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Advances in Management of Poultry Production Using Biotelemetry

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1. Introduction

In this chapter, the authors review recent developments in the use of biotelemetry in poultry production. The chapter begins with an overview of advancements in biotelemetry and outlines the types of equipment that are commercially available as well as those adapted and developed by researchers primarily for use in farm animals. The authors then highlight the significant milestones achieved by the scientific community in using biotelemetry towards a more holistic poultry production guided by birds' physiological responses to environmental stressors. In particular, the authors discuss efforts at the University of Georgia towards building the next generation closed-loop poultry environmental controller which responds directly and in real-time to physiological needs of the birds.

Biotelemetry is defined as the remote detection and measurement of physiological, bioelectrical, and behavioral variables to monitor function, activity, or condition of conscious unrestrained humans or animals. This encompasses a broad range of techniques of varying invasiveness including video monitoring, non-contact thermometry, radio tracking and the use of internally or externally mounted remote sampling systems (Morton et al., 2003). Biotelemetry is not a new concept and it was first introduced by Einthoven in 1903 when he measured the electrocardiogram using immersion electrodes remotely connected to a galvanometer via telephone lines (Cromwell et al., 1973, as cited in Hamrita et al., 1998). In later years, NASA played a big role in the advancement of biotelemetry by using it to transmit astronaut biomedical data such as heart rate and body temperature to earth. In (N. F. Güler & Übeyli, 2002), the authors provide a detailed history of early uses and developments of biotelemetry.

Biotelemetry consists of sensing the variable of interest from the animal using miniature sensors or transducers. These can be placed on the animal, ingested by the animal, or implanted inside the animal by means of injection or surgery. The output of the sensor or transducer is modulated to a form which can be transmitted wirelessly over a distance from the animal to a receiver using an embedded transmitter. The received signal is demodulated and the measured variable extracted through proper signal conditioning and calibration by the data acquisition system. Biotelemetry data has been transmitted through every medium including air, vacuum, water, and biologic tissue using a variety of modulating carriers such as electromagnetic waves (especially at radiofrequency- hence the name radiotelemetry), light, and ultrasound (N. F. Güler & Übeyli, 2002). By far the most common carriers of biotelemetry data are radio waves. Due to the proliferation of biotelemetry in recent years, the Federal

Communications Commission (FCC) has allocated dedicated frequency bands for biotelemetry use in the VHF range, generally over 100 MHz. Typically variables that have been monitored through biotelemetry fall in four categories: (1) Bioelectrical such as ECG, EMG, and EEG; (2) physiological such as blood pressure, blood flow, and temperature; (3) behavioral such as activity levels; and (4) chemical such as pH.

Through biotelemetry, it is possible to continuously monitor multiple physiological variables without handling or restraining the animal and attaching it to wires and probes. This reduces stress and physiological disturbance of animals by removing the influence of the measurement procedure and thereby improving the quality of data. This also allows for unattended operation reducing labor. Also, animals instrumented with implanted telemetry are free of infections that result from exteriorized catheters and lead wires (N. F. Güler & Übeyli, 2002). Biotelemetry provides the opportunity to increase the frequency of observation or continuously monitor multiple variables over extended periods of time therefore significantly increasing access to larger amounts of physiological data. Additionally, biotelemetry makes possible real-time processing of collected data and the ability to act on it. Knowing how key parameters are changing in real-time in animals allows, for instance, faster adjustment of feeding times to activity rhythms, more objective identification of the preference/tolerance margins towards environmental variables and precise assessment of the impact of environmental or operational changes (Baras & Lagardère, 1995). Lastly, biotelemetry reduces bias and observation influence, therefore contributing to more accurate measurements (Eigenberg et al., 2008). These characteristics of biotelemetry have improved a wide range of applications and enabled new possibilities that were previously unimaginable.

It is however worth mentioning that telemetry can cause suffering to animals in the short and long term if appropriate procedures and refinements are not implemented. In (Morton et al., 2003), the authors state that telemetry is often presented as a refinement, in that it can reduce or eliminate stress caused to animals but like all other procedures on animals, it also needs to be refined. They indicate that the impact of telemetry on animals in practice depends on whether or not surgery is used; the devices used; whether the technique restricts the subjects' abilities to express a range of desirable behaviors; and whether ways of refining both procedures and husbandry were fully researched. The authors provide a 40-page report detailing ways to refine both husbandry and procedures in telemetry applications to minimize suffering and improve welfare of animals. Similarly in (Hawkins et al., 2004), the authors detail husbandry refinements for telemetry procedures.

2. Biotelemetry systems

In this section, we describe the basic principles of biotelemetry systems and survey existing systems which are available for physiological monitoring. The discussion will include both commercially available systems as well as those developed by researchers. The review of commercially available systems is restricted to those used for livestock animals.

A typical biotelemetry system consists of the following components: (1) transmitter, (2) receiver/decoder, and (3) data acquisition unit. The sensor and the transmitter are usually combined into one unit which is implanted in or ingested by the animal. The transducer detects the physiological variable and converts it into a form which can modulate the signal from the transmitter. An antenna at the receiving end is necessary for proper recovery of the transmitted signal. The main role of the receiver is to decode or demodulate the signal, i.e.

convert it to the original signal being measured. Dedicated multichannel programmable receivers with computer interfacing capabilities are now commercially available. Some of these receivers could accommodate as many as 100 transmitters at different carrier frequencies. The data acquisition system turns the received signal into measurements of the variable being monitored based on the calibration information provided by the user. The data acquisition system is usually interfaced with a computer to provide a user-friendly interface which facilitates control of the measurements as well as storage of the collected data (Hamrita et al., 1997). In earlier stages of biotelemetry, researchers used data loggers mounted on animals (Hahn et al., 1990, Feddes & Deshazer, 1993, Harris et al., 2001, and Eigenberg et al., 2002, all as cited in Lowe et al., 2007) to record and store the collected data (Lowe et al., 2007). More recently, most systems use remote data transmission (Gedir, 2001, as cited in Lowe et al., 2007; Lacey et al., 2000a; Brown-Brandl et al., 2003; Silva et al., 2005). In some applications, researchers have mixed data logging in the implant as well as transmission to a data acquisition system (Lowe et al., 2007).

Modulation methods used most in biotelemetry systems include frequency modulation (FM) where frequency of the carrier varies proportionally to the signal being transmitted; amplitude modulation (AM) where amplitude of the carrier varies proportionally to the signal; and pulse modulation where the carrier is a series of pulses. There are several types of pulse modulation techniques including pulse amplitude modulation (PAM) where the amplitude of the pulse varies proportionally, pulse width modulation (PWM) where the pulse width varies proportionally to the signal, and pulse-interval modulation (PIM) where the carrier signal is turned on and off at a rate that is proportional to the variable being transmitted.

