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The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material. Welcome to our online course on the Anatomy and Physiology of Farm Animals. This comprehensive program delves deep into the intricate workings of the anatomical structures and physiological processes that govern the health, growth, and productivity of farm animals.Throughout this course, you will develop a comprehensive understanding of farm animal anatomy, including the skeletal system, muscular system, cardiovascular system, respiratory system, digestive system, reproductive system, and more. You will learn to identify and describe the different anatomical features and their functions, enabling you to recognize and appreciate the uniqueness of various farm animal species.Building upon your anatomical knowledge, you will explore the fascinating realm of farm animal physiology. By delving into topics such as digestion, respiration, circulation, reproduction, and metabolism, you will gain insights into the fundamental physiological processes that govern farm animal health and well-being. You will uncover the interplay between anatomical structures and physiological functions, enabling you to interpret physiological changes and assess animal health with greater precision.Practical application is a key aspect of this course. You will learn to apply your anatomical and physiological knowledge in animal health management. By recognizing signs of disease, interpreting physiological deviations, and implementing appropriate preventive measures and treatments, you will be equipped to ensure optimal health outcomes for farm animals.Nutrition plays a vital role in farm animal health and productivity. In this course, you will explore the intricate relationship between farm animal physiology and nutrition. You will learn to formulate balanced diets based on specific nutrient requirements, understand nutrient digestion and absorption processes, and evaluate the impact of nutritional factors on growth, reproduction, and overall animal performance.Moreover, this course will empower you to make informed decisions in farm management practices. By understanding the influence of anatomical and physiological factors on housing design, ventilation systems, handling facilities, biosecurity protocols, and breeding programs, you will be able to optimize animal welfare, enhance productivity, and contribute to the success of farm operations.Our course provides a rich learning experience with engaging lectures, interactive modules, quizzes, and practical examples. Whether you are a farmer, veterinary professional, animal researcher, or simply interested in understanding the remarkable complexities of farm animal anatomy and physiology, this course is designed to cater to your needs.Embark on this educational journey and unlock a world of knowledge that will empower you in the realm of farm animal care, management, and research. Enroll now and take the first step toward mastering the fascinating domain of farm animal anatomy and physiology. Page 2Welcome to our online course on the Anatomy and Physiology of Farm Animals. This comprehensive program delves deep into the intricate workings of the anatomical structures and physiological processes that govern the health, growth, and productivity of farm animals.Throughout this course, you will develop a comprehensive understanding of farm animal anatomy, including the skeletal system, muscular system, cardiovascular system, respiratory system, digestive system, reproductive system, and more. 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Inclusion in an NLM database does not imply endorsement of, or agreement with, the contents by NLM or the National Institutes of Health. Learn more: PMC Disclaimer | PMC Copyright Notice . 2020 Aug 26;10(9):1512. doi: 10.3390/ani10091512Strategy for the protection and welfare of farm animals, and the sustainable animal production is dependent on the thorough understanding of the adaptation physiology. Real-time, continuous, and precise measurement of the multi-dimensions and complex intricacies of adaptive capacity of farm animals namely the mental, behavioral, and physiological states are possible only through the sensor-based approaches. This paper critically reviews the latest sensor technologies as assessment tools for the adaptation physiology of farm animals and explores their advantages over traditional measurement methods. Digital innovation, diagnostics, genetic testing, biosensors, and wearable animal devices are important tools that enable the development of decision support farming platforms and provides the path for predicting diseases in livestock. Sensor fusion data from a multitude of biochemical, emotional, and physiological functions of the farm animals not only helps to identify the most productive animal but also allows farmers to predict which individual animal may have greater resilience to common diseases. Insights into the cost of adoption of sensor technologies on farms including computing capacity, human resources in training, and the sensor hardware are being discussed.Despite recent scientific advancements, there is a gap in the use of technology to measure signals, behaviors, and processes of adaptation physiology of farm animals. Sensors present exciting opportunities for sustained, real-time, non-intrusive measurement of farm animal behavioral, mental, and physiological parameters with the integration of nanotechnology and instrumentation. This paper critically reviews the sensing technology and sensor data-based models used to explore biological systems such as animal behavior, energy metabolism, epidemiology, immunity, health, and animal reproduction. The use of sensor technology to assess physiological parameters can provide tremendous benefits and tools to overcome and minimize production losses while making positive contributions to animal welfare. Of course, sensor technology is not free from challenges; these devices are at times highly sensitive and prone to damage from dirt, dust, sunlight, color, fur, feathers, and environmental forces. Rural farmers unfamiliar with the technologies must be convinced and taught to use sensor-based technologies in farming and livestock management. While there is no doubt that demand will grow for non-invasive sensor-based technologies that require