Long Term Rumen Temperature Analysis of Dairy Cattle with Help of Bolus Sensor

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***Abstract*—The article contains the analysis of data from a dairy cattle rumen bolus experiment. The bolus contained a 3D accelerometer and a thermometer and was used to monitor a cow for 9 days. The frequency of drinking could be determined from the measured temperature data, checked on the basis of the control video recording. The monitoring of changes in the cow's body temperature was also analyzed based on the measured data series.**

***Keywords*—dairy cattle, rumen bolus**

I. Introduction

In the modern economy, there is an increasing demand for economical production, which typically manifests itself in the automation of processes. This phenomenon has also reached precision agriculture and dairy farms. As a result, the continuous increase in the size of herds, the creation of farms often containing several thousand animals, and the continuous decrease in the amount of human labor can be observed. At the same time, increasing the milk yield per cow is also a requirement. This strict set of requirements can only be fulfilled by using the cutting edge technical possibilities. Thus, the need for continuous monitoring of farm animals also arose [1]. In addition to the goals mentioned above, the basic requirements of animal welfare were already formulated in the 1970s, and farms are trying to pay more and more attention to complying with them. What are these principles? In 1979, the FAWC (the UK's Farm Animal Welfare Council) formulated the 5 basic animal rights, freedom from hunger and thirst, from discomfiture, from pain, injury and disease, from fear and distress and freedom to express most normal behaviors. At the same time, it became clear that the observance of fundamental rights cannot be evaluated objectively [2]. The EU FP6 research program eventually developed semi-objective protocols for animal welfare assessment. The definition of good health was absence of disease, injuries and pain, with physical, social and mental well-being assessed through four measures of appropriate behavior [2]. Along these principles, it is advisable to develop monitoring systems that can indicate phenomena and problems related to animals, and can provide information and alerts to farmers in relation to animals. Such a possible monitoring system can be created with the help of a complex sensor placed in the cattle's rumen [3], which measures the conditions of the cow's rumen with several sensor modalities, processes the information and sends it to the integrated animal welfare monitoring system. Such a system can detect problems related to feeding the cow [4], the animal's illness [5], lameness, heat stress during warm episodes in summer, but it can also indicate to the farmer the cow's estrus or the onset of calving [2].

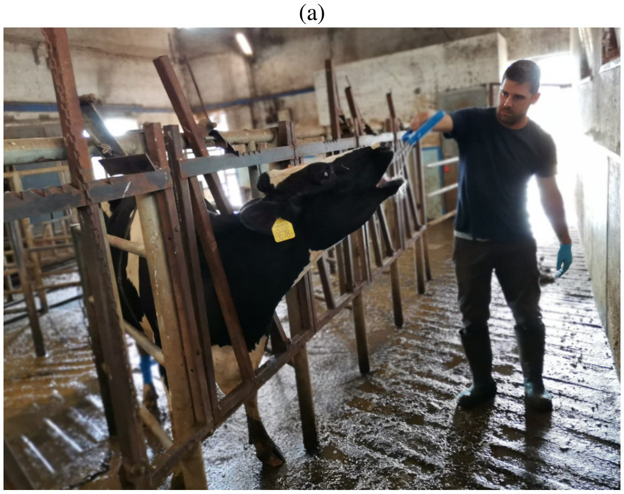
In this publication, we would like to present such a sensor experiment and, during the processing of the temperature data measured by the sensor, we are looking for the answer of what questions the continuous measurement of the rumen temperature helps to answer, what physiological information it provides us with. There were similar attempts in the literature earlier [6]. Chapter II of the article presents the architecture of the sensor and the measurement system. Chapter III. discusses the evaluation of the received data and the interpretation of the results. The final version of the bolus is planned for working at least 2 or 3 years long, which is reachable if the communication events are radically restricted and the sent data amount also limited. In this preliminary experiment the main aim was to get real sensor data from the system for data processing and data compression algorithm development.

II. Measurement method

This measurement was intended to be a preliminary experiment. A bolus sensor meant to be used throughout the entire life of a cattle must be optimized in terms or energy consumption with constrained sampling and processing strategies with as few radio communications as possible. As the opposite, an experimental bolus has to serve raw, unprocessed data with continuous sampling, with the same sensors and physical layout of the final design, if possible. The bolus has two integrated sensors: a triaxial accelerometer and a temperature sensor. Based on previous experience the sample rate was set to 25 Hz in case of the accelerometer and to 1 Hz for the temperature sensor. The collected raw data was sent to the gateways through a custom error resilient radio link, where the data is collected for off-line processing.

