Validation of a new health monitoring system (RumiWatch) for combined automatic measurement of rumination, feed intake, water intake and locomotion in dairy cows

Nils Zehner[1,4]*, Joël J. Niederhauser[2], Franz Nydegger[1], Anne Grothmann[1], Markus Keller[1], Matthias Hoch[3], Angelika Haeussermann[4], Matthias Schick[1]

[1]Agroscope Reckenholz-Tänikon ART, 8356 Ettenhausen, Switzerland
[2]InnoClever GmbH, 4410 Liestal, Switzerland
[3]Itin + Hoch GmbH, 4410 Liestal, Switzerland
[4]Christian-Albrechts-University, Institute of Agricultural Engineering, 24118 Kiel, Germany

**Corresponding author. E-Mail: nils.zehner@art.admin.ch*

Abstract

Ruminating activity and feed intake are important non-invasive measurable parameters of ruminant health. In present dairy farming, health problems are causing more than 50% of early cullings of lactating cows. Still a reliable method for automatic measurement of rumination activity and feed intake is not yet available. For this reason a newly developed health monitoring system for dairy cows (RumiWatch) at research station Agroscope Reckenholz-Tänikon ART, Switzerland, aims at the early identification of metabolic problems in ruminants. The sensor-based system enables automatic measurement of rumination, feed intake, water intake and locomotion. It incorporates a noseband sensor, data logger with on-line data analysis, pedometer and evaluation software. The data are transmitted wireless or using a SD Memory Card to a computer operating the evaluation software. The low-energy system has a focus on long-term (months to several years) operating time at minimized energy consumption. Automatic measurement of parameters is based on a generic algorithm without animal specific learning data. Detailed on-line analysis enables quantification of total rumination time, number of boli and chews per bolus while ruminating. Equivalent analysis is conducted for additional parameters (feed intake, locomotion). For validation of automatic measurement, the evaluation data were analyzed in comparison with direct observation and video observation. Results show that the concordance in quantification of jaw movements by automatic and by visual evaluation was R^2 = 0.7908 for ruminating jaw movements and R^2 = 0.7691 for eating jaw movements. The current RumiWatch health monitoring system is suitable for research and advisory purposes. Going through further stages of development it can contribute to an improved management of animal health to secure animal welfare and profitability of dairy farming.

Key words: automatic measurement, health monitoring system

1. Introduction

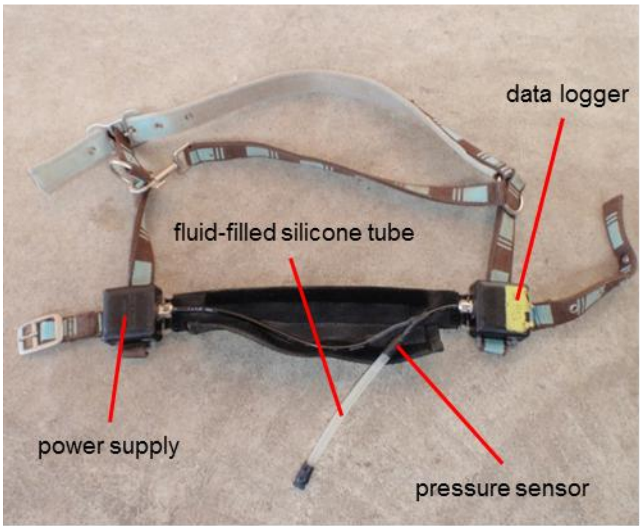
Metabolic disorders of dairy cows are a problem with high physiological and economic impact. Especially ruminating activity is considered an important non-invasive measurable factor for early identification of metabolic problems in ruminants. The automatic measurement of ruminants chewing and ruminant activity can enable the early detection of feeding deficiencies and thus facilitate a decision to adjust the ration. Several studies have been aiming at the development of a technical or automatic method for measuring rumination and feed intake in ruminants (Rutter et al., 1997; Ungar & Rutter, 2005; Nydegger et al., 2011). Also the automatic measurement of locomotion has gained an increasing scientific interest (Scheibe & Gromann, 2006; Mol et al., 2009). Solutions for automatic recording or analysis of animal behavioral parameters have a focus on scientific and counseling purposes. A potential field of application also has to be seen in intensive livestock farming systems with high numbers of individuals, high level of productivity and thus high management expenditure. Considering automatic measurement of rumination and feed intake, the equipment available on the market is either unsuitable for use in modern loose housing systems with head gates or does not allow individual jaw movements to be recorded.