minimum contact with animals and can provide remote access to data, their true success lies in the acceptance of these technologies by the livestock industry.Keywords: adaptation physiology, sensors, precision livestock farming, wearable animal sensors, animal biometrics, animal cognitionAdaptation physiology or acclimatization is defined as an individual organisms biological response to environmental stress. Adaptation can be broadly classified into genetic (generational or long-term) and non-genetic (phenotypic or short-term) responses to a stressor [1]. Under chronic stress experienced over several generations, the animals acclimatization response becomes genetically fixed, making the animal adapted to its environment.The physiological and behavioral processes adopted by farm animals in response to environmental changes are not only crucial for their survival, but frequently also affect the profitability and productivity of livestock systems. Farm animals is a term used to describe a group of animals housed together in a barn or an animal husbandry. These animals are typically raised for the commercial utility of produce such as dairy, leather, meat, eggs, wool, etc. Livestock must face the multipronged challenge of physical, chemical, nutritional, and thermal stress [2]. Stressors or the challenges are several and may or may not have a direct influence on the animal performance. Factors that act as stressors and thereby influence livestock productivity include age, breed, geographical location, water availability, nutrient availability, photoperiod, environmental conditions, interactions with humans, and management practices [3]. Stressors trigger physiological mechanisms that allow animals to maintain physical equilibrium and homeostasis [4]. Farm animals respond to environmental stressors by altering physiological parameters like rectal temperature and respiration rate, drooling, panting, sweating, heart rate variability, and decreased feed intake [5].In order to determine which technological advances can improve both livestock productivity and animal welfare, it is crucial to measure the physiological parameters or adaptation physiology of farm animals. This emphasis on measurement is driving the development of specific sensor-based technologies that can monitor these physiological changes. Quantitation of stressors in farm animals often involves invasive techniques that require animal restraint or close contact between animals and humans, which can increase the animals stress levels [6]. These techniques are also time-consuming, subjective, and labor-intensive, making them unsuitable for a rational evaluation of stress in farm animals [7].Smart systems such as sensor technology play an important economic role in this area [8], offering considerable long-term financial advantages. The economic welfare modelling framework is a powerful tool for reinforcing policy decision-making in appraising alternate scenarios for animal diseases. Sensing platforms and tools are helpful in disease prevention and control strategies, giving them an important role in advancing public health policy [9].The economic impact of livestock disease is wide-reaching and multifaceteddirect costs of a disease include production losses in addition to the costs of treatment and preventative care. Furthermore, sick animals have a lower economic value. Common treatment practices have a critical financial impact on the farmers and can impact long-term herd structure as a consequence of the outbreak. In terms of production parameters, as estimated in a previous study [10], milk production in cattle with Lumpy skin disease is reduced by up to 65% during the acute phase and 35% upon the cattle recover from the disease, revealing the diseases protracted and marked negative impacts. These economic losses can be largely avoided with the implementation and integration of remote sensor technology or automated technologies in agricultural and livestock practices.Livestock welfare in farms remains a major concern; in order to protect livestock from poor welfare situations, it is imperative to interpret their behavior as well as their cognitive needs and capacities [11]. The recent COVID-19 pandemic particularly demands minimal contact with farm animals, and the current situation is only expected to increase the demand for the use of sensor-based technologies and processes that can protect the health of both farm personnel and livestock. Driven by an interest in animal welfare, research has gathered speed in the development of new sensing approaches and biosensing methods for non-invasive assessment of physiological stress response in animals [12]. For instance, remote sensing-based technologies and image processing are being widely researched to aid in the detection of animal health problems and stress levels [13]. With respect to assessing adaptation physiology in farm animals, sensor technology is considered to be pivotal as it can assist in acquiring time series of behavioral and physiological data. These sensors include biosensors and wearable technologies, which are based on advanced statistical and computer science methods that can be used to predict and assess adaptive responses and resilience in farm animals.Automated remote monitoring and detection of animal welfare indicating parameters using real-time analysis of sounds, images, videos, and data tracking for body and body weight conditions may improve biological metrics in livestock [14]. Remote sensor devices such as microphones, cameras, accelerometers, and thermometers can provide credible information when their data is merged with individual animal identification and referenced observations and incorporated in algorithms [15].Sensors in animal health management can help facilitate timely diagnosis and follow-up treatment for sick farm animals [16]. The use of sensor-based technologies enables early identification of disease symptoms and subsequent disease management, minimizing the economic losses associated with infection spread in the herd. These are vital for the survival of any business [17]. Moreover, these sensors can be linked to cell phones and other mobile devices so that data can be analyzed and recorded automatically and remotely. The aim of this paper is to critically review sensor technologies as assessment tools for the adaptation physiology of farm