Proper signal amplification within the transmitter unit is performed and, depending on the transmission media, may include a miniature “coil” or “whip” antenna for radio communications, an LED for infrared or visible light communications, or an ultrasonic transducer for acoustic communications. When multiple transmitters are used, each transmitter sends its output signal at a different carrier frequency so that outputs of different transmitters are not mixed. However, it is common to measure multiple variables within the same transmitter and have each variable modulate the carrier frequency differently. In the case of AM and FM modulation, this is called frequency multiplexing. In the case of pulse modulation, this is called time multiplexing (N. F. Güler & Übeyli, 2002). Using a light carrier has been shown to provide high bandwidth communication, and is relatively more immunity from interference (Ackermann et al., 2006).

In biotelemetry systems, long operational life of the wireless sensor unit is an essential requirement. These systems have typically been powered using either batteries embedded inside the transmitter units or through external power sources. External powering of biotelemetry sensors includes RF power from a base unit and inductive powering based on magnetic coupling (Ko et al., 1977, de N. Donaldson & Perkins, 1983, Vanschuylenbergh & Puers, 1996, and Jeutter, 1983, all as cited in N. F. Güler & Übeyli, 2002). For sensor units powered using internal batteries, the size of the device often constrains both the operational life and the transmission range. For a given chemistry, there is a generally proportional relationship between battery size and energy storage capacity, so that smaller sized batteries have shorter useful lives in a given device. Concerning RF transmitters, the useable range often shrinks with the size of the transmitter due to decreased space for signal amplification circuitry and efficient antennae. In addition, the power consumption of the device tends to increase proportionally with the intended transmission range, the sensor sampling frequency, and the data transmission rate. To prolong the life of the battery in an implanted

biotelemetry system, some researchers have experimented with remote power switching (Varosi et al., 1989, as cited in Hamrita et al., 1998; Leung et al, 1986, as cited in N. F. Güler & Übeyli, 2002).

In order to select the best transmitter for a given application, all the factors discussed above have to be taken into consideration and sometimes compromises must be made. For more in-depth reviews and overviews of biotelemetry systems, the reader is referred to the following sources (Hamrita et al., 1997; Akyildiz et al., 2002; Budinger, 2003; Güler, N. F. & Übeyli, 2002; Hawkins et al., 2004; Luong et al., 2008; Morton et al., 2003; Ruiz-Garcia et al., 2009; Strydis, 2005; Wang et al., 2006; Wathes et al., 2008).

A variety of biotelemetry equipment is available for detecting, monitoring, and storing various variables. Some of these systems are designed to be implanted inside the animal, others are to be ingested by the animal, and others are to be attached to the animal. Some are widely used in human medicine, while others are currently intended solely for animals. The transmitters in these biotelemetry systems vary in size, resolution, range, communication links, sampling rate, number of channels, number of sensors per transmitter, and power consumption. They may consist of many different types of sensors such as temperature, biopotential, and acoustic monitoring, and visible and infrared imaging, which are able to monitor a wide variety of electrical, physiological, chemical, and behavioral conditions. The table below provides a survey of commercially available systems. Note that the communication link used in all these systems is based on radio frequency.

2.1 Commercial biotelemetry systems

Manufacturer	Implantable/ Ingestible/ Attachable	Intended subject	Sensor types	Number of sensors per transmitter	Power requirements/ battery life	Data transmission range
HQ Inc. formerly HTI Technologies	Ingestible	Capsule for human ingestion	Temperature	1	Integrated battery with unknown life	Short range
Remo Technologies Limited	Implantable (some attachable)	Small modules (can be less than 10 grams or even sub- gram)	EEG, ECG, EMG, skin temperature, limb angle, acceleration	Up to 3 biopotential channels plus temperature with some models supporting additional channels	Integrated battery with multiple month life	300 mm
DSI (Data Sciences International)	Implantable	Mouse to large animal	EEG, ECG, EMG, temperature, pressure, activity	Up to 4 biopotential channels plus integrated temperature, pressure, and activity sensors	Integrated batteries with lives from 1.5 to 12 months (some - models with replaceable batteries)	
Telonics	Attachable collars	Birds to elephants	Location with some models offering GPS, ambient temperature, and mortality sensing	Varies with models	Integrated batteries with up to multi-year lives depending on transmission schedule	Long range (many miles)

Table 1a. Commercial Biotelemetry Equipment Providers

Manufacturer	Implantable/ Ingestible/ Attachable	Intended subject	Sensor types	Number of sensors per transmitter	Power requirements/ battery life	Data transmission range
AVM Instrument Company	Implantable and Attachable (collars, ear tags, and glue-on modules)	Hissing cockroaches to tortoises and elk	Location with some models offering temperature, activity, mortality sensing, and sleep/end of hibernation sensing	Varies with model	Integrated batteries with lives from 2 days to 7 years	Long range (many miles)
Mini Mitter	Implantable transponder	Mice to humans	Heart rate, temperature, and gross motor activity depending on model	Up to 3	Passive transponder powered by receiver and only active when in proximity to receiver/ logger	Very short range (12 cm)
Telemetry Research	Implantable	Animals 200 grams and over	Pressure and/or biopotential channels	Up to 3	Integrated batteries - rechargeable in- situ by inductive charger	Up to 5 meters
emka Technologies	Implantable devices and Attachable collars	Animals 200 grams and over	EEG, ECG, EMG, temperature, activity, respiration, sympathetic nerve activity, pressure (implanted and non-invasive versions)	Up to 8 for emkaPack and up to 2 for implantable devices	emkaPack uses two replaceable AA/R6 alkaline batteries for up to 80 hours of use	Up to 5 meters
BlueBox Sensors	Implantable sensors	-	Oxygen, Nitric Oxide, and glucose	-	-	-
Advanced Telemetry Systems	Implantable and Attachable (collars, ear tags, and glue-on modules)	Many sizes and species	Location with some models offering GPS, temperature, activity, and mortality sensing	Varies with model	Integrated battery (months to years depending on pulse rate of transmitter)	Long range (many miles)
TSE Systems	Implantable and Attachable	All sizes of lab animals up to human	ECG, EEG, EMG, EOG, temperature, activity, etc.	Up to 4	-	-

Table 1b. Commercial Biotelemetry Equipment Providers

2.2 Biotelemetry systems developed by researchers

Although there is a wide variety of commercially available biotelemetry equipment, many researchers from various fields have had to design and develop their own biotelemetry systems in an attempt to improve on existing commercially developed ones (I. Güler & Kara, 1996; Wouters et al, 1994, and Kettlewell et al, 1997, as cited in Strydis, 2005; Ackermann et al., 2006; Silva et al., 2005) or to meet specific monitoring needs (Lowe et al., 2007; Quwaider

et al, 2010; Cross et al., 2004). In some cases, circuitry is added to give more intelligence to the sensor itself (Puers, 1999; Wouters et al, 1994, as cited in Strydis, 2005). It is also common for researchers to adapt commercially available systems for their applications. For instance in (Eigenberg et al., 2008), the authors adapted a biomedical temperature measurement system for animal use.

