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Measurement and Simulation of Camel Core Body Temperature Response to Ambient Temperature

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ABSTRACT

The objectives of the study were to use a biotelemetry system for continuous measurement of camel core body temperature and to use a system identification technique to model and simulate the core body temperature response to diurnal changes in ambient temperature. Air and core body temperatures of five Arabian camels were recorded every thirty minutes over a six days period. During the course of this study, camels maintained their temperature near a constant level (36.5 °C ± 0.04). Deep body temperature response to ambient air temperature was modeled using a system identification technique. A linear difference equation (ARX model) was used to build a mathematical model from measured input (air temperature) and output (core body temperature). The parameters of the ARX model were estimated using the least squares method. Quality of the model was evaluated by simulation with input from a new data set. The model output was in good agreement with the measured one where the root mean square difference between measured and simulated output was 0.58°C.

Key Words: Measurement; Modeling; Simulation; Telemetry; Temperature response

INTRODUCTION

Interactions between livestock animals and the surrounding environment are very complex. Understanding the influences of environment on animals behavioral, physiological and immunological status is necessary for control and management of animal housing (Barnett & Hemsworth, 1990; Aerts *et al*., 2003; Al-Haidary, 2004). Homeothermic animals are continuously balancing heat loss and heat production to maintain a near constant body temperature. Information from measured core body temperatures were used to characterize stress levels of many livestock animals. Hahn *et al*. (1990 & 1992) investigated the thermoregulatory responses and feeding behavior of cattle and swine. To evaluate tympanic temperature thermoregulatory responses of cattle to thermal environment, Parkhurst and Hahn (1989) considered Data Dependent Systems (DDS) time series analysis, phase diagrams, spectral analysis and Green's functions analysis. Later, Hahn *et al*. (1992) proposed non-linear dynamic evaluations of tympanic temperature responses using fractal analysis for defining stress response thresholds. Poultry thermoregulatory response to heat stress conditions was reported by Aerts *et al*. (2003), Kettlewll *et al*. (1997) and Hamrita *et al*. (1997 & 1999). Air temperature and relative humidity were found to be affecting broiler body temperature response (Lacey *et al*., 2000). Aerts *et al*. (1999) modeled the static and dynamic responses of total heat production of broiler chickens to step changes of air temperature and light intensity.

Camels are homothermic animals. However, over a wide range of environmental conditions, body temperature of camels were found to fluctuate by a magnitude of 6°C, (Schmidt-Nielsen *et al*., 1957). They reported that the rectal temperature of healthy camels at rest can vary from 34 to more than 40°C during the summer, while diurnal changes in the winter are in the order of 2°C. Diurnal variation in rectal temperature of camel deprived of drinking water may exceed 6°C during the summer. On the other hand, the variations in rectal temperature of camels that have free access to water are around 2°C. There has not been any scientific characterization of the Arabian camel's deep body temperature and the available data are outdated. Therefore, the objectives of this study are to gain a better understanding of the body temperature control of the Arabian camels and to model the core body temperature response using a system identification technique.

MATERIALS AND METHODS

Experimental set up. Five, two years female, Arabian camels (*Camelus dromedarius*) average body weight 300 kg were used in this study to characterize in detail the diurnal rhythm of core body temperature. The animals were housed in the farm of animal production department College of food and Agriculture Sciences, in Riyadh, Saudi Arabia. They were fed twice daily at 0700 and 1600 h, and watered *ad libitum.* Ten days prior to the initiation of the study, all animals were surgically implanted intraperitoneally with calibrated telemetric temperature transmitters (Mini-Mitter Co. Inc.; Model VHF-T-1; Sun River, Oregon) for monitoring continuously core body temperature at thirty minutes intervals throughout the experiment. Temperature calibration coefficients were generated by collecting time interval data from the transmitters at two known temperatures. Prior to calibration, the transmitters were placed in a water bath with a magnetic stirrer and precision thermometer. The transmitters were placed one inch apart to avoid possible interactions affecting the signals. Two different temperature points were required, low and high points. The low temperature was approximately 26^{o}C and the high temperature was 45^{o}C.