Studies at research station Agroscope Reckenholz-Tänikon ART, Switzerland, are aiming at the development of a reliable system for early identification of metabolic problems in ruminants. The RumiWatch project was initiated by research station Agroscope Reckenholz-Tänikon ART, Switzerland and funded by the Swiss Commission for Technology and Innovation CTI. The objective is to provide a method for combined automatic measurement of rumination, feed intake, water intake and locomotion. Further intent is to contribute to an improved management of animal health and so to secure animal welfare and profitability of dairy farming. Research activities are conducted in collaboration with commercial (Itin + Hoch GmbH, InnoClever GmbH) and scientific partners (Department of Veterinary Medicine at Zurich University, Schluechthof Agricultural School) for successive development of a profound health monitoring system for dairy cows (RumiWatch).

2. Materials and methods

2.1 Health monitoring system and operating principle

RumiWatch (Itin + Hoch GmbH, Liestal, Switzerland) is a sensor-based system enabling automatic measurement of rumination, feed intake, water intake and locomotion. It incorporates a noseband sensor, data logger with on-line data analysis, pedometer and evaluation software. The noseband sensor is similar to the method developed by Nydegger et al. (2011). It consists of a vegetable oil-filled silicone tube with a built-in pressure sensor placed in the casing of a halter over the bridge of the cow's nose (Fig. 1).



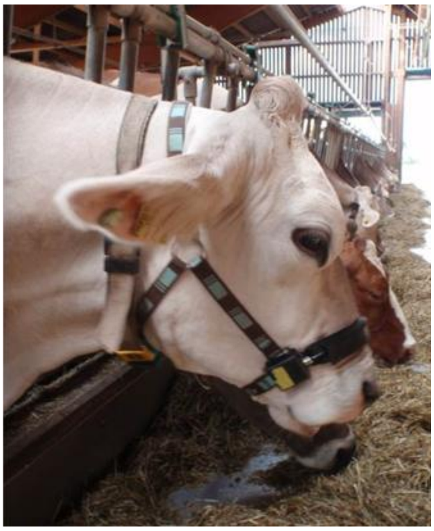


FIGURE 1: RumiWatch noseband sensor containing a fluid-filled silicone tube with built-in pressure sensor and two electronic units

The curvature of the noseband is altered by the cow's jaw movement, causing a pressure change in the silicone tube. The pressure sensor is connected to a data logger placed in a protective casing on the right side of the halter. A second casing on the left side of the halter serves for storage of power supply. The data logger registers the pressure in the noseband sensor at a constant logging rate of 10 Hz and saves the raw data to a SD Memory Card. Selectable formatting of the memory card allows a recording period up to four months. The data are transmitted wireless or using a SD Memory Card to a computer operating the evaluation software ("RumiWatch Manager"). The low-energy system has a focus on long-term (months to several years) operating time at minimized energy consumption. Due to ultra-low power components predicted battery lifetime is up to three years under laboratory conditions. Automatic measurement of jaw movements is based on a generic algorithm without animal specific learning data. The system allows individual jaw movements to be recorded. Incoming pressure data are automatically classified as "ruminating", "eating", "drinking" or "other activity". Detailed on-line analysis enables quantification of total ruminate time, number of boli and chews per bolus while ruminating. Equivalent analysis is conducted for additional behavior parameters (feed intake, water intake).

The cow's motion states are measured via a three-dimensional accelerometer that functions as a pedometer. Data logger, data storing and transmission, logging rate and energy management are identical to the previously described noseband sensor. Pedometer analysis algorithm allows classification und quantification of different motion states, i.e. walking, lying, and standing. Electronic and software components of RumiWatch were developed by InnoClever GmbH (Liestal, Switzerland).

2.2 Validation method

For validation of automatic measurement the evaluation data were analyzed in comparison to direct observation and video observation of high-yielding dairy cows. The method chosen for validation was a parallel registration of the animal's activities by RumiWatch and by visual observation. The aim was to determine the measuring accuracy of algorithms applied for automatic classification and quantification of jaw movements (noseband sensor), and classification of motion states (pedometer). The validation criteria and observation methods for the different kinds of behaviors are outlined in Table 1.