In (I. Güler & Kara, 1996), the authors designed and implemented a novel biotelemetry system for biomedical applications which is based on digital data processing and transmission as opposed to existing systems which rely on analog data transmission. The motivation behind this design was to provide high noise immunity and better synchronization between the transmitters and the receiver. The transmitter digitizes analog physiological signals, converts them into serial form and transmits them via an FM transmitter. The receiver amplifies and pulse-shapes the received data, converts it into 8-bit parallel form and then into analog signal. The system showed a stable and high performance within a distance of 100 m.

In (Lowe et al., 2007), the authors designed, built and tested a dual mode telemetric logging system to monitor, transmit and record physiological waveforms (electrocardiogram (ECG), electroencephalogram (EEG) and respiration) from farm animals during commercial transport and slaughter. The system combined telemetry with a logging device, small enough to be mounted on a variety of species including poultry. The motivation behind this design is that in some situations where no reliable radio link could be established, the telemetry system is capable of logging several minutes of data. The developed system had a radio communication range of several meters.

In (Quwaider et al., 2010), the authors designed and developed a novel wireless body-mounted sensor to remotely monitor the location and activity of unrestrained laying hens. In the study, laying hens were fitted with a lightweight (10 g) wireless body-mounted sensor to monitor their location in space relative to key resources and general level of physical activity. Sensor data were validated by correlating them to video-based observations of the sensor-wearing hen.

In (Cross et al., 2004), the authors presented the design of an automated biotelemetry based vaginal controlled release drug delivery system for cows. The intravaginally located device is a low-invasive platform that detects estrus while providing external control of variable drug delivery. The device consists of off the shelf components and allows for monitoring of temperature, pressure, activity, and light intensity. A two-way radio link allows communication with a base station.

In (Wouters et al, 1994, as cited in Strydis, 2005), the authors implemented a complex design to address the need for reliable injectable telemetry sensor systems for large-scale animal husbandry applications featuring extreme miniaturization and ultra-low power consumption as well as increased flexibility, versatility and intelligence. The authors achieved increased intelligence and multi-purpose use of implantable transponders by using a combination of software (through a miniature off-the-shelf microprocessor (MP)) and hardware through a customized generic Sensor Interface Chip (SIC). To conserve power, the authors have the microprocessor operate in a sleep mode most of the time except when data is being collected. The SIC includes a battery check circuit which monitors the voltage-level of the battery and creates an alert if this level is lower than a specific user defined level. The system has the capability of storing data on the on-chip memory or sending it remotely to the receiver. Additionally, through several commands the user can fine-tune sensor and battery operation. The authors in (Puers, 1999) conducted a study dealing with the merits of

such an approach. The author in (Strydis, 2005) conducted a more in depth review of this study which was used as a basis for our brief review.

In (Ackermann et al., 2006), the authors addressed the need in some biotelemetry applications for high bandwidth communication. For example, transmitting 100 channels of neural waveform data for a cortical prosthetic control system may require up to 40 Mbps for a 100-channel array. Other applications may also require high rate transcutaneous data transfer, including cochlear implants, visual prosthetics and cortical stimulation sensory prosthetics. The authors considered various high rate transcutaneous data transmission methods such as the use of percutaneous wires, acoustic energy, and RF, but they opted for the use of optical telemetry for three reasons. According to them: (1) Optical telemetry is a mature, well-established technology: fiber-optic and free-air optical communication systems are common in consumer goods and are quite well understood. (2) The optical portion of the EM spectrum is unregulated worldwide for communications purposes, and interference from other sources can be made insignificant. (3) Feasibility of high rate optical transcutaneous data transfer has been established and used for several biomedical applications such as in neuromuscular stimulators (Taylor et al., 2002 [5], as cited in Ackermann et al., 2006), artificial hearts or implanted cardiac assist devices (Mitamura et al., 1990 [6], Miller et al., 1992[7], and Inoue et al., 1998 [8], all as cited in Ackermann et al., 2006), bladder stimulators (Sawan et al., 1997 [9], as cited in Ackermann et al., 2006), laboratory animal monitoring systems (Kudo et al., 1988 [10], as cited in Ackermann et al., 2006), and neural recording systems (Goto & Nakagawa, 2002 [11]; and Larson, 1999 [12], as cited in Ackermann et al., 2006).

In (Kettlewell et al., 1997, as cited in Strydis, 2005), the authors devised a multichannel, radiotelemetry system for continuous monitoring of ECG, deep-body temperature and respiratory movements. Preliminary tests of a prototype device have been performed in poultry. In designing this system, the authors gave active consideration to package size and weight, robust construction, large transmission range and low power consumption. Also, the authors actively sought to deliver a device compliant with regulations and specifications defined by the Department of Trade and Industry (DTI, UK). The implantable transmitter is not an integrated chip and/or micro-machined device, but rather a package of individual components. The signal from the respiratory sensor is superimposed upon the temperature signal by amplitude modulation and, then, mixed with the ECG signal. Superimposed, analog data from three channels are FM modulated and transmitted from the telemetry implant to an external system for further handling. The author in (Strydis, 2005) conducted a more in depth review of this study which was used as a basis for our brief review.

In (Bae et al., 2008), the authors designed and built a radio receiver to monitor pulse signals from multiple temperature transmitters. The receiver provides serial communication and analog voltage output and is optimized for real-time monitoring and control based on temperature telemetry sensors. Calibration of the radio receiver with commercial temperature transmitters provided an accuracy within $\pm 0.1^{\circ}\text{C}$.

In recent years, some researchers in the biotelemetry field have experimented with wireless sensor networks. Sensor networks offer various advantages over using individual sensors (Silva et al., 2005): (1) Sensor networks greatly improve the accuracy of information obtained from collaboration among sensor nodes and real-time information processing at those nodes (Min, R. et al., 2002, as cited in Silva et al., 2005); (2) distributed data processing in these networks has the potential of improving the accuracy of vast quantities of sensing

information (Asada et al., 2000, as cited in Silva et al., 2005); (3) through sensor networks, data can be integrated to provide a rich, multi-dimensional view of the system monitored; (4) sensor networks function accurately when an individual sensor fails making them more robust and reliable. In (Silva et al., 2005), the authors developed a wireless sensor network prototype to monitor physiological responses of livestock. The system uses a novel low-cost wireless communication protocol named Wireless Floating Base Sensor Network (FBSN) protocol. The sensor implant measures physiological responses from digital sensors, digitalizes data, and transmits it to the base module. The base module in turn, using an FBSN protocol, controls data collection from different animal modules and stores the data. The equipment was validated through an experiment to monitor bovine brain electrical activity in six free moving animals although the system was designed with the ability to monitor other physiological responses in any number of animals.