Ambient air temperature was monitored continuously using data logger (Pace Scientific, USA), and relative humidity was recorded thorough the study using a hygrograph. Data were collected for six connectives days.

Surgical procedure. Animals were fasted 24 h, and water was withheld 12 h prior to surgery. Camels were restrained and the left side of the flank of each animal was cleaned and shaved for an adequate area surrounding the surgical site, surgically scrubbed with antiseptic solution (1% Iodine solution), and rinsed with 70% alcohol. Finally, the skins were sprayed with antiseptic solution and allowed to dry. The surgeries were performed with animals locally anesthetized. A 20 cm vertical incision was made in the middle of the left skin and musculature for insertion of the temperature transmitter (40 mm diameter, 70 mm length). After surgery, all animals received 10,000 im ib procaine pen G for three days. Skin sutures were removed 10 days post-surgery.

Model development. To simulate the dynamic core body temperature response of the camel to the diurnal changes in air temperature, a system identification technique was used. System identification allows building mathematical models of a dynamic system based on measured input-output data. This can be accomplished by adjusting parameters within a given model until its output coincides as well as possible with the measured output. A linear difference equation ARX (Auto Regressive with exogenous variable) model with single-input-single-output (SISO) was assumed. Fig. 1 shows a general black box system, where air temperature is the input signal and the core temperature is the output signal.

The polynomial transfer function of such a model can be expressed as:

y (t) = q-nk (B(q)1A(q)) u (t) + (I1A(q)) e (t) (Ljung, 1987)

Where:

y (t) = output (core temperature) at time t, u (t) = input (air temperature) at time t,

e (t) = prediction error or disturbance at time t,

A (q), B(q) = polynomials in the delay operator q', A(q) = 1 + a, q' +............+ ana q na,

B(q) = b, +b2 q. +............ + bnn q°b+,~

a; bj = model parameters to be estimated,

A simple linear difference can be written as follows:

A (q) y (t) = B (q) u (t - n k) + e (t)   (2)

Equation (2) usually written in more explicit from as:

y(t)+a, y(t-1)+....+ana y(t-na) = b, u(t-nk) + b2 u (t-nk-1) + ... + bnb u(t-nk-nb + 1) + e(t)

Equation 3 is thus entirely defined by the three integers na, nb and nk. na is equal to the number of poles and nb-1 is the number of zeros, while nk is the pure time-delay (the dead-time) in the system. For a system under sampled-data control, typically nk is equal to 1 if there is no dead-time. MATLABw System Identification Toolbox® software was used to estimate the model parameters. The resulting model was evaluated based on the root mean square difference between measured and simulated output.

RESULTS AND DISCUSSION

Collected data during the six days period were processed to obtain the model parameters and simulate the core temperature response. To determine if there are any effects in the output signal (core body temperature) as a result of the change in the input signal (air temperature), the recorded input and output data were plotted as shown in Fig. 2. Clearly, the figure shows the output follows the same sinusoidally diurnal pattern of the input but with lower amplitude. We did not observe the high diurnal variations in camel's core temperature as already reported by Schmidt-Nielsen *et al.* (1957). The sinusoidally diurnal pattern in air temperature during the six days period were almost constant despite some slight changes that occurred from day to another. The peak air temperatures were close to 40°C, while the low temperatures were around 27°C.