animals and explore their advantages over traditional measurement methods. Furthermore, the review aims to highlight the challenges involved in the deployment of sensing technologies, especially regarding their applicability in farm settings.The literature cited in this paper were collected using the Google scholar and the Web of Science tools. To showcase the leading-edge research in this field and to ensure the recency and narrow down the search, the author restricted the search to papers published only in the past 5 years. Keywords used were, animal sensors; livestock wearables; animal physiology and sensors; farm animal sensing technology; facial recognition and animals; precision livestock farming and sensors; adaptation physiology measurement. Both the Boolean and individual searches were conducted as part of this study. Dairy cattle, pigs/swine, chicken and poultry birds, and sheep were primarily focused as part of the consideration of the common livestock. The number of papers cited in this review is 143, with 36 that were published before 2015. The papers published before 2015 were included as the information on the sensing technologies for farm animals were scant, and to emphasize the content on the need for sensors in the adaptation physiology of animals.Precision Livestock Farming (PLF) is a tool for active livestock management with a focus on improving animal welfare and health and enhancing the economic, social, and environmental sustainability of livestock farming. The importance of well-managed animal welfare is not limited to ethical viewpoints; it is also crucial to realize a more efficient process of producing animal products. The metabolic energy balance in a homeothermic living organism includes several different components: basal metabolism, the thermal component, the physical component related to movement or delivering power, the production term (meat, milk, eggs), and the mental component. When applying stress-monitoring techniques originally developed for humans, animal frustration can be monitored in real time. This indicates that real-time animal welfare monitoring based on physiological signals is, in fact, a realistic pathway (Figure 1). Parameters such as temperature, heart rate, peripheral vasodilation, respiratory rate, sweat production, basal and energetic metabolisms, feed intake, diseased conditions, and sound all respond to stressful conditions [16]. Farmers can more quickly detect livestock health problems by evaluating their animals physiological responses via measurements of the temperature in body parts, respiration rate, heart rate variability, body weight, feed, emotions, non-invasive biomarkers and water intake, activity, and movement. Wearable sensors and novel biomarkers for transforming the adaptation physiology of farm animals.An animals ability to maintain homeothermy indicates that the animal is better adapted to the climatic variations of its environment. Tolerance of higher temperatures, for instance, is identified by animals capability to dissipate excess body heat and keep their standard body temperature within the limits of homeothermy [3]. For this reason, monitoring changes in animals body temperature can help determine their physiological stress responses to their environment. As an example, it has been shown that broilers in high and medium-density housing have higher body, wing, head, neck, and skin temperatures than those housed in lower densities [18]. These results can be used to estimate potential stressors for farm animals. The cloacal temperature of a bird is typically measured by inserting digital thermometer into the birds cloaca [19]. This invasive procedure requires that the animal be manually restrained and handled [20], which would lead to stress-induced hyperthermia. Shortcomings of these conventional temperature measurement methods make them not practical for regular heat stress monitoring [21]. For an accurate, reliable, and continuous measurement of body temperature, farmers can deploy biologgers such as telemetry devices or the radio-telemetry data loggers by integrating with halters or collar/leg sensors for larger animals such as cows, pigs, and horses. Body temperature measurement with thermal infrared sensors is considered safer and more efficient than conventional techniques for livestock including broilers and poultry birds [22]. Infrared thermometry is non-obstructive in nature, which makes it suitable for assessing animal stress. Furthermore, the use of digital thermography (thermographic camera) makes it possible to detect even minimal temperature variations [23].Body temperature can be efficiently and accurately determined with non-invasive infrared technique [24]. In broilers, for instance, the temperature of the region around the eye is considered to be indicative of the total body temperature because of lack of feather insulation around the eye region [25]. All objects produce radiant heat in the infrared region of the electromagnetic spectrum. As bodies have temperatures above absolute zero, they emit radiation that forms an electromagnetic spectrum that can be absorbed by other surrounding bodies [26]. Thermal infrared (TIR) sensors generate these images (thermograms) by capturing the infrared radiation emitted by objects. The information generated by these images is then determined by algorithms to detect the temperature change. Thermographic images may point to alterations in blood flow resulting from increased body temperature due to stressful environmental conditions. These changes can be related to blood flow and heat transfer in animals [26]. The temperature of the eye area measured by TIR sensors has been shown to correlate significantly to changes in core body temperature [6]. Temperature measurements from different body parts provide information about animal health and allow for timely decision-making for livestock welfare (e.g., isolating animals with higher body temperature or managing the internal temperatures of animal housing units).Respiratory rate (RR) is one of the variables used to assess the physiological adaptability of animals [27]. In response to alterations in environment, such as transport of cattle by road, animals respiratory rates increase to maintain homeothermy. Evaporation is a key regulatory response for animal body temperature [27]. RR has been shown to be affected by