3. Use of biotelemetry in poultry production research

Poultry production has changed radically from the traditional flock running loose in the farmyard to a system where the majority of production is carried out in large confined facilities. Animals that are grown indoors are more susceptible to stress and diseases. Environmental stresses cause substantial economic losses due to increased mortality, downgrading and condemnations of carcasses and associated problems of environmental pollution, reduced production, reduced feed intake and body weight gain, and impaired immune function (Payne, 1966, as cited in Green & Xin, 2009; Mader et al., 2002, Brown-Brandl et al., 2003, and Hahn, 1999a, 1999b, all as cited in Silva et al., 2005). Poultry researchers and ultimately poultry growers need to understand how the birds respond to environmental stressors to make improved management decisions. Externally noticeable responses to environmental stressors are usually preceded by internal physiological responses, such as a change in body core temperature and/or heart rate, which often provide the first stress indicators. These physiological responses, if measured properly, are the ultimate indicators of stress and they allow us to detect stress at much earlier stages. Technological advances in biotelemetry have fueled the notion among researchers that management of poultry production could be significantly improved through real-time physiological monitoring of the birds. Hence, during the last ten years or so, biotelemetry has been successfully used in a wide range of research pertaining to poultry production. This section highlights some of this research through various examples. In particular, we highlight efforts at the University of Georgia towards building the next generation closed-loop poultry environmental controller which responds directly and in real-time to physiological responses of the birds.

3.1 Biotelemetry validation studies in poultry

Many poultry biotelemetry studies were aimed at validating new commercially available telemetry systems and measurement techniques, and have clearly demonstrated their effectiveness for accurate continuous monitoring of poultry physiology. The majority of these studies were concerned with monitoring of temperature.

In (Brown-Brandl et al., 2003), the authors conducted a comparative evaluation of a telemetry-based deep body temperature measurement system (HQ, Inc., West Palmetto, Fla.) for use in poultry research as well as research involving livestock. Three independent laboratories conducted the evaluation. For poultry, the deep body temperature

measurements sensors were of the ingestible type allowing for short-term monitoring. The authors developed and used computational algorithms to filter out spurious data. After careful consideration, the authors concluded that due to the cost of the system, the surgeries involved (in some applications), and the need for data filtering, careful consideration has to be given to ensure that telemetry is the proper method for the experiment.

In (Hamrita et al., 1997), the authors evaluated the use of a biotelemetry system (Mini Mitter, Bend, Oregon; Telonics, Inc, Mesa, Arizona) with implanted transmitters in measuring deep body temperature of poultry under various ambient temperature conditions. The sensors successfully detected body temperature variations due to diurnal rhythm, as well as noticeable responses in deep body temperature to step changes in ambient temperature.

In (van den Brand & van de Belt, 2006), the authors validated the use of a biotelemetry temperature monitoring system in a chicken embryo. In this preliminary study, the authors determined the impact of the implanted temperature transponder on embryo mortality as well as the optimal location (air cell, albumen, or yolk) and day of implantation in the egg. The authors determined that implantation of telemetric temperature transponders in eggs is possible, but not at all sites and all days of incubation.

In (Lacey et al., 2000a), the authors used a telemetric deep body temperature measurement system to measure deep body temperature of poultry under various ambient temperature and relative humidity conditions. Results showed that the measured responses were consistent among all birds, significantly different for the different environmental conditions, and a change in response from one set of conditions to the other was clearly attributed to the change in ambient conditions and not to fluctuations in the measurement system or in between bird variation.

3.2 Poultry stress studies using biotelemetry

Many studies were concerned with monitoring and evaluating physiological and behavioral responses of poultry under various stressful environmental stimuli and management conditions to (1) gain a better understanding of poultry thermoregulatory responses; (2) improve management practices; and (3) evaluate the effectiveness of various environmental conditions. The most studied environmental variable is temperature with a few studies focusing on humidity and air velocity. Poultry response variables that have been examined include deep body temperature (Kettlewell et al., 1997; Hamrita et al., 1998; Lacey et al., 2000a, 2000b; Mitchell et al., 2001, as cited in Silva et al., 2005; Brown-Brandl et al., 2001, as cited in Wang et al., 2006; Blanchard et al., 2002; Yanagi et al., 2002a, 2002b; Brown-Brandl et al., 2003; Tao & Xin, 2003a, 2003b; Crowther et al., 2003; Khalil et al., 2004; van den Brand & van de Belt, 2006; Hamrita & Hoffacker, 2008; Leterrier et al., 2009); brain and heart activity (Blanchard et al., 2002; Crowther et al., 2003; Aubert et al., 2004; Khalil et al., 2004; Lowe et al., 2007; von Borell et al., 2007; Coenen et al., 2009); and physical activity (Khalil et al., 2004; Quwaider et al., 2010). The majority of studies were concerned with deep body temperature responses to heat stress. Heat stress results from the inability of birds to thermoregulate and maintain homeostasis under elevated ambient temperatures and humidity (Green & Xin, 2009).

In (Leterrier et al., 2009), the authors used biotelemetry to monitor and evaluate poultry deep body temperature responses to various treatments of stressful room temperature conditions. The purpose of the study was to investigate the effects of prior exposure to high temperatures on the birds' acclimation to heat stress. The authors experimented with exposing birds to heat stress at various stages in their lives and used both deep body

temperature and observations of panting behavior to assess their state. Telemetry sensors were implanted in the body cavity.

In (Hamrita et al., 1997), the authors investigated poultry deep body temperature responses to stressful changes in ambient temperature. The experiment proved that noticeable changes in deep body temperature occurred under heat stress conditions. In (van den Brand & van de Belt, 2006), the authors were concerned with monitoring temperature of chicken embryo under natural brooding conditions in an effort to determine artificial incubation conditions.

In recent years, heart rate and heart rate variability have been increasingly used in animal research to study disease, stress, characteristics, and welfare of animals. In (von Borell et al., 2007), the authors provide an excellent comprehensive review of the use of heart rate monitoring in farm animal studies. This study was commissioned by the “measuring welfare” working group of the EU whose concerted action on ‘Measuring and Monitoring Welfare’ (COST Action 846) has identified heart rate as a key research area with the potential to “contribute to our understanding and interpretation of stress and welfare status in farm animals”. Their “Heart Rate and Heart Rate Variability Task Force” conducted the study in which they outlined the appropriate methodologies for heart rate monitoring and analysis in different species, and identified areas of future research. They determined that for poultry (and avian in general), monitoring and analysis of heart rate has been used in very few studies. This scarcity is attributed to the difficulty of obtaining high quality data and the lack of fundamental research to evaluate the physiological meaning of heart rate variability indices. They cite a few heart rate studies focused on the development of cardiac rhythms (Pearson et al., 1998 [210], Moriya et al., 1999 [211], 2000 [212], 2002 [213], and Tazawa et al., 2002 [214, 215], all as cited in von Borell et al., 2007); a study used to better understand the relationship between coping style and feather pecking (Korte et al., 1999 [29], as cited in von Borell et al., 2007); an other study to show that exposure to high levels of carbon dioxide in 2-week old broilers increases the incidence of cardiac arrhythmias (Korte et al., 1999 [218], as cited in von Borell et al., 2007); and a study in quail to understand how they respond to emotional stress (Gaudinière et al., 2005 [220], as cited in von Borell et al., 2007).