The sealed, water-tight bolus sensor was injected to one test animal at Agárdi Farm Kft. Seregélyes (see Fig. 1).During the´ time of the application the animal was taken into a cage to prevent injuries and to provide easier access. As a control, the behavior of the animal was regularly inspected and video recordings were also made.

(a)



(b)

Fig. 1: Injecting the bolus sensor into the rumen of the cattle with the applicator. (a) The applicator is inserted in its total length. (b) The applicator is pulled out after injecting the bolus.

Every collected data was stored with timestamps. Temporal positioning of the recorded video data was achieved by regularly showing a clock to the camera, to create reference points.

During the first phase of the data processing only the temperature measurements were analyzed (see Chapter III.).

A. Hardware architecture

The experimental rumen bolus sensor is built into a durable water-tight enclosure. The cylindrical device has a diameter of 40 mm and length of 140 mm, and made from POM-C plastic. The enclosure has a cavity inside formed as a blind hole with diameter of 36 mm and length of 135 mm. The power source is a 3 V D type battery, which is able to store 14 Ah of capacity.

The main component of the electronic part is an ST STM32L496RET6 microcontroller with a maximum clock of 80MHz PLL. The bolus is equipped with 2 different sensors:

- A Sensirion STS35 thermometer
- An ST LSM6DSO triaxial accelerometer

The radio communication chip is a Würth AMB3626-M, operating on 169MHz. The software running on the microcontroller measured 1 temperature and 25 acceleration samples each second and sent this data through the radio link to the gateways. Each packet was transmitted two times to make the system more robust.

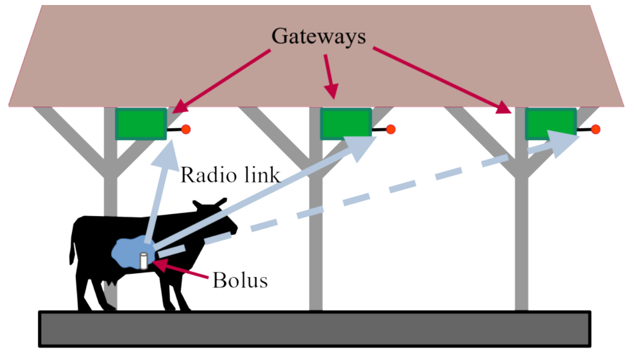


Fig. 2: The architecture of the experimental measurement setup

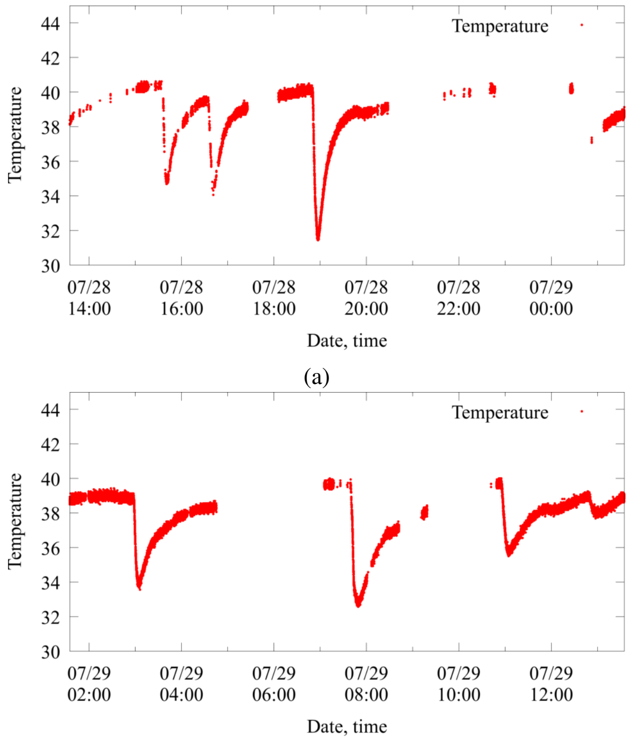
The test area (approx. 100 m $\times$ 15 m) was covered with 3 gateways. The hardware of the gateways is based on the Raspberry Pi 3B single board computer, which runs the data collection software. Measurement records are collected into CSV files. Time synchronization is done with Network Time Protocol (NTP) through 4G cellular connection. The architecture of the measurement system is shown in Fig. 2.

III. Results and Discussion

In this paper the temperature measurements and data analysis is presented. First the data collected by the 3 gateways were cleaned and merged. Then the time series were split into 12-hour intervals and each segment was visualized. Fig. 3 shows two example 12-hour intervals.

TABLE I: Drinking events and temperature data during the experiments

Date	Drinking events	Drinking events in rarefaction	Maximum daily temperature
28/07	6	5	33.41
29/07	7-8	7-8	35.6
30/07	5	5	25.08
31/07	5	6	26.67
01/08	8	8	31.34
02/08	8	8	34.15
03/08	7	7	34.12
04/08	3	2	35.68



(a)

(b)

Fig. 3: The temperature of the rumen measured during a 12-hour period from noon to midnight (a) and from midnight to noon (b).

