Heart Rate Monitoring of Livestock

Subjects: Others
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For all homoeothermic living organisms, heart rate (HR) is a core variable to control the metabolic energy production in the body, which is crucial to realize essential bodily functions. Consequently, HR monitoring is becoming increasingly important in research of farm animals, not only for production efficiency, but also for animal welfare. Real-time HR monitoring for humans has become feasible though there are still shortcomings for continuously accurate measuring. This paper is an effort to estimate whether it is realistic to get a continuous HR sensor for livestock that can be used for long term monitoring. The review provides the reported techniques to monitor HR of living organisms by emphasizing their principles, advantages, and drawbacks. Various properties and capabilities of these techniques are compared to check the potential to transfer the mostly adequate sensor technology of humans to livestock in term of application. Based upon this review, we conclude that the photoplethysmographic (PPG) technique seems feasible for implementation in livestock. Therefore, we present the contributions to overcome challenges to evolve to better solutions. Our study indicates that it is realistic today to develop a PPG sensor able to be integrated into an ear tag for mid-sized and larger farm animals for continuously and accurately monitoring their HRs.

Keywords: livestock ; hear rate monitoring ; photoplethysmography (PPG) ; electrocardiography (ECG) ; photoplethysmographic imaging (PPGI) ; precision livestock farming (PLF)

1. Introduction

The world needs livestock products to feed all people, and the total meat production was over 342.4 million tons in 2018 [1]. The Food and Agriculture Organization of the United Nations (FAO) estimates that the worldwide meat consumption may increase to 73% by 2050 [2], thus the food production, animal industry in particular, must become more sustainable. Currently, precision livestock farming (PLF) is regarded as the heart of the biological engineering endeavor towards sustainability in food production, using image and sound analysis, sensors, information technology, and decision-making to monitor, model, and manage animal production, reproduction, health, welfare, and environmental impact. Europe is considered the birthplace of PLF research, and it still continues strongly with over three decades of research and innovation through at least 4 EU-funded (EU-PLF, BioBusiness, AllSmartPigs, BrightAnimal) and many other national projects[3]. Current agricultural research agendas in the EU[4]and US [5]have evidenced that the importance of PLF is growing worldwide. Faced with the large worldwide demand for animal products, the question becomes: how many of these animals have a life worth living? This high number of animals is an opportunity to create sensors and hardware that can be very cheap per unit so they change the efficiency of the livestock sector and the animal welfare as described in many papers on PLF.

All humans and homoeothermic animals generate metabolic energy to live and to reproduce. For over 95% of their life, most of these living organisms generate their energy in the aerobic mode, by breathing air to lungs and by heart beats transporting the oxygen rich blood to the cells to produce metabolic energy. For homoeothermic living organisms, the heart rate (HR) is a crucial variable to control the metabolic energy production in the body by controlling the components in the metabolic energy balance. This includes the basal metabolism which refers to the minimum energy needed to keep all organs functioning in an extremely quiet state and thus to stay alive, the thermal component to control body temperature, the physical component, as well as the mental component, which is a key component in transferring feed energy efficiently into production and to prevent depression of the immune system due to stress. The less efficiently the metabolic energy is used in the body, the more feed energy will be wasted in manure, emissions, stress systems, etc. Therefore, HR is becoming increasingly important in research of farm animals, and so far it remains a challenge to monitor HR accurately and continuously by a reliable, affordable sensor on the animal or with a remote sensing technique. Current HR monitors for animals, such as implantable transmitters and externally-mounted equipment, are mainly used in research settings with the intentions of analyzing physiological responses, diseases, psychological and environmental stress, or individual characteristics, for instance the temperament and its coping strategies. They are however inconvenient and inappropriate for long-term continuous monitoring. In recent years, HR monitoring for humans has become feasible though there are still drawbacks in continuous and accurate measurement. In this paper, we present a comparative review of current techniques to measure HR on living organisms, with focus on their advantages and drawbacks, and discuss the potential to transfer some of the techniques that have been successfully applied in humans to livestock.

2. Physiological Effects

All HR monitoring methods, presented in this review, are aimed for real-time detection of HR. We focus on HR defined as the number of cardiac beats at a given moment, which is usually expressed in beats per minute (bpm). According to the principles of different techniques, acquisition of HR signals relies on specific physiological effects. Figure 1 provides an overview of different categories of physiological effects, and how they are linked to the HR, as well as the measuring techniques. Typically, such effects are comprised of bioelectrical effects, mechanical effects, and thermal effects[6].

Bioelectrical effects: Electrical excitation of the heart causes dynamic electromagnetic fields on the body surface that can be measured by electrocardiography (ECG), such as wet and dry electrodes, and capacitively coupled ECG (CCECG).

Mechanical effects: Blood travelling through the vascular system causes organ motion and deformation, as well as blood volume variation. These phenomena are mechanical operations and can be subcategorized into three groups as follows.

(1) Body surface displacement: At every heartbeat, the pulse wave travelling through the body produces subtle changes in displacements and vibrations of the body surface. Several sensor techniques rely on these effects, such as ballistocardiography (BCG)/seismocardiography (SCG), Doppler radar and lasers (optical vibrocardiography), as well as video-based motion.

(2) Superficial perfusion: The ejection of blood from the heart into the vascular tree causes blood volume changes in the microvascular bed of the tissue. Since blood absorbs light more than the surrounding tissues[7], these microscopic changes in the optical properties of the body surface can be measured by photoplethysmography (PPG) and photoplethysmographic imaging (PPGI) methods.

(3) Intrathoracic dynamics: The impedance distribution within the human body varies with physiological activity. During the cardiac cycle, the motion of the cardiac wall and aorta, as well as the opening and closing of heart valves, causes variations of impedance distribution. Cardiac pulsation also modulates tissue impedance by blood perfusion[8]. The local changes in impedance caused by the cardiac cycle inside the thorax do not project actively onto the body surface. However, the electrical/magnetic impedance measurements can be used to detect the variations.

Thermal effects: The flow of blood through the vicinity of major superficial vessels leads to changes in skin temperature that can be detected using thermal imaging techniques.

Figure 1. Overview of physiological effects and respective techniques for heart rate (HR) measurement.

3. Future work

Knowing that this year again over 65 billion animals will be slaughtered for food production, it would be a serious advantage if we could monitor animal health and welfare in a continuous and automated way. This needs accurate, reliable, and affordable sensors. As we have seen so far, there are currently a significant number of different sensor technologies for HR monitoring under investigation, and this paper has critically reviewed the progress[9]. Eight promising measuring technologies used on human beings were investigated, and the principles and the theories of HR measurement were discussed. Moreover, advantages and drawbacks with further elaboration were emphasized by comparing various properties and capabilities related to the application to livestock. By analyzing the challenges to design such a sensor, we conclude that it is realistic today to develop a continuous PPG sensor for HR monitoring that can be integrated into an ear tag for mid-sized and larger animals, such as cow, pig, sheep, goat, etc. Research endeavors of HR online monitoring on pigs would be a game changing milestone in the livestock sector. Moreover, the monitoring could become applicable for small species such as poultry when more miniaturized hardware is realized in a predictable future. We hope that this study will inspire researchers and technology companies to invest in such technology and develop prototypes of the ear tag as well as to produce the sensors in very high numbers. It will allow monitoring of animal welfare based upon physiological variables and to follow the metabolic energy balance of animals day and night in an automated way. This energy balance directly links to production results and creates disruptive innovation for animal health monitoring.

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