In (Crowther et al., 2003), the authors evaluated the use of heart rate and skin temperature as indicators of stress in ostriches during night transportation. Literature has identified a number of stressors that have negative impacts on the welfare of ostriches during transportation such as vibration and movement, heat stress, and dehydration and suggested that ostrich welfare during transit might be improved by using darkened vehicles. Comparisons were made between transportation during the day and at night. Statistical tests suggested that heart rate and skin temperature measurements recorded during the night were lower than those recorded during the day. The conclusion was drawn that transporting ostriches at night is potentially beneficial for the reduction of stress and maintenance of welfare.

In (Aubert et al., 2004), the authors monitored heart rate and heart rate variability of poultry embryos at the end of incubation to test the hypothesis that autonomic nervous cardiac modulation is present at the end of development.

In (Quwaider et al., 2010), the authors used a wireless accelerometer-based body-mounted sensor to remotely monitor the location and activity of unrestrained laying hens to enable care givers to visually assess the health, welfare, or movement of hens or to follow a particular hen over time. Sensor data concerning hen’s proximity to specific resources such as nest boxes, perches, water, and feeders were validated by correlating them to video-based

observations of the sensor-wearing hen. An 84% overall agreement between sensor data and video data was consistently obtained.

In (Coenen et al., 2009), evaluated the welfare implications of euthanizing broilers with three gas mixtures in commercial application of controlled atmosphere stunning. Free moving birds were instrumented with electrodes to measure brain activity (electroencephalogram, EEG) and heart rate. These signals were recorded using a custom-built telemetry-logging system worn by each bird in a spandex backpack.

In (Blanchard et al., 2002), the authors used biotelemetry for intermittent physiological monitoring of poultry on different diets and under changing lighting conditions. The purpose was to determine whether measurements of poultry electrocardiograms (ECG) and temperature over extended periods of time could provide useful physiological information about broilers at risk for sudden death syndrome, and therefore give some insight into the underlying mechanisms of the syndrome. Transmitters were implanted subcutaneously at the base of the right side of the neck with ECG leads placed over the right shoulder and left groin areas.

In (Khalil et al., 2004), the authors used biotelemetry to monitor heart rate, body temperature, and locomotor activity of hens as stress indicators to evaluate the effects of sudden changes to different management factors, such as food withdrawal and reduction to lighting hours. The authors determined that sudden changes in a management program have significant measurable impact on the birds.

In (Yanagi et al., 2002a), the authors used biotelemetry to evaluate poultry deep body temperature responses to heat stress and the use of surface wetting for its relief. An environmental control and measurement system was developed for this study consisting of automatic control of air temperature and relative humidity, manual setting of air velocity, and continuous monitoring of surface and core body temperatures of the animal. Animal surface temperatures were monitored with an infrared thermal imager, deep body temperatures were monitored with a surgery-free telemetric sensing unit, and animal behavior was recorded using surveillance video. The authors advocated for a variable application rate of water depending on the environment's thermal conditions. They used the system to determine water evaporation rate of the hens cooled by intermittent partial surface wetting at various temperature, relative humidity, and air velocity combinations and quantified the animals' physiological responses to the cooling scheme. In a similar study (Tao & Xin, 2003b), the authors measured the effects of surface wetting on broilers with an ingestible wireless telemetry device, and digital imaging.

A high level of relative humidity is commonly known as an exacerbating factor in poultry heat stress problems (Brown et al., 1997, as cited in Hamrita, 2000a). However, as stated in (Shlomo et al, 1995, as cited in Lacey, 2000a), its exact effects have not been "clearly elucidated." Hence, more research efforts are required to better understand the combined effects of ambient temperature and relative humidity on poultry and to incorporate this knowledge in optimizing poultry housing management and control. Information on the interactive effects of ambient temperature, relative humidity, and ventilation rates on poultry subjected to heat stress is meager (Yanagi et al., 2002a). Humidity can aggravate the adverse effect of high temperature (Steinbach, 1971, as cited in Tao & Xin, 2003a) because animals increasingly rely on latent heat loss with rising temperature (Tao & Xin, 2003a).

In (Lacey et al., 2002a), the authors used a telemetric deep body temperature measurement system to determine the effects of stressful ambient temperature and relative humidity conditions on poultry. Three levels of ambient temperature (31, 34, and 37 °C) and two

levels of relative humidity (50 and 80%) were considered. Results showed that the effects of ambient temperature and relative humidity on mean deep body temperature of broilers are cumulative. Higher relative humidity increases the effective ambient temperature experienced by the bird and results in raised deep body temperature.

In (Tao & Xin, 2003a), the authors monitored continuously using biotelemetry core body temperature responses of poultry to acute exposure to multiple thermally challenging environmental conditions. The conditions consisted of 18 factorial combinations of three dry-bulb air temperatures, two dew point temperatures, and three air velocities. Based on the measurements, the authors developed a temperature-humidity-velocity index (THVI) to describe the synergistic effects of the environmental variables on the birds. The authors classified the states of the birds into normal, alert, danger, or emergency and expressed them in terms of the THVI.

3.3 Modeling poultry physiological responses

Continuous biotelemetry monitoring of poultry provides dynamic responses that define relationships with environmental variables. Combining continuous environmental records and response measures allows models to be constructed to predict future outcomes for a range of inputs (Eigenberg et al., 2008). Some researchers have studied predictability of physiological responses of poultry to various environmental variables. (Aerts et al., 1998) used a recursive regression model to predict 15 min ahead heart rate responses to changes in AT and light-dark alternations. In (Lacey et al., 2000c), the authors used artificial neural network models to predict deep body temperature (DBT) responses of broilers to stressful step changes in ambient temperature. Experiments were conducted using a telemetry system to measure DBT responses of birds under various stress conditions. The collected data was used to train and test various neural network architectures, and the Elman-Jordan was determined to be most suitable. The ability of the developed models to predict DBT responses to AT schedules not used in training and/or responses from a bird not used in training was examined. The models performed reasonably well when predicting responses of a different bird to AT schedules used in training. The models performed well when predicting responses of a bird used in training to new AT schedules. However, predictions of the models were less accurate when dealing with a different AT schedule on a different bird. The authors concluded that using a larger data set with more birds and more AT schedules would likely lead to improved DBT predictions. Results of this study indicate that neural networks could potentially be used for predicting the impact of heat stress conditions on bird physiology.