high milk yield, pregnancy, forced activity, excitement, and pathological conditions [28]. An increased RR is a significant stress indicator, particularly in thermally stressed animals [29]. Thermal stress results in a reduction in milk production, animal fertility, and general welfare [30], so early detection of alterations in RR can help farmers take specific measures to prevent animals from stress, thereby avoiding production losses while addressing animal welfare.Visually counting flank movements is the most common technique for assessing respiratory rates in cattle [31]. However, this is a labor-intensive and time consuming method, and the continuous assessment of RR in long-term studies can be difficult and physically demanding, eventually resulting in miscounts [28]. Misinterpretation of results can also occur from nonspecific flank movements that do not arise from respiration [32]. Moreover, the continuous presence of a person can cause the animals stress and influence their respiratory rates, misleading the measurements. Therefore, RR sensors were introduced to assess RR without causing stress to animals. The initial respiratory sensors tested on animals were designed for human application. These devices consisted of a belt attached around the animals chest (similar to a holter) that measured thoracic and abdominal movements. Another system to monitor respiratory rate is a laser distance sensor during milking [33]. Respiratory sensors have been reported to accurately monitor respiratory rates in cattle [28].Sweating is a physiological mechanism to regulate body surface temperature. Sweat is generated by the sweat glands in the rainy and dry seasons. The maximum mean values are reported in the mornings and afternoons during dry season, which aids heat dissipation by evaporation; maximum sweating capacity is achieved under high temperatures and low humidity, when the sweat glands are stimulated by increased blood volume to the epidermis [27]. The composition of sweat could be helpful in determining the internal physiological changes or disturbances in an animal. Sweat glands on pigs are considered non-functional as they are not stimulated by heat stress. Imperceptible perspiration in the form of water vapor may have biomarkers such as miRNA (micro Ribonucleic acid) or micro-concentrations of cortisol or hormones. Validated biomarkers from the sweat of dairy cows, pigs, and other farm animals are not yet available and would open up new avenues of non-invasive sensing.Immunosensors can target biological fluids like saliva and sweat instead of blood, making these sensors less stressful and invasive for animals. Immunosensors provide highly sensitive and specific assessment of hormones like cortisol and lactate in animal biological fluids using label-free electrochemical and chronoamperometric methods. For instance, a mobile, handheld potentiostat integrated with Bluetooth communication and power source can be used for point-of-care applications. Bioengineers have designed sensors with a sandwich-like structure that can contain the sensing mechanisms, secure the biosensor to skin, and use capillary action to draw sweat or other fluids towards the sensing mechanism [34]. Overall, the immunosensor showed remarkable specificity and sensitivity in addition to its non-invasive and point-of-care capabilities, making the diagnostic tool a versatile sweat-sensing platform. Skin-deployable microfluidic platform provides a significant capability for on-the-go real-time collection and monitoring of sweat biomarkers. Resettable epifluidic sweat patches can be placed on the skin of pigs or the sweat-secreting glands of dairy cows to collect and analyze sweat composition as a visual indicating sensor [35].The cardiovascular system is regulated by the autonomic nervous system and controls the physiological systems impacted by stress [36]. The vagal element of the autonomic nervous system regulates heart rate during stress in farm animals [37]. Heart rate increases when animals are subjected to heat above their tolerance limits [27], so changes in heart rate can indicate physiological and psychological stress, disease, and coping strategies in animals [36]. Conventionally, electrocardiogram (ECG) has been used to detect heart rate variability. Despite providing good signal quality, its long-term use for continuous heart rate monitoring is inconvenient as the wet electrodes must be in close contact with skin. Additional limitations include restriction of movement, allergic reactions, skin irritation, and signal degradation due to continuous contact with wet electrodes [38]. Although dry electrodes and non-contact electrodes are available, they require the use of a chest band to keep the electrodes in place. This can be inconvenient, especially for use in animals.Photoplethysmography (PPG) is a non-invasive and cost-effective method for the detection of blood volume alteration. PPG is an optical measurement that uses infrared lights to detect changes in blood volume in the microvascular bed of tissue [39]. This contrasts with the electrocardiogram (ECG), which measures heart rate by placing electrodes on the chest of the target animal. Doppler radar-based sensing technologies include: ultra-wide band radar [40] and near-field coherent sensing. Machine-knitted washable sensor platform based on textile has been developed and validated for precise epidermal arterial pulse waves and respiratory signals simultaneously [41]. However, this tool has been demonstrated only for biomedical human applications and would need further modifications for adoption in livestock sector. Researchers have experimented with non-invasive wearable sensing systems composed of photoplethysmogram and electrocardiogram (ECG) for continuous monitoring of vital signs in companion animals [42], but these systems have yet to be fully explored in the livestock sector. Body size and the shape of animals, chewing habits of pigs, licking habits of cows, body weight, dust and the harsh barn and farm environments, and discomfort to animals are some of the factors that make the adoption of HR and RR wearable sensing systems challenging for animal farming (Table 1). Commercially available textile-based wearable sensors, such as Hexoskin, Biometric Shirt, Dinbeat UNOs multiparameter harness-sensing tools developed for humans and pet animals for