In a recent study, we have shown that T_{core} of camels exhibited a monophasic variations with one peak and one trough, reaching maximum at noon and minimum during early morning, with an amplitude of 0.5^{o}C (Al-Haidary, 2006). These finding are concordant with other authors working with different species. A distinct T_{core} rhythm was reported in cattle (Lefcourt & Adams, 1996; Brown Brandl *et al*., 2003) sheep (Sudarman & Ito, 2000) and gazelle (Al-Johany *et al*., 1998; Fuller, 2004). Monitoring T_{core} with a

Table I. The coefficients a and b of the ARX model and their standard deviations

	a_1	a_2	a_3	a_4	b_1	b_2	b_3	b_4
Estimate	-3.7892	5.5711	-3.7688	0.9909	-0.0012	0.0030	-0.0029	0.0010
Standard Deviation	0.0233	0.0675	0.0685	0.0244	0.0024	0.0071	0.0070	0.0024

Fig. 1. Input u (t), output y (t), and disturbance e (t)

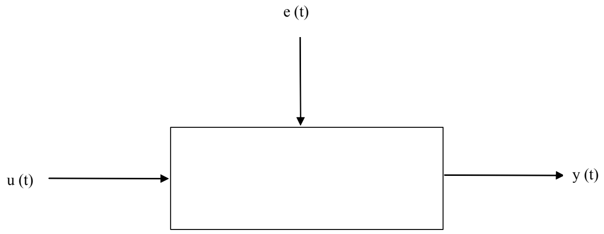


Fig. 2. Recorded input (air temperature) and output (core body temperature) during six consecutive days

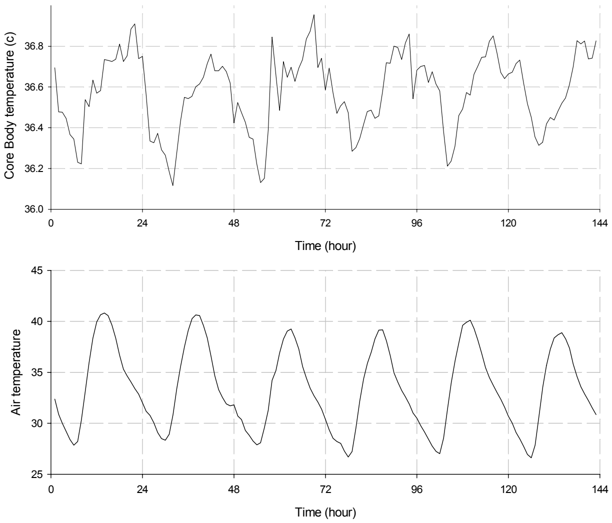
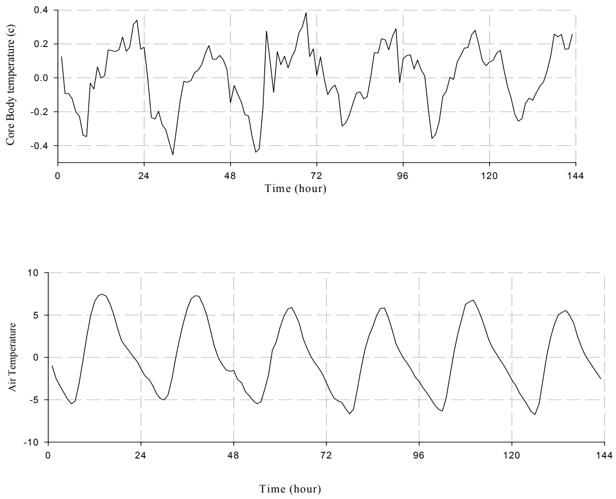


Fig. 3. The change in input and output signals after the mean values were removed



telemetry system in this study shows that camels are homoeothermic animals and they can maintain near constant body temperature over a wide range of environmental conditions, in the range of 36 to 37°C in agreement with other authors (Schroter *et al.* 1987; Ayoub & Saleh 1998). Core body temperature of camels exhibited a circadian rhythm reaching maximum at 2100 h (36.82^{o}C) and minimum at 0800 h (36.21^{o}C) with 0.61^{o}C amplitude.