3.4 Environmental control of poultry housing using telemetric real-time physiological feedback

Environmental control is an important factor in the alleviation of heat stress in poultry environments. Several studies have been reported in the literature for computer-based environmental control of the poultry housing environment. In most of these studies, the environmental variables of interest are temperature, humidity, static pressure, and ventilation rates (Timmons et al., 1995, Mitchell, 1986, 1993, Allison et al., 1991, Timmons, 1987, Flood, 1991, Zhang, 1993, Geers et al., 1984, and Berckmans et al., 1986, all as cited in Hamrita & Mitchell, 1999) with temperature being the most widely studied variable. The most basic and common form of control in these reported studies aims at maintaining temperature in the environment within a desired range by controlling ventilation and

heating rates (Hamrita & Mitchell, 1999). In most cases, the control actions are based on feedback measurements of ambient temperature collected from a single location in the building using a thermistor or a thermocouple (Aerts et al., 1996, as cited in Hamrita & Mitchell, 1999). Other more advanced studies have emerged which were concerned with developing control strategies that would increase economic efficiency of the poultry house through optimization (Timmons et al., 1986, as cited in Hamrita & Mitchell, 1999), incorporation of natural wind speed (Simmons and Lott, 1993 as cited in Hamrita & Mitchell, 1999), reducing energy costs by controlling temperature with a 24 hour integration period (Timmons et al., 1995, as cited in Hamrita & Mitchell, 1999), and acclimation (Davis et al., 1991, as cited in Hamrita & Mitchell, 1999).

Perhaps the most important factor that has been neglected in the above control strategies is the animal itself. A number of researchers have pointed out the potential for improvement by gaining insight into the physiological responses of the animals to environmental stressors (Aerts et al., 1996, as cited in Hamrita et al., 2008; Hamrita et al., 1997; Goedseels et al., 1992, and Barnett & Hemsworth, 1990, as cited in Lacey et al., 2000c). The authors in (Hamrita & Mitchell, 1999) called for the use of new dynamic control strategies which rely on real-time physiological feedback from the birds.

To our knowledge, the only research effort so far which has explored poultry environmental control using real-time physiological feedback from the birds is at the University of Georgia. In this program, several studies were conducted to establish a link between deep body temperature (DBT) and environmental variables (Hamrita et al., 1997, Hamrita et al., 1998, Lacey et al., 2000a, 2000b, 2000c, and Hamrita & Hoffacker, 2008). Through these studies, it was determined that DBT is a significant, measurable, effective, and predictable indicator of heat stress in poultry. These studies culminated in the design of a poultry housing environmental controller using DBT as a real-time feedback variable. The study described in (Hamrita & Hoffacker, 2008) established precedence for an environmental controller which responds directly and in real-time to birds physiological responses. Using an experimental tunnel ventilation enclosure placed inside an environmentally controlled chamber, implanted radio telemetry sensors, and a programmable logic controller, a proportional-integral type feedback controller was designed to maintain poultry DBT, under stressful ambient temperature conditions, below a given threshold by controlling air velocity rates. The results indicated that (1) air velocity has a measurable, dynamic, and almost immediate impact on DBT of birds under heat stress; and (2) DBT of heat-stressed broilers can be maintained below a set point by varying air velocity using feedback control. These preliminary results suggest that using DBT as a feedback variable to manipulate air velocity within poultry housing is a promising approach.

4. Use of biotelemetry in other fields

Other fields have preceded poultry in the use of biotelemetry and studies of the use of biotelemetry in other species are available for wildlife, livestock, fish, laboratory animals and humans. A quick survey of some of these studies may be a useful source of information for poultry research as they contain interesting equipment and methodologies.

A broad survey of the literature seems to indicate that the most advanced use of biotelemetry is in human medicine. There has been increased interest in the medical field in remote patient monitoring driven by the need for real-time patient data and the ability to monitor multiple patients simultaneously (Tan et al., 2009). Several studies in the literature have surveyed advances in biotelemetry in the medical field and they give insight into the

advanced state of medical biotelemetry equipment and its applications (Akyildiz et al., 2002; N. F. Güler & Übeyli, 2002; Budinger, 2003; Lewis & Goldfarb, 2003; Strydis, 2005; Byrne & Lim, 2007; Luong et al., 2008; Ruiz-Garcia et al., 2009; Lin et al., 2010; Yilmaz et al., 2010).

5. Conclusion

This chapter provided, through a large number of examples, a comprehensive overview of the use of biotelemetry in poultry production. The chapter outlined the types of equipment that are commercially available as well as those adapted and developed by researchers for use in poultry production research. Many poultry biotelemetry studies were aimed at validating new commercially available telemetry systems and measurement techniques and have clearly demonstrated their effectiveness for accurate continuous monitoring of poultry physiology. The majority of these studies were concerned with the monitoring of deep body temperature. Biotelemetry has been successfully used in a wide range of research pertaining to poultry production. Many studies were concerned with monitoring and evaluating physiological and behavioral responses of poultry under various stressful environmental stimuli and management conditions to (1) gain a better understanding of poultry thermoregulatory responses; (2) improve management practices; and (3) evaluate the effectiveness of various environmental conditions. Continuous biotelemetry monitoring of poultry provides dynamic responses that define relationships with environmental variables. These relationships have been described using mathematical models constructed to predict future outcomes for a range of inputs. A pioneer study used biotelemetry to design an environmental controller which maintains poultry deep body temperature, under stressful ambient temperature conditions, below a given threshold by controlling air velocity rates. This study is the first step in designing the future poultry environmental controller which responds directly and in real time to the birds' physiological responses.

6. References

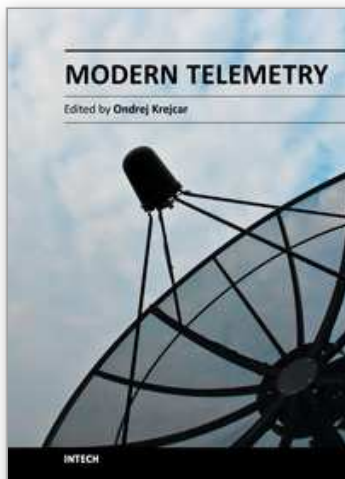
- Ackermann, D. M., Smith, B., Kilgore, K. L., & Peckham, P. H. (2006). Design of a high speed transcutaneous optical telemetry link. *Proceedings of the 28th IEEE EMBS Annual International Conference*, ISBN 1-4244-0033-3, New York City, USA, Aug 30-Sept 3, 2006
- Aerts, J. M., Berkmans, D., & Schurmans, B. (1998). Predicting the heart rate of broiler chickens based on a combination of a telemetry sensor and mathematical identification techniques. *Proceedings of the 1998 Annual Meeting of the Institute of Biological Engineering*, USA, July 10-12, 1998
- Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. *Computer Networks*, Vol. 38, No. 4, (March 2002), pp. 393-422, ISSN 1389-1286
- Aubert, A., Beckers, F., Ramaekers, D., Verheyden, B., Leribaux, C., Aerts, J.-M., & Berckmans, D. (2004). Heart rate and heart rate variability in chicken embryos at the end of incubation. *Experimental Physiology*, Vol. 89, No. 2, (February 2004), pp. 199-208, ISSN 0958-0670
- Bae, Y., Yang, H., & Min, W. (2008). Real-time monitoring of poultry deep body temperature using a custom-built RF receiver. *Proceedings of the 4th International Symposium on*

