automated approaches for monitoring and investigation of cattle and pig feeding, drinking, lying, locomotion, aggressive and reproductive behaviours. The performance of developed systems is reviewed in terms of sensitivity, specificity, accuracy, error rate and precision. These technologies can support the farmer by monitoring normal behaviours and early detection of abnormal behaviours in large scale enterprises.

1. Introduction

Livestock production is the largest user of land in the world for grazing and production of feed grains. The global demand for livestock products is expected to further increase due to population growth, rising incomes and urbanisation (Bruinsma, 2003). Increase in market demand for meat and milk products, to provide food for a growing population, has led to a rapid growth in the scale of cattle and pig enterprises globally. As the scale of animal husbandry around the world increases, addressing the issue of animal welfare becomes more essential. The relationship that people have with animals, and the duty they have to ensure that the animals under their care are treated correctly, is fundamental to animal welfare. Due to the current scale of production, there is increasing awareness that the monitoring of animals can no longer be done by farmers in the traditional way and requires the adoption of new digital technologies.

Livestock welfare can be defined using such parameters as their behaviour, physiology, clinical state and performance (Averós et al., 2010; Costa et al., 2014; Nasirahmadi et al., 2015). There are many links between animal behaviour, health, emotions and good welfare which have been widely reviewed (e.g. Broom, 2006; Bracke and Spoolder, 2011; Murphy et al., 2014), and identification of normal and abnormal behaviours helps to deliver better health, welfare and production efficiency (Nasirahmadi et al., 2017). Early and real-time detection of normal behaviours (e.g. lying, feeding and drinking) and abnormal behaviours (e.g. aggression and lameness) of animals reduces the cost of animal production, limiting losses from diseases and mortality, and improves the job satisfaction of stockpeople. The advancement of knowledge and technology in the current century, along with human expectations for a sufficiency of high-quality livestock products, has increased demand for improved production monitoring. With the development of new technologies, the application and integration of new sensors and interpretation of data from multiple systems with reducing processing times means that information supply for farmers and researchers has become easier (Barkema et al., 2015).

There are many studies in the literature that demonstrate how such technologies can help in observation of both normal and abnormal behaviours of animals. Examples include using radio frequency systems for locating animals, which utilize sensors and radio signals from a transmitter to triangulate a location, and the use of these location data to provide information on feeding and drinking behaviours of cattle (Sowell et al., 1998; Quimby et al., 2001; Wolfger et al., 2015; Shane

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et al., 2016) and pigs (Reiners et al., 2009; Brown-Brandl et al., 2013a, 2013b; Andersen et al., 2014; Maselyne et al., 2014; Gertheiss et al., 2015). Further examples of the application of new technology are activity and lying behaviour monitoring in cattle and pigs using accelerometers attached to the animals (Robert et al., 2009; Trénel et al., 2009; Ringgenberg et al., 2010; Jónsson et al., 2011). This technique has been widely applied for locomotion and lameness assessment (e.g. Nielsen et al., 2010; Grégoire et al., 2013; Conte et al., 2014), as has the use of other sensors which have been reviewed by (Rutten et al., 2013; Schlageter-Tello et al., 2014; Van Nuffel et al., 2015) for cows and (Nalon et al., 2013) for pigs. However, attachment of sensors to monitor animal behaviours may cause stress and, in some cases, is impractical to use for scoring group behaviours due to their cost and vulnerability. An alternative technology which has been widely considered in many agricultural and industrial processes is machine vision (Shao and Xin, 2008; Costa et al., 2014; Nasirahmadi et al., 2016b; Oczak et al., 2016). Automatic computer imaging systems could help both farmers and researchers to address the problems of monitoring animals, e.g. for visual scoring, animal weighing and other routine tasks which are both time-consuming and costly, and could result in more objective measurements by means of image processing techniques. A machine vision approach is a cheap, easy, non-stressful and non-invasive method which can be adapted to different animals, in both indoor and outdoor situations, using the animals' natural features (e.g. shape, colour, movement) for monitoring their behaviours.

This review summarises machine vision and image processing techniques to automatically measure cattle and pig characteristics and behaviours. The article is structured in nine sections. Section 2 covers different types of camera and imaging systems used in this field. Section 3 and its subsections illustrate the use of image processing for individual physical characterisation of cattle and pigs. Section 4 addresses feeding and drinking behaviours, Section 5 discusses lying behaviours and Section 6 covers how image processing is used for detection of lameness and normal locomotion. Section 7 illustrates automatic monitoring of aggressive behaviours of animals, while Section 8 shows how mounting behaviours of cattle and pigs can be captured by image processing. Challenges and future research needs for animal monitoring are discussed in Section 9. Finally, conclusions are presented in Section 10.