Observing the 24-h air temperature rhythm by data logger revels that air temperature reaches minimum value (27.4^{o}C) at 0600 h, then start to rise until it reaches a high point of 39.8^{o}C at 1400 h. T_{core} follow the same sinusoidally diurnal pattern of the air temperature but with lower amplitude. There was 2 - 3 h lag between the maximum air temperature and the maximum T_{core}.

Mean values or linear trends from the measured signals were removed through a detrending process. Fig. 3 shows the changes in measured input and the output signals after the mean values were removed. Data were then divided into two portions. One portion of the measured data were selected for estimation purposes and another portion for validation purposes. The high frequency noise from the measured input and output signals were removed through a linear filter (the same filter for all signals). Fig. 4 shows the filtered input and output data of the two selected portions of the data.

The ARX model parameters were estimated from the sample of the data (solid line in Fig. 4) that were designated for estimation purposes. The coefficients a and b in the ARX model (Equation 3) were estimated using the Least Squares method, which minimizes the sum of squares of the right-hand side minus the left-hand side of the equation, with respect to a and b. The order of the polynomial coefficients (na, nb & nk) of many model structures was estimated simultaneously. The best resulting model had the

Fig. 4. Filtered input and output signals. Solid line data were used for estimation purposes while the dash line data used for validation purposes

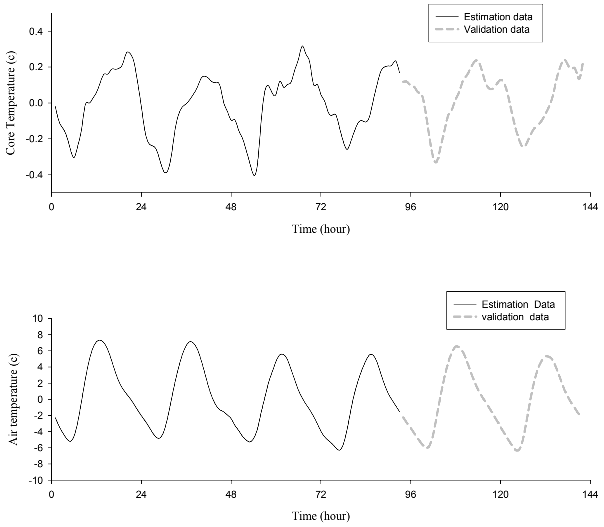
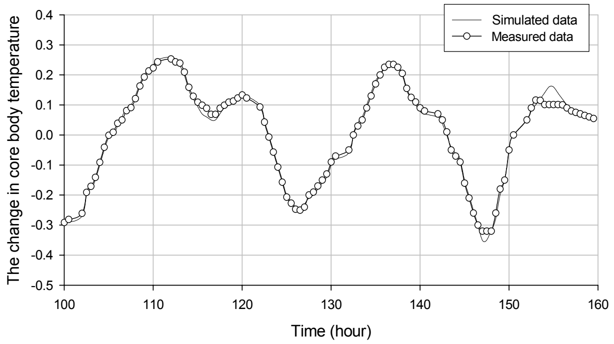


Fig. 5. Measured and simulated core body temperature using ARX model



following order of the polynomial coefficients: na = 4, nb = 4, and nk = 1. The estimated coefficients a and b of the ARX model and their standard deviations are summarized in Table I. A very good way of obtaining insight into the quality of a model is to simulate it with the input from a fresh data set, and compare the simulated output with the measured one. Fig. 5 shows the simulation of the ARX model using a new validation data set. By comparing the measured and the model output, it is very clear the properties of the system have been picked up by the model and the root mean square difference between the measured and simulated core temperature was around 0.58°C.

CONCLUSION

It was found that the camel maintained a near constant body temperature (around 36.5°C ± 0.04) during the six days period. The core temperature followed the same sinusoidally diurnal pattern of the air temperature but with lower amplitude. The model used in this study was able to simulate the measured core temperature very closely, although we had only tested the model response to a single input. Further studies are needed to test the response to multi- inputs under different environment conditions and to include analysis of the dynamic properties of the system.

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