- Machinery and Mechatronics for Agriculture and Biosystems Engineering*, Taichung, Taiwan, May 27-29, 2008
- Baras, E. & Lagardère, J.-P. (1995). Fish telemetry in aquaculture: review and perspectives. *Aquaculture International*, Vol. 3, No. 2, (June 1995), pp. 77-102, ISSN 0967-6120
- Blanchard, S. M., Degernes, L. A., DeWolf, Jr., D. K., & Garlich, J. D. (2002). Intermittent bioelectric monitoring of electrocardiograms and temperature in male broilers at risk for sudden death syndrome. *Poultry Science*, Vol. 81, No. 1, (June 2002) pp. 887-891, ISSN 0032-5791
- Brown-Brandl, T. M., Yanagi, Jr., T., Xin, H., Gates, R. S., Bucklin, R. A., & Ross, G. S. (2003). A new telemetry system for measuring core body temperature in livestock and poultry. *Applied Engineering in Agriculture*, Vol. 19, No. 5, (September 2003), pp. 583-589, ISSN 0883-8542
- Budinger, T. F. (2003). Biomonitoring with wireless communications. *Annual Review of Biomedical Engineering*, Vol. 5, No. 1, (August 2003), pp. 383-412, ISSN 1523-9829
- Byrne, C., & Lim, C. L. (2007). The ingestible telemetric body core temperature sensor: a review of validity and exercise applications. *British Journal of Sports Medicine*, Vol. 41, No. 3, (March 2007), pp. 126-133, ISSN 0306-3674
- Coenen, A. M. L., Lankhaar, J., Lowe, J. C., & McKeegan, D. E. F. (2009). Remote monitoring of electroencephalogram, electrocardiogram, and behavior during controlled atmosphere stunning in broilers: Implications for welfare. *Poultry Science*, Vol. 88, No. 1, (January 2009), pp. 10-19, ISSN 0032-5791
- Cross, P. S., Künnemeyer, R., Bunt, C. R., Carnegie, D. A., & Rathbone, M. J. (2004). Control, communication and monitoring of intravaginal drug delivery in dairy cows. *International Journal of Pharmaceutics*, Vol. 282, No. 1-2, (September 2004), pp. 35-44, ISSN 0378-5173
- Crowther, C., Davies, R., & Glass, W. (2003). The effect of night transportation on the heart rate and skin temperature of ostriches during real transportation. *Meat Science*, Vol. 64, No. 4, (August 2003), pp. 365-370, ISSN 0309-1740
- Eigenberg, R. A., Brown-Brandl, T. M., & Nienaber, J. A. (2008). Sensors for dynamic physiological measurements. *Computers and Electronics in Agriculture*, Vol. 62, No. 1, (June 2008), pp. 41-47, ISSN 0168-1699
- Green, A. R. & Xin, H. (2009). Effects of stocking density and group size on thermoregulatory responses of laying hens under heat-challenging conditions. *Transactions of the ASABE*, Vol. 52, No. 6, (December 2009), pp. 2033-2038, ISSN 0001-2351
- Güler, I. & Kara, S. (1996). A low-cost biotelemetry system for long time monitoring of physiological data. *Journal of Medical Systems*, Vol. 20, No. 3, (June 1996), pp. 151-156, ISSN 0148-5598
- Güler, N. F., & Übeyli, E. D. (2002). Theory and applications of biotelemetry. *Journal Of Medical Systems*, Vol. 26, No. 2, (April 2002), pp. 159-178, ISSN 0148-5598
- Hamrita, T. K., Hamrita, S. K., Van Wicklen, G., Czarick, M., and Lacy, M. (1997). Use of biotelemetry in measurement of animal responses to environmental stressors. ASAE Paper No. 974008, St. Joseph, Michigan
- Hamrita, T. K., Van Wicklen, G., Czarick, M., & Lacy, M. (1998). Monitoring poultry deep body temperature using biotelemetry. *Applied Engineering in Agriculture*, Vol. 14, No. 3, (May 1998), pp. 327-331, ISSN 0883-8542

- Hamrita, T. K. & Mitchell, B. (1999). Poultry Environment and Production Control and Optimization: A Summary of Where We Are and Where We Want to Go. *Transactions of the ASAE*, Vol. 42, No. 2, (Month 1999), pp. 479-483, ISSN 0001-2351
- Hamrita, T. K. & Hoffacker, E. C. (2008). Closed-loop control of poultry deep body temperature using variably air velocity: a feasibility study. *Transactions of the ASABE*, Vol. 51, No. 2, (April 2008), pp. 663-674, ISSN 0001-2351
- Hawkins, P., Morton, D. B., Bevan, R., Heath, K., Kirkwood, J., Pearce, P., Scott, L., Whelan, G., & Webb, A. (2004). Husbandry refinements for rats, mice, dogs and non-human primates used in telemetry procedures. *Laboratory Animals*, Vol. 38, No. 1, (January 2004), pp. 1-10, ISSN 0023-6772
- Kettlewell, P. J., Mitchell, M. A., & Meeks, I. R. (1997). An implantable radio-telemetry system for remote monitoring of heart rate and deep body temperature in poultry. *Computers and Electronics in Agriculture*, Vol. 17, No. 2, (May 1997), pp. 161-175, ISSN 0168-1699
- Khalil, A. M., Matsui, K., & Takeda, K. (2004). Influence of sudden changes in management program on physiological and behavioral parameters in hens. *Animal Science Journal*, Vol. 75, No. 3, (May 2004), pp. 253-259, ISSN 1740-0929
- Lacey, B., Hamrita, T. K., Lacy, M. P., & Van Wicklen, G. L. (2000a). Assessment of poultry deep body temperature responses to ambient temperature and relative humidity using an on-line telemetry system. *Transactions of the ASAE*, Vol. 43, No. 3, (June 2000), pp. 717-721, ISSN 0001-2351
- Lacey, B., Hamrita, T. K., Lacy, M. P., Van Wicklen, G. L., & Czarick, M. (2000b). Monitoring deep body temperature responses of broilers using biotelemetry. *Journal of Applied Poultry Research*, Vol. 9, No. 1, (Spring 2000), pp. 6-12, ISSN 1056-6171
- Lacey, B., Hamrita, T. K., & McClendon, R. W. (2000c). Feasibility of using neural networks for real-time prediction of poultry deep body temperature responses to stressful changes in ambient temperature. *Applied Engineering in Agriculture*, Vol. 16, No. 3, (May 2000), pp. 303-308, ISSN 0883-8542
- Leterrier, C., Colina, Y., Collin, A., Bastianelli, D., Constantin, P., & de Basilio, V. (2009). Effects of late room temperature increases on body temperature and panting behaviour in chicken. / Effets d'elevations tardives de la temperature ambiante sur la temperature corporelle et l'hyperventilation chez le poulet. *World Poultry Science Association (WPSA), Proceedings of the 8th Avian French Research Days*, St Malo, France, March 25-26, 2009
- Lewis, B., & Goldfarb, N. (2003). The advent of capsule endoscopy -- a not-so-futuristic approach to obscure gastrointestinal bleeding. *Alimentary Pharmacology & Therapeutics*, Vol. 17, No. 9, (May 2003), pp. 1085-1096, ISSN 0269-2813
- Lin, C. T., Ko, L. W., Chang, M. H., Duann, J. R., Chen, J. Y., Su, T. P., & Jung, T. P. (2010). Review of Wireless and Wearable Electroencephalogram Systems and Brain-Computer Interfaces -- A Mini-Review. *Gerontology*, Vol. 56, No. 1, (January 2010), pp. 112-119, ISSN 0304-324X
- Lowe, J. C., Abeyesinghe, S. M., Demmers, T. G. M., Wathes, C. M., & McKeegan, D. E. F. (2007). A novel telemetric logging system for recording physiological signals in unrestrained animals. *Computers and Electronics in Agriculture*, Vol. 57, No. 1, (May 2007), pp. 74-79, ISSN 0168-1699