measuring heart rate variability, respiratory rate, and maximal oxygen consumption would find new avenues of application in livestock farming.Outcomes of using sensor technology for assessing adaptation physiology of farm animals.Farm AnimalPhysiological Parameter/Biological Sample InvolvedSensing TechnologyOutcomeReferenceCattleRutting span behavior and back postureVideo and Photo sensorsHealth and reproductive assessment[6]CattleEye orbital area temperatureInfrared thermographyNon-invasive and automated detection of bovine respiratory disease onset[49]CattleGrazing behaviorMotion sensorsAccurate classification of grazing and rumination[50]CattleFeeding behavior differences associated with lamenessNeck-mounted mobile sensorDetection of differences in feeding behavior that are associated with lameness[51]CattleGrazing, standing, and ruminatingCollar, halter, and ear tag sensorsClassification accuracy achieved by different sensor placement[52]CattleFeeding, ruminating, and other activityRumiWatch halter and AccelerometerCollar mounted accelerometer accurate than RumiWatch noseband sensor[44]CattleRespiratory rateDifferential pressure sensorSuitability of the device as a respiratory rate sensor[28]CattleDrinking and water intake behavior RFID, water flow meter, and accelerometer sensorsReliability of a combined approach recording several behavioral measures[17]Cattle and sheep Eye and muzzle temperatureDigital infrared thermal imagingAlternatives to using vaginal or rectal temperature[26]Cows, goat, and sheepBody accelerationAccelerometersPotential for estimating energy expenditure in grazing farm animals[53]CowsGrazing and ruminating timesTri-axial accelerometersAn alternative to visual observations[47]CowsRuminating and eating behaviorNoseband pressure sensorAn alternative to direct observation[54]PigsGait and locomotion Pressure matObjective way to analyze and quantify gait[55]PigsDrinking behaviorRFID systemAccuracy in assessing drinking behavior of individual pigs[56]PigsConformation and postureAccelerometerCharacterization of posture changes[57]BroilerBody (rectal) temperatures as well as head, neck, wing, body, and shank surface temperatures Infrared cameraAssociation between body surface body temperature and stocking density rate in broilers[18]BroilerBroiler head and flock temperatureInfrared thermal cameraAchieving a higher identification accuracy[58]HorsesWalking and trottingPressure sensorSimultaneous quantification of differences in hoof contact area and limb loading[59]HorsesFacial expressionsEquiFACSNostril dilator showed a 92% correct classification in duration in pain/no pain[60]CattleBlood samplesBiosensorBovine Herpes Virus[61]CowsBlood and serumMicrofluidics based biosensorKetosis, Beta hydroxybutyrate[62]ChickenHen movement and activityThree-axis accelerometersImpact of Northern Fowl Mite on the welfare[63]Chickens, Cattle and PigsScreaming in pigs, tail biting in pigs, distress calls and alarm calls in chicks, cough sounds in cattleMicrophones, audio recording sensorsMonitoring aggressive interactions, context-based cattle calls labelling, classification of distress vocalizations[64]Studies on cattle behavior have indicated that illness causes animals to spend less time feeding and more time resting [43]. Feeding and ruminating behavior in cattle provides significant information about their productivity, health, and welfare [44]. Changes in ruminating and feeding timing of cows are indicative of an underlying alteration in their welfare and comfort [45]. It has also been reported that cows diagnosed with metritis spent less time ruminating than their healthy counterparts during the pre- and post-calving periods [46]. As alterations in feeding behavior could also be indicative of illness in animals, several sensing methods have been employed to measure feeding behavior.Wearable accelerometers have been evaluated as a tool for measuring cow behavior [44]. HOBO accelerometers, which are attached to the jaws of cows, can record the time each animal spends grazing and ruminating [47]. Neck-mounted accelerometers, based on either a multi-class support vector machine (SVM) or a decision-tree algorithm [48], have been tested for the evaluation of bovine ingestive behaviors. Neck-mounted triaxial accelerometers have been validated to assess drinking events, along with the algorithm that can distinguish feeding from drinking from a water trough [17].A noseband sensor called RumiWatch was developed to monitor eating and ruminating activities in dairy cows [54]. Animals deal with stressors like social changes, environmental changes, satiety, and infection by changing their behavior. Monitoring this behavior on a large scale becomes impractical because of the manpower required for continuous monitoring of a large groups of animals. Wearable sensor technologies make it possible to simultaneously measure real-time physiological parameters in a herd on a large scale when coordinated with appropriate interpretations of outputs [44]. Thus, wearable sensor technologies have an edge over traditional herd-based approaches as the data from wearable sensors can be analyzed immediately, enabling quick reaction times.Water flow sensors can monitor group drinking behavior in pigs and are considered more precise than experienced observers [65]. The issues and limitations of water sensors includes variable water flow rates, installing sensors in existing plumbing, short drinking bouts, unspecified drinking behavior when a snout is in an outlet, and wastage of water [66].The requirements of an RFID system include an RFID transponder or ear tag and an RFID antenna located at the drinking sink or feeding unit. RFID systems (at drinking and feeding areas) have been used to monitor the events and duration of feeding and drinking behavior of individual pigs [56]. High-frequency (HF), low-frequency (LF), and ultra-high-frequency (UHF) are the frequency ranges typically used for RFID tags. These systems can have significant differences in read ranges as well as varying responses to the influence of materials, especially water and metal [67].A combination of stationary RFID, accelerometer, and water flow meter sensors has been used to measure beef cattle drinking behavior and herd water consumption in grazing systems. This approach was determined to be reliable in recording behavioral measures, such as the