2. Imaging systems for livestock monitoring

Image acquisition, which is the first step of any machine vision system, is defined as the transfer of signals from a sensing device (i.e. camera) into a numeric form. Cameras are a crucial element in machine vision applications, however, each type of camera offers different information on parameters of the image. For the purposes of this literature review, the cameras applied in cattle and pig behaviour detection can be divided into Charge Coupled Device (CCD), infrared and depth sensor cameras. The CCD cameras create images in two dimensions and are sensitive to visible wavelength bands reflected from objects (Mendoza et al., 2006). These types of camera need an additional source of light to make the image visible and the machine vision system consists of single or multiple cameras, e.g. video surveillance cameras, capturing objects which are visible to a human. Examples of using this type of camera in livestock behaviour detection are numerous (Shao et al., 1998; Hu and Xin, 2000; Porto et al., 2015; Nasirahmadi et al., 2016b). The captured images are potentially suitable for image processing algorithms to extract image features based on colour, shape and textural properties. CCD cameras have the ability to provide pixels of objects in red, green and blue (RGB) bands. Nowadays, different image processing algorithms help to convert these bands to information on grey, hue, saturation, intensity and other parameters.

Infrared or thermal cameras work similarly to optical or common CCD cameras, in that a lens focuses energy onto an array of receptors to produce an image. By receiving and measuring infrared radiation from the surface of an object, the camera captures information on the heat that the object is emitting and then converts this to a radiant temperature reading (James et al., 2014; Matzner et al., 2015). Thus, while CCD cameras measure the radiation of visible bands, thermal cameras detect the characteristic near-infrared radiation (typically wavelengths of 8–12 μm) of objects (McCafferty et al., 2011). Thermal imaging was developed for industrial, medical and military applications, but it has also been applied in many livestock production studies, as reviewed by (Eddy et al., 2001; Gauthreaux and Livingston, 2006; McCafferty, 2007; McCafferty et al., 2011). All live animals emit infrared radiation, and the higher the temperature of an object, the greater the intensity of emitted radiation and thus the brighter the resulting image (Kastberger and Stachl, 2003; Hristov et al., 2008).

In the last decade, the number of applications related to 3D imaging systems in machine vision has been growing rapidly, thanks to improved technology and reducing cost. The use of this type of imaging system in agricultural products has been recently described by (Vázquez-Arellano et al., 2016). Depth imaging is a core component of many machine vision systems and, within this technology, time of flight (TOF) and Kinect cameras have been used widely in livestock applications. TOF cameras sense depth by emitting a pulse and then measuring the time differential for that emitted light to travel to an object and back to a detector. They can provide a 3D image using an infrared light source and CCD detector (Kolb et al., 2010; Pycinski et al., 2016) and the camera lens gathers the reflected light and images it onto the sensor or focal plane (Fig. 1). The 3D depth sensing makes it possible to overcome common issues causing problems with 2D imaging systems, such as background removal, segmentation, feature extraction and sensitivity to lighting variance. TOF systems are limited by the number of data points that they capture at a given time and their relatively limited field of view, and the depth systems can lead to accuracy errors (Shelley, 2013). Although it is much easier and cheaper to use the 3D camera approach in farm environments rather than stereo vision, Laser or 2D triangulation, which are common alternatives for 3D reconstruction, the depth images still require some processing work to remove unwanted objects (e.g. noise, background) and in some cases calibration to deliver better results is needed. The Kinect depth sensor,

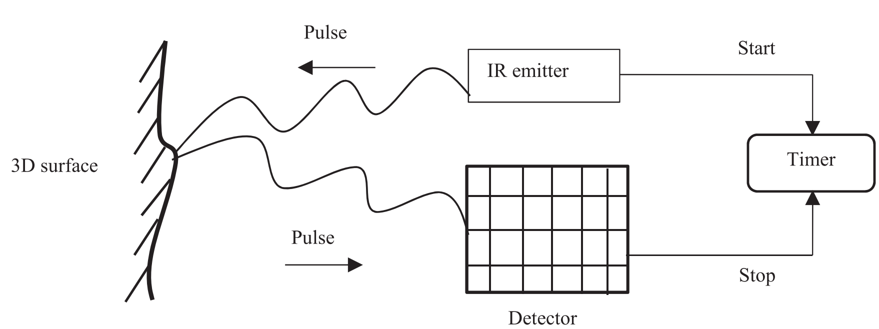

Fig. 1. The principles of 3D depth sensing.