A. Data integrity

During the data cleaning and merging phase the nature of data integrity was well observable. Since the bolus had to be powered on approx. 2 days before the experiment to let the silicon sealing dry, the first received real measurement data packet has a sequence number of 64301. Then the sequence numbers were increasing for approx. 8 days. When the battery started to run low the bolus started to keep resetting at every few minutes, resulting in unstable measurements.

In the experiment 3 gateways were used to provide a broader coverage. As opposed to the expectations most of the data packets were received either by all the 3 gateways, or none of them at all. Probably in some positions (like lying) or when the direct line of sight between the bolus and the receiver antenna was covered by another cattle the attenuation was too high. Smaller and larger gaps are clearly visible in Fig. 3. Note that the cattle are regularly moved from the barn to another locations e.g. for milking.

B. Data quality

Assuming, that the mass of the rumen of the cattle is large (note that its volume is approx. 0.12 m^3) the temperature can be considered constant in the minute-scale. However in Fig. 3 a thick line is visible, which suggests a high noise level. To estimate measurement error a continuous sample series for 30 minutes was selected from a calm time interval (see Fig. 4), then the most important statistical properties were calculated. The mean of the sample is 38.99 °C and the standard deviation is $\sigma = 0.12$ °C. This is in a good concordance with the factory description of this temperature meter sensor. The maximum and minimum values were 38.5 °C and 39.44 °C, being -0.49 °C and +0.45 °C from the mean.

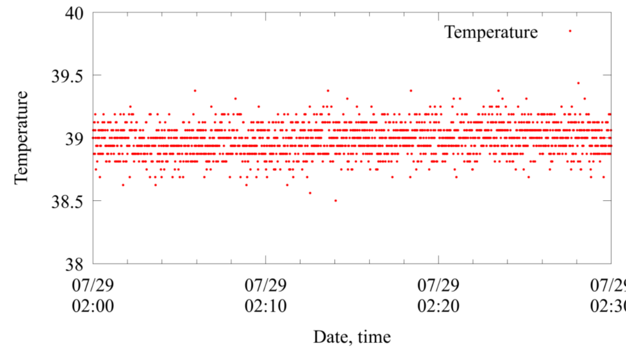


Fig. 4: The selected data slice.

The quantization of the measurements is clearly visible. The resolution of the thermometer is $\frac{1}{16}$ °C.

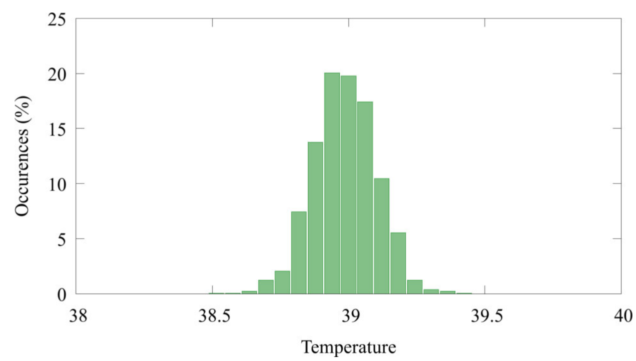


Fig. 5: The histogram of the selected slice.

The histogram of the slice of data is shown in Fig. 5, showing a Gaussian distribution.

C. Data analysis

In both Fig. 3(a) and (b) 3 large negative peaks are visible. In the (a) graph another similar peak is probable, but it is invisible, due to the missing data. In the (b) graph another, much smaller negative peak is visible with slightly different nature. The larger negative peaks belong to drinking events in good concordance with the literature [7]. The water intake happens nearly instantly at this time scale. The water intake happens nearly instantly at this time scale. The temperature of the water available in the barn is approx. 14 °C. It mixes with the content of the rumen and the resulting temperature gives the minimum of the negative peak. Note that some time is required for the mixing and for the bolus to follow the temperature change. After this point an approximately exponential warming up follows, when the rumen content reaches the original temperature.

During the 8-day period a total of 51 drinking events were observed based on the temperature data, which were approximately uniform in each day. Drinking behavior was not significantly different between daytime and night. Daily drinking events were determined from the measured temperature curve (Table I.). The measurements were done during hot summer days, so it was interesting the correlation between drinking events and daily maximum temperature. The Pearson correlation was 0.052 that means no correlation between temperature and number of drinking events. It is possible that the amount of water drunk is correlates with the temperature so later it should be investigated with appropriate mathematical model and measured controls.