frequency, duration, and number of visits to the water point per animal as well as the duration of drinking events per animal visit [17].Garrido-Izard and colleagues have monitored a combination of ear skin temperature sensors, body weight measurement, and the amount of feed consumed and the duration per animal in order to identify animal behavior changes based on the integration of their intake patterns and the thermal data. Animals with higher-temperature measurements showed less thermal variability, and vice versa. The study also showed that animals with less alteration in feed intake during breeding have higher efficiencies [68].Posture and lying behaviors can be automatically quantified to increase the productivity and welfare of domesticated animals because changes in posture and activity indicate health and welfare issues [69]. For instance, changes in behaviors like walking, standing, and lying can indicate sickness in cows [70]. Monitoring postural changes is important in assessing calf or swine wellness or painful conditions. Numerous studies have studied postural behavior differences in cows who receive painful stimuli [71].Accelerometers, electromechanical devices that measure acceleration forces, have proven very accurate in monitoring activity and movement in the animals. The use of accelerometers has recently been widely used to quantify or evaluate animal behavior [8], grazing behavior in cattle [72], lying behavior in sows and lameness in cows [73]. The accelerometers smaller size and the versatility of the data generated make these technologies effective for examining animal behavior in farm settings [74]. Accelerometers are considered to be most efficient in assessing activity in pigs. Increased activity is indicative of stress in pigs, while reduced activity has been associated with disease [75] or changes in the environmental conditions of a barn [76].Analysis of data from two-dimensional accelerometers has revealed that the percentage of time spent standing increases in calves after castration [77]. In another study, it was shown that five days after castration, calves preferred more time in lying down and less time in walking activity [78]. The differences between these two studies could possibly stem from the duration of monitoring and a considerable time-dependent change in behavior.The current animal welfare determining factors are mostly conducted at a single point in time (i.e., providing water and food and treating diseases or illnesses as they arise), these assessments are often considered insufficient. Pattison and colleagues have designed a methodology for the continuous monitoring of interaction between animals fitted with proximity sensors attached to neck collars. The resulting data and levels of serum cortisol concentrations are expected to provide a visual map of the social structures of each group. This will allow scientists to explore the potential of proximity sensors as a welfare monitoring platform for measuring an animals freedom to express its normal behavior in natural state [79].Accelerometer sensors have been used to accurately measure active and not-active behaviors of tiestall-housed dairy cows [80] and predict the behavior of dairy cows from the signal pre-processing sensor data [81]. Lying behaviors in calves have also been analyzed after administering analgesic drugs. Lying behavior decreased in calves following the induction of experimental lameness using an amphotericin B synovitis-arthritis induction model [82]. Accelerometer sensors have also been effectively used in the regular assessment of behavioral changes in response to pain [71]. The use of two accelerometers can automatically quantify the lying behavior in free-farrowing sows; challenges of automation in the lying behavior have been addressed in both free-farrowing sows as well as sows housed in movement-restricting barn environments [73]. More recently, data from triaxial accelerometers has been used to define general behavior recognition framework in the form of a hybrid model combined with biomechanical principles and machine learning tools [83].In domestic animals, aggression between individuals is a serious stressor and cause of injuries. Research is increasingly exploring facial expressions as a non-invasive means of obtaining quantitative data on an animals emotional state. Camerlink and colleagues have demonstrated the use of video imaging in analyzing the emotional state of pigs in an event of aggression or confrontation in dyadic contest. Facial metrics can be a powerful way of measuring the aggressive intention of animals. Facial metrics after retreat and/or during the episode of aggression in pigs differed significantly from the facial features prior to and during aggression [84].Mounting behavior, observed in both female and male pigs throughout their lifetime, is mostly prominent during estrus. This behavior is manifested as follows: a pig typically places two front hoofs on the head or the body of another pig in the lying position. Mounting behavior can cause epidermal wounds, lameness, and fractures, resulting in economic losses and decreased productivity. Li and colleagues have developed a learning algorithm that detects swine mounting behavior based on the visible light images to enable timely detection and intervention [85]. This method has demonstrated high accuracy, sensitivity, and specificity. However, the sample size of the research included only four mini pigs, so the system still needs to be validated on a larger scale.Pressure mats are composed of a series of array of pressure sensing components with the measuring frequency that enables the mats to differentiate the simultaneous impact of different limbs [55]. Systems from various pressure sensor manufacturers have been able to successfully assess locomotion in healthy cows, horses, and sheep [59,86,87]. These systems were capable of assessing lameness in cows [88].Pedometers objectively measure an animals total number of steps and the total distance travelled via an algorithm that calculates the steps from the raw data [71]. While pedometers are comparatively easy to deploy and use, there is considerable variation in the number of steps traveled by each calf on different days and environmental conditions. There might be an association between the distance traveled by calves and stressful and painful