TABLE 1: Validation criteria and observation methods for validation of automatic measurement by the method RumiWatch

Behavior	**Validation criterion**	**Observation method**	**Cows [n]**	**Sample size [min]**
Rumination	Classification, quantification of ruminating jaw movements	Direct, visually	12	435.0
Feed intake	Classification, quantification of eating jaw movements	Direct, visually	12	530.0
Water intake	Classification of drinking jaw movements	Video, visually	5	172.2
Locomotion	Classification of motion states (walking, standing, lying)	Video, visually	2	4614.6

Direct visual observations of rumination and feed intake were conducted with a total number of 12 cows (six in first lactation, six in second or higher lactation) during 14 days by using a tablet computer (teXXmo kaleo 104, teXXmo Mobile Solution GmbH & Co. KG, Böblingen, Germany) with touchscreen display. Jaw movements were registered and counted in a spreadsheet (MS Excel) modified with VBA-routines for direct observation of behavior parameters (with time stamps). Each jaw movement (ruminating or eating) was registered with its date and time, to the second. Thus concordance of visual and automatic evaluation can be analyzed with a very high resolution.

For validating the automatic measurement of water intake, sensor data were compared to observer protocols of drinking bouts, based on continuous video observations of a total number of 5 cows for 22 days. For video observation of water intake, an infra-red zoom camera (EverFocus EZ430, EverFocus Electronics Corporation, Taipei, Taiwan) was mounted above the trough (Suevia Tip-Over Trough, length 1.5 m, capacity 70 l, water flow up to 25 l/min, Suevia Haiges GmbH, Kirchheim, Germany). So drinking behavior of cows equipped with noseband sensors was recorded from bird's eye view, continuously by day and night.

For validation of motion states (walking, standing, lying), sensor data were compared to observer protocols based on continuous video observations of two cows on three consecutive days per cow. For video observation of motion states, a wide-angle color camera (Panasonic WV-CP450, Panasonic Corporation, Osaka, Japan) was mounted at the roof joist in the stable above the group of experimental animals to be observed.

Cows were kept in a loose housing system with cubicles, solid flooring, and half-automated manure removal. A total mixed ration with different proportions of concentrate and forage was provided by an automated feeding system (Pellon Group Oy, Ylihärmä, Finland).

2.3 Data analysis

Statistical data analysis was conducted with the program MATLAB (Version 7.10.0, Edition R2010a, The MathWorks Inc., Natick, USA). The program was running a specified script enabling a comparison of sensor data and observer protocols exact to the second. Contemporaneous segments (*i*) of 5-minute-intervals were extracted both from the sensor data and observer protocols. Selection criteria for the segments were that they were definitely and solely classified as either ruminating or eating by visual observation. Afterwards the variance in quantification of jaw movements between visual and automatic evaluation was evaluated statistically. The measuring accuracy was determined by calculating the mean absolute percentage error (MAPE) between jaw movements counted visually by direct observation (considered true value) and automatically by RumiWatch (considered experimental value) for all segments analyzed (Eq. 1):

$$MAPE = \frac{100\%}{N} \sum_{i=1}^{N} \frac{JMV_i - JMA_i}{JMV_i} \qquad \text{(Equation 1)}$$

JMV = jaw movements counted visually (true value)
JMA = jaw movements counted automatically (experimental value)

Additionally, the standard error of the mean and the coefficient of determination were calculated for all segments in the sample. Equivalent data analysis was conducted for rumination and feed intake.

3. Results

3.1 Validation of rumination and feed intake

The calculated accuracy in measurement of rumination and feed intake is shown in Table 2.

TABLE 2: Mean absolute percentage error (MAPE), standard error of the mean (SEM) and coefficient of determination (R^2) between jaw movements counted visually by direct observation and automatically by RumiWatch (p-value < 0.05)

Parameter	Segments [N]	MAPE [%]	SEM [%]	R^2	p
RJM	87	-0.56	3.86	0.7908	< 0.05
RJM/BOLUS	87	0.61	15.31	0.6065	< 0.05
EJM	106	4.25	8.5	0.7691	< 0.05

RJM = Ruminating jaw movements
RJM/BOLUS = Ruminating jaw movements per bolus
EJM = Eating jaw movements

3.2 Validation of water intake

As a result, a specific pressure profile of water intake recorded by the noseband sensor was found that is clearly distinguishable from those of rumination and feed intake (Fig. 2).