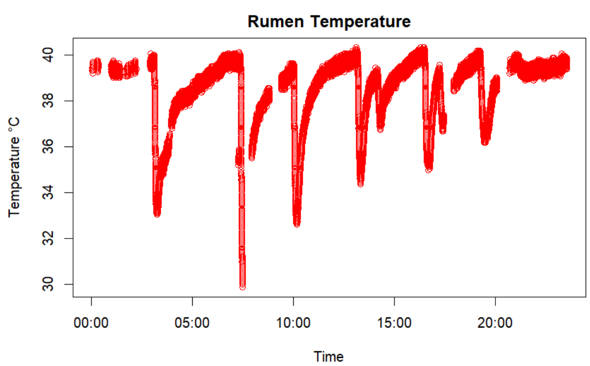


Fig. 6: Drinking events on native temperature data

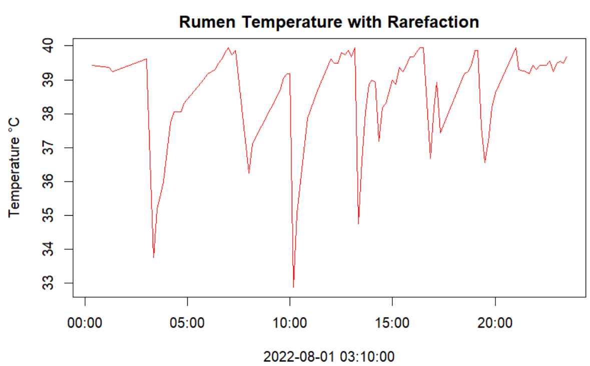


Fig. 7: Drinking events on resampled temperature data series (measurement period 10min)

In the next experiments the aim is to measure longer interval, which is achievable by decrease the frequency of measurements. So the original dataset was resampled to select measurements only every 10 minute (sampling frequency 1/600 Hz). This resampled data is shown on Fig.7. The line is thin because the noise of the sensor is not visible due to resampling. The large negative peaks connected to the water intake are also visible on this chart. The drinking events were determined and counted from the graph (Fig 7.) and Table I. shows the results which are relevant comparing with the higher frequency measurement. Mean error is 0.38. However, the

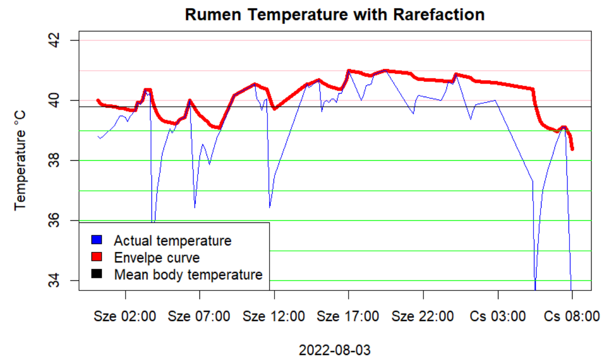


Fig. 8: Detection of estrus based on the temperature meter measurements

minimum values of the resampled graphs sometimes largely differ from the original chart, because the temperature fall after drinking is relatively quick, its duration between 20 and 30 minutes. Temperature measurements are useful in detection of drinking events and detection of illnesses or other physiological events connected with temperature changes (etc. estrus). To detect the base body temperature an envelope curve was created to compensate the effect of drinking on the body temperature. The standard deviation of the temperature is 0.12 and the temperature changes during the drinking is at least 5-6 °C. So the interval maximums were calculated (at first in every 6 hours), and the points of the curve were detected with a weighted average between maximum and actual temperature, in which the positive deviation is weighted with 20-fold weight. So the drinking threshold is 2-4 °C. The Figure 8 shows an example of the envelope curve. This envelope curve possibly reflects the real body temperature – however, it should be strengthened with further experiments. Figure 8. shows the body temperature in a two days' period. In this period the estrus is detectable (smaller temperature increase wave and after starts the estrus near 1 °C temperature increase for 12-18 hours. [8]) This detection should be support yet with activity data.

IV. Summary

In this paper a long-term measurement was presented with a rumen bolus sensor. A sensor device was applied into the rumen of a dairy cattle, which measured acceleration and temperature data continuously for 10 days. The temperature data was processed and the typical pattern of drinking was identified. These patterns can easily be detected even with a much sparse sampling, even within the future bolus. The base rumen temperature also was detected, which can be applicable to monitor the health status of the animal or detect important physiological events as estrus.

Acknowledgment

"This research was funded by NKFI Hungary, grant number 2020-1.1.2-PIACI-KFI-2020-00109". The authors would like to thank to Levente Kovács MATE Hungary for his advice and Agárdi Farm Kft. Seregélyes to help in the investigation.

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