procedures; one study determined that calves traveled fewer steps for four days following castration [89], while another study showed the association between stress experienced by calves and the number of steps traveled following castration.Stress influences the distance traveled by calves, though gender differences must be accounted for in such studies; it is observed that steers travel fewer steps per day than bulls [89]. Pedometers have reportedly been useful in intelligently designed experiments to investigate changes in behavior after the animals go through a painful experience. Pedometers have been demonstrated in identification of early lameness in dairy cattle, though a 15% decrease in activity was required in order to accurately detect 92% of the lame cattle [90]. Pedometers can be valuable tools for detecting and assessing musculoskeletal pain as they rely on the direct quantification of locomotion.TIR and RGB (red, green, and blue) image based sensor data has reportedly been useful in evaluating the walking posture and gait analysis of cattle through recorded videos [91]. Changes in posture while walking can indicate skeletal problems in livestock, so TIR sensors can be implemented to judge animal well-being.Various research investigations in the last decade have demonstrated the advantage of GPS telemetry devices for assessing livestock behavior when used in combination with other sensors/devices [50]. This has been used to distinguish between activities or assess energy expenditure [53]. GPS collars with activity sensors form an efficient technique for simultaneously monitoring the movements of grazing livestock and inferring animal behavior [52].RTLS have been developed to locate the position of an object anywhere inside a specific area. The design of an RTLS consists of a receiver positioned closer to the desired monitoring space, active or passive tags deployed on the target objects, and a hardware and software to receive and interpret positional data. Tags used with RTLSs are typically smaller in size and have a longer battery life than existing GPS systems [71]. RTLS technology has been investigated to assess the association between behaviors like distance travelled and duration of time spent at feed bunk with clinical illness scores. An association was also found between the distance travelled by calves and the level of lung consolidation by RTLS monitoring, which indicated that assessing movement can help evaluate the wellness status of livestock animals [92]. The associations derived from these studies strongly suggest that RTLS platform is a legitimate tool for producing quantitative measurements of cattle activity. They can be further helpful in evaluating significant changes in pain status or wellness in response to an intervention [71]. RTLS has the distinctive advantage in monitoring an animals location anywhere within the farm; therefore, it does not restrict assessment to only drinking and feeding behaviors.Vocalization process in animals happens through the active generation of sounds with organs to express distinct physiological status. Vocalization may be spontaneous or triggered by an external event [93], but their reflection of an animals inner state makes them an efficient tool for monitoring animal wellbeing, stress response, and interaction among species. Heat stress is an important environmental stressor affecting poultry production and welfare, specifically growth, egg production, and impaired poultry health. Changes in behavioral and physiological responses due to heat stress might manifest as distinct vocalizations such as gakel, squawk, and alarm calls [94]. Du et al. [95] have demonstrated a correlation between vocalization in egg-laying hens and the temperature humidity index (THI). The authors specifically concentrated on the quantitative measurement of frustration-related vocalizations (squawk, gakel, and alarm calls) and concluded that specific vocalizations such as poultry squawk and alarm calls are significantly correlated with THI. Furthermore, because of thermal inertia in a henhouse, which is a potential early warning detection tool to avoid lags in monitoring the ambient environment [95].Acoustic monitoring (or vocalization measurement) is a non-invasive and an accurate method of measuring biological responses in livestock; it can be used as an indicator of animal well-being in precision livestock farming, which focusses on addressing animal welfare concerns by facilitating the automated, continuous monitoring of livestock and enabling timely and appropriate interventions [96].Changes in sound pressure can be transformed into electrical signals, which are then received by audio equipment and processed as digital signals using signal processing techniques through standard computers. The definite evaluation of audio data is typically based on spectral analysis, where acoustic signals automatically separate into bands of appropriate frequencies. This is then followed by subsequent processing [57].Vocalization in pigs can be used for several different purposes, such as identification of sex, age (Figure 2), and stress levels through a decision-tree to classify distress condition in pigs with an accuracy of 81.92% using the machine-learning technique [97]. In turkey farming, cannibalism is identified as a major problem resulting in animal stress and loss of productivity. Certain behavioral changes have been identified in animals prior to cannibalistic behavior, including pecking activity. Acoustic data analysis in combination with machine learning techniques has been tested as a tool to continuously monitor pecking activity for potential use on turkey farms [98]. Bioacoustics applications in Precision Livestock Farming. Physiological parameters measurement through on-line sound analysis as a basis for health and welfare monitoring in pigs, cows, and poultry.Currently, the activity-based sensors used in the animal farming industry are optical or animal-attached sensors. While sensors attached directly to animals are difficult to manage, the sensitivity of optical sensors decreases in the presence of dirt or changes in the ambient lighting conditions. In cases where spatial distribution of the animal movement or the activity is irrelevant, Manteuffel [99] has demonstrated that simple stationary sensors to measure animal activity can be beneficial due to