- Luong, J. H. T., Male, K. B., & Glennon, J. D. (2008). Biosensor technology: Technology push versus market pull. *Biotechnology Advances*, Vol. 26, No. 5, (September 2008), pp. 492-500, ISSN 0734-9750
- Morton, D. B., Hawkins, P., Bevan, R., Heath, K., Kirkwood, J., Pearce, P., Scott, L., Whelan, G., & Webb, A. (2003). Refinements in telemetry procedures. *Laboratory Animals*, Vol. 37, No. 4, (October 2003), pp. 261-300, ISSN 0023-6772
- Puers, R. (1999). Sensor, sensor interfacing and front-end data management for stand-alone microsystems. *Journal of Micromechanics and Microengineering*, Vol. 9, No. 2, (June 1999), ISSN 0960-1317
- Quwaider, M. Q., Daigle, C. L., Biswas, S. K., Siegford, J. M., & Swanson, J. C. (2010). Development of a wireless body-mounted sensor to monitor location and activity of laying hens in a non-cage housing system. *Transactions of the ASABE*, Vol. 53, No. 5, (October 2010), pp. 1705-1713, ISSN 0001-2351
- Ruiz-Garcia, L., Lunadei, L., Barreiro, P., & Robla, J. I. (2009). A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends. *Sensors*, Vol. 9, No. 6, (June 2009), pp. 4728-4750, ISSN 1424-8220
- Silva, A. C. de S., Arce, A. I. C., Souto, S., & Costa, E. J. X. (2005). A wireless floating base sensor network for physiological responses of livestock. *Computers and Electronics in Agriculture*, Vol. 49, No. 2, (November 2005), pp. 246-254, ISSN 0168-1699
- Strydis, C. (2005). Implantable microelectronic devices: A comprehensive study. *MSc Thesis in Computer Engineering*, Delft University of Technology, The Netherlands, June, 2005
- Tan, R., McClure, T., Schulam, P., & Schmidt, J. (2009). Development of a minimally invasive implantable wireless vital signs sensor platform. *Studies In Health Technology And Informatics*, Vol. 142, No.1, (January 2009) pp. 380-385, ISSN 0926-9630
- Tao, X., & Xin, H. (2003a). Acute synergistic effects of air temperature, humidity, and velocity on homeostasis of market-size broilers. *Transactions of the ASAE*, Vol. 46, No. 2, (April 2003), pp. 491-497, ISSN 0001-2351
- Tao, X., & Xin, H. (2003b). Surface wetting and its optimization to cool broiler chickens. *Transactions of the ASAE*, Vol. 46, No. 2, (April 2003), pp. 483-490, ISSN 0001-2351
- van den Brand, H., & van de Belt, K. (2006). Using telemetry to measure chicken embryo temperature: developing the technique. *Proceedings of the 12th European Poultry Conference*, Verona, Italy, September 10-14, 2006
- von Borell, E., Langbein, J., Despres, G., Hansen, S., Leterrier, C., Marchant-Forde, J., Marchant-Forde, R., Minero, M., Mohr, E., Prunier, A., Valance, D., & Veissier, I. (2007). Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals -- A review. *Physiology & Behavior*, Vol. 92, No. 3, (October 2007), pp. 293-316, ISSN 0031-9384
- Wang, N., Zhang, N., & Wang, M. (2006). Wireless sensors in agriculture and food industry-Recent development and future perspective. *Computers and Electronics in Agriculture*, Vol. 50, No. 1, (January 2006), pp. 1-14, ISSN 0168-1699
- Wathes, C. M., Kristensen, H. H., Aerts, J.-M., & Berckmans, D. (2008). Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall? *Computers and Electronics in Agriculture*, Vol. 64, No. 1, (November 2008), pp. 2-10, ISSN 0168-1699

- Yanagi, Jr., T., Xin, H., & Gates, R. S. (2002a). A research facility for studying poultry responses to heat stress and its relief. *Applied Engineering in Agriculture*, Vol. 18, No. 2, (March 2002), pp. 255-260, ISSN 0883-8542
- Yanagi, Jr., T., Xin, H., & Gates, R. S. (2002b). Measurement and control system for studying animal-environment interactions. *Proceedings of the World Congress of Computers in Agriculture and Natural Resources*, Iguacu Falls, Brazil, March 13-15, 2002, pp. 374-380
- Yilmaz, T., Foster, R., & Hao, Y. (2010). Detecting Vital Signs with Wearable Wireless Sensors. *Sensors*, Vol. 10, No. 12, (December 2010), pp. 10837-10862, ISSN 1424-8220



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Telemetry is based on knowledge of various disciplines like Electronics, Measurement, Control and Communication along with their combination. This fact leads to a need of studying and understanding of these principles before the usage of Telemetry on selected problem solving. Spending time is however many times returned in form of obtained data or knowledge which telemetry system can provide. Usage of telemetry can be found in many areas from military through biomedical to real medical applications. Modern way to create a wireless sensors remotely connected to central system with artificial intelligence provide many new, sometimes unusual ways to get a knowledge about remote objects behaviour. This book is intended to present some new up to date accesses to telemetry problems solving by use of new sensors conceptions, new wireless transfer or communication techniques, data collection or processing techniques as well as several real use case scenarios describing model examples. Most of book chapters deals with many real cases of telemetry issues which can be used as a cookbooks for your own telemetry related problems.

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