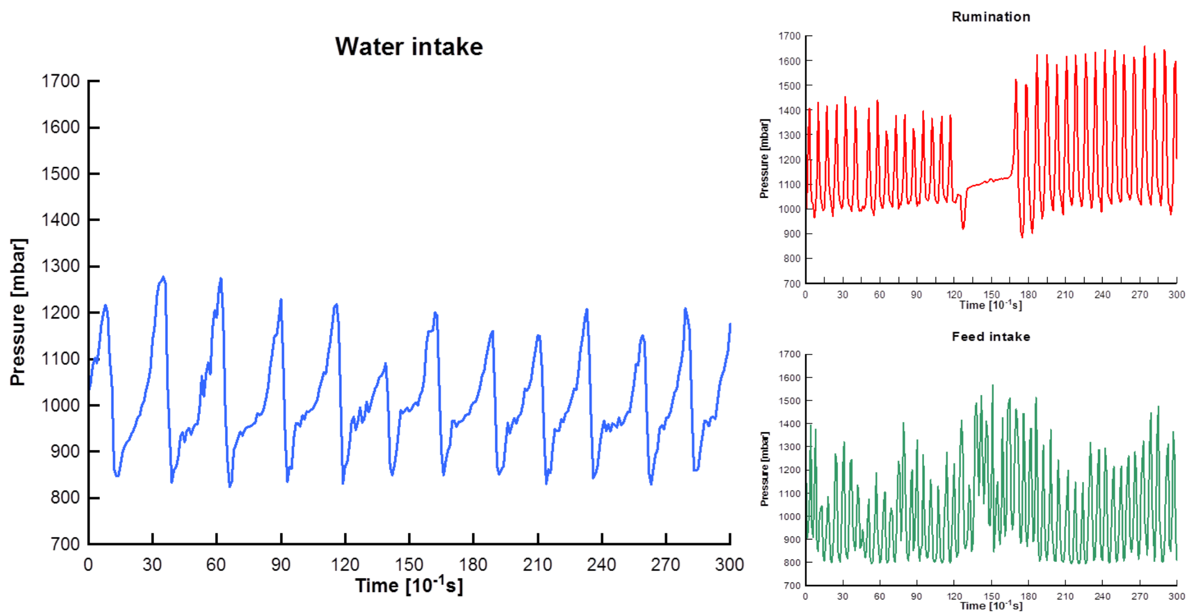


FIGURE 2: Comparison of pressure profiles during water intake, rumination and feed intake, taken from the same animal and noseband sensor, plotted over 30 seconds

A provisional algorithm is able to identify drinking bouts in recorded sensor data of different cows. The implementation of a robust analysis algorithm for automatic measurement of water intake behavior by the RumiWatch system is in full development. Detailed validation of automatic measurement of water intake will be shown in subsequent publications.

3.3 Validation of locomotion

Preliminary algorithms enable to classify walking, standing and laying behavior. Implementation of a robust algorithm for automatic measurement of dairy cows' motion states by RumiWatch is in full development. Detailed validation procedure for automatic measurement of motion states and detection of lameness is in progress. Results will be described in subsequent publications.

4. Discussion

Parallel registration of jaw movements using a tablet PC allows comparison of visual and automatic evaluation with a very high resolution and is advantageous for structured data processing and data analysis. The accuracy of automatic classification and quantification of jaw movements by RumiWatch is satisfying, considering that no animal specific learning data were used and it is still possible to fine-tune the analysis algorithm. With special regard to energy management and storage capacity, the method RumiWatch has significant advantages over the IGER behavior recorder (Rutter et al., 1997) and the ART-MSR-sensor (Nydegger et al., 2011). Post-processing of measurement data is superfluous, as long as no higher measuring accuracy than previously shown is demanded by the user. The finding that water intake behavior of dairy cows can be registered automatically using a noseband sensor and without any stationary measuring instrument has not been described in scientific literature before. The pressure profile of water intake behavior logged by the noseband sensor can be clearly distinguished from rumination and feed intake behavior by visual examination. In future investigations, parallel water flow measurement at the trough aims to clarify remaining uncertainties. Further intent is to determine the feasibility of an algorithm for noseband sensors that enables volumetric valuation of animal specific water consumption.

5. Conclusions

In its current state, the RumiWatch health monitoring system is suitable for research and advisory purposes. Further research is required for the initiation of threshold values (“alert values”) and detection of health condition changes (“healthy”, “affected”, “sick”). The critical values need to be defined for rumination and feed intake as well as for water intake, locomotion and resting behavior. Therefore a profound database has to be established, consisting of animal data representing either healthy or animals at different stages of health impairment, e.g. lameness or ruminal acidosis. Such alert system enables an early recognition of health problems, metabolic disorders and feeding deficiencies indicated by reduced ruminating activity, feed intake and water intake. The user can benefit from the system for nutrition management and in future, as a health and cow’s welfare sensor. Diagnosis of and reactions to critical conditions can be made and exerted at an early stage by veterinarians and dairy farmers. Furthermore the RumiWatch system may serve as an appropriate tool for research activities on chewing activity and feed evaluation.

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