easy signal interpretation requiring little computational power. Soon, doppler-based radar sensors will find new avenues in the dairy cow guided gate system to measure the cows heart rate and breathing pattern before entering the rotor milking machines.Currently, there are no tangible ways to measure reproductive performance, especially with respect to uterine contractility and suitable diagnostic tests for the onset of labor in sows. Unsuitable uterine contractility can result in embryonic loss, miscarriages, ectopic pregnancies, and abnormalities of puerperium in sow [100]. One potential diagnostic tool is the measurement of bioelectric signals from swine uterus using electromyography and magnetomyography. To overcome the drawbacks in the crude uterine contraction information obtained through tocodynamometer or with an intrauterine pressure catheter, a 3D uterine electrical activation pattern measurement system has been demonstrated using electro-myometrial imaging (EMMI) [101].EMMI surface electrical recording has been shown to be a safe, accurate, non-invasive, and feasible method to measure uterine contractions in sheep. Electrophysiological studies using electromyogram sensing systems by Domino et al. [102] demonstrated that myoelectric activity in various regions of sows reproductive tract can be used as a reliable measurement to assess pregnancy health as the contractility regulation was superiorly observed in the uterine horn tip. A tocodynamometer provides an indirect measure of the intrauterine pressure and is the current standard method to determine labor. A combination of electromyography and magnetomyography sensing platforms is expected to replace tocodynamometers in the near future. In a preliminary study, Brassel et al. [103] have evaluated the performance of automated health monitoring integrated with an accelerometer-based estrus detection system (ODS) for dairy cows on pasture. Although the ODS was able to flag health problems faster than human farmers, the use of ODS generated an extremely high rate of false positives [103].Absence of disease is an essential component of overall animal health and well-being. Disease, lameness, and limb disorders pose a significant challenge to the dairy industry today. Along with dairy cows, sheep flocks around the farm also face the most persistent and common health challenge of lameness. Lameness results in decreased milk production and is an important motivator for early culling of animals. Lameness is painful, and animals suffering from pain frequently diverge from their normal behavior by changing activity, gait, appetite, posture, and appearance [104].The amplitude and frequency of ruminal contractions in cattle are impacted by metabolic diseases (such as ruminal acidosis and hypocalcemia) and other diseases that cause fever or pain. Wireless intraruminal bolus sensors inserted through the esophagus have been developed to monitor the temperature and pH values of the rumen and reticulum [105]. The assessment process has been simplified by the advent of commercially available boluses for the measurement of reticuloruminal pH, where the boluses regularly transmit pH information wirelessly to a central processing region.Wireless and indwelling sensors for rumen facilitates high-resolution pH measurements in determining the kinetic behavior and identification of rumen acidosis. The data from this analysis can assess the physiological status of the rumen and, therefore, the whole animal. While indwelling rumen pH sensors allow for continuous measurement of pH in individ

of animal health and epidemiological data from the sensors and devices [14] to producers, inspection, and government agencies. Hence, internet connection in livestock farms becomes necessary. The limited internet connectivity and the data moving capacity for both rural and urban farms remain a bottleneck for adoption of sensor-based platforms in investigation of adaptation physiology of farm animals.Globalization, the post-Covid-19 world, rising per-capita incomes, human population growth, ecological pressures, and global warming are some of the many important parameters that will influence the role of technology in the field of adaptation physiology for farm animals. It is evident that Covid-19 is building individual and societal resilience as it forces entire industries to find new and innovative solutions for farming, livestock, and other industrial sectors. The emphasis on reducing animal experiments for research purposes and limiting physical contact with animals is expected to fuel future research and development as well as create new commercial applications for sensor-based technologies in the agricultural and livestock sectors.Sensor-based technology can assess many biochemical, metabolic, physical, and immunological parameters related to adaptation physiology in farm animals. These include measurements of heart rate variability, respiration rate, body temperature, sweating rate, metabolism, health and diseases, vocalization, activity, movement, postural, feed and water intake behavior, and emotional contagion. The presented critical review illustrated the promising outcomes of sensor-based technology in farm animals as an innovative approach for maximizing animal welfare and providing better alternatives for gauging animal health and response. In addition, sensor-based technologies help in the recognition of robust breeds (i.e., animals with better adaptation capabilities and stress response).Despite promising outcomes, the use of novel, highly precise sensor-based technologies face several challenges that must be addressed in future research. These key challenges include the validation of large-scale machine learning techniques and issues related to the sensitivity of conventional sensor-based methodologies. Another important challenge will be imparting the necessary skillset to farmers in rural areas, so they are equipped and willing to maximize their use of the available technology. Educating the end-users of sensor-based technology in the use of information technology-based sensor devices is the only way these innovative new developments can reach their full potential.This research received no external funding.The author declares no conflict of interest.1.Gaughan J.B., Sejian V., Mader T.L., Dunshea F.R. 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