VALIDATION OF RUMIWATCH NOSE-BAND SENSORS FOR MEASURING NUTRITIONAL BEHAVIOUR OF DAIRY COWS

Kabylbekova Dinara
MSc Thesis
Green Biotechnology and Food Security
University of Eastern Finland
Faculty of Science and Forestry
Department of Environmental and Biological Sciences
September 4, 2016

UNIVERSITY OF EASTERN FINLAND
Faculty of Science and Forestry, Department of Environmental and Biological Sciences
Green Biotechnology and Food Security
Dinara Kabylbekova: Validation of RumiWatch nose-band sensors for measuring nutritional behaviour of dairy cows
MSc thesis, 38 pages
Supervisors: Jaakko Mononen PhD, Professor and Salla Ruuska MSc
September 4, 2016

Key words: dairy cattle, automated monitoring, feeding, rumination, drinking, validation

ABSTRACT

Changes in rumination and feeding behaviour may be signs of health problems in cattle. Automated systems for monitoring behaviour can be an effective tool in the prevention and diagnosis of the disease in cattle in the early stages. The objective of the thesis was to evaluate the reliability of the functioning of the RumiWatch System (RWS) – a sensor-based device that measures ruminating, feeding and drinking behaviour in dairy cattle. The device registers the cow's jaw movements through a pressure sensor.

RumiWatch noseband sensors were attached to five non-lactating dairy cows of the breeds Nordic Red and Holstein. Video recording observation was used to validate the system by using a confusion matrix method. In terms of the performance indicators, rumination behaviour accuracy was 89%, and RWS was especially good in differentiating "not ruminating" from "ruminating" (specificity 93%). However, it was slightly worse in recognizing all true rumination cases (sensitivity 78%), and classified some of the other behaviours erroneously as "rumination" (precision 79%).

For eating behaviour, accuracy was much lower (67%) than for ruminating, resulting mainly from poor precision (51%) and to some extent from lower specificity (82%). Instead, RWS's sensitivity was slightly higher for eating (82%) than ruminating. In the case of drinking, accuracy (98%) and specificity (99%) were very high but precision (6%) and sensitivity (7%) were extremely low, which reflected the accuracy paradox of the imbalanced data for drinking.

In conclusion, the RWS in this study proved to be a relatively useful device for measuring ruminating and eating but not drinking. RWS might become a valuable tool for researchers and farmers in the future, but further validation is desirable. The confusion matrix approach is useful in the validation of RWS, as well as other devices, since it reveals the types of the misclassifications a classifier makes, which helps to adjust the classifying algorithm.

УНИВЕРСИТЕТ ВОСТОЧНОЙ ФИНЛЯНДИИ
Факультет естественных наук и лесного хозяйства, Кафедра Окружающей среды и Биологических наук
Зеленая Биотехнология и Пищевая безопасность
Динара Кабылбекова: Проверка аппарата “RumiWatch” для измерения пищевого поведения дойных коров
Магистерская работа, 38 страниц
Руководители: Профессор Яко Мононен и MSc Салла Рууска
Сентябрь 4, 2016

Ключевые слова: дойные коровы, автоматизированный мониторинг, кормление, жвачка, проверка

АБСТРАКТ

Изменения в пищевом поведении у крупного рогатого скота являются признаками проблем со здоровьем. Автоматизированные системы для мониторинга поведения являются эффективным средством для профилактики и диагностики заболевания у животных на ранних стадиях. Основная цель данного исследования состояла в том, чтобы оценить надежность функционирования устройства RumiWatch (RWS) - системы мониторинга состояния здоровья жвачных животных. Система состоит из хомута, шагомера и анализирующей компьютерной программы. Устройство регистрирует движения челюсти жвачных через датчик давления на хомуте при пережевывании жвачки, поедании кормов и потреблении воды.

Исследование проводилось на пяти дойных коровах пород Скандинавская Красная и Голшитинская. Каждая корова была оснащена устройством RumiWatch. Для проверки функциональности устройства RWS сравнивались данные полученные с аппарата и видео наблюдений методом матрицы неточностей. Показатели эффективности системы были следующими: достоверность для пережёвывания жвачки – 89%, специфичность – 93%. Тем не менее устройством были зарегистрированы не все истинные случаи данного поведения – чувствительность 79%. Показатели поведения при поедании кормов были немного ниже чем при пережевывании жвачки: достоверность – 67%, точность – 51%, специфичность – 82%. Результаты при потреблении воды показали высокие достоверность – 98% и специфичность – 99%, но низкие точность – 6% и чувствительность – 7%, что является следствием несбалансированности данных питьевого поведения.

В заключение отметим, что аппарат RumiWatch в данном исследовании доказал, свою надёжность при измерении пищевого поведения животных во время пережевывания жвачки и поедания кормов, но не потребления воды. Система RumiWatch требует дополнительной проверки для широкого практического применения.

ШЫҒЫС ФИНЛЯНДИЯ УНИВЕРСИТЕТІ
Жаратылыстану ғылымдары және орман шаруашылығы факультеті, Қоршаған орта және Биологиялық ғылымдар кафедрасы
Жасыл Биотехнология және Тағам қауіпсіздігі
Динара Кабылбекова: “RumiWatch” қондырғысы арқылы сүтті ірі қара малының дұрыс азықтандырылуын анықтау
Магистірлік жұмыс, 38 бет
Жетекшілер: Профессор Яко Мононен және MSc Салла Рууска
Қыркүйек 4, 2016

Түйін сөздер: сауын сиыр, автоматтандырылған мониторингі, азықтандыру, тексеру

ТҮЙІНДЕМЕ

Ірі қара малдың азықтануындағы өзгерістер, оның денсаулығында кінәрат бар екендігінің көрсеткіші болып табылады. Мінез-құлық мониторингі үшін автоматтандырылған жүйелер жануарлардағы ерте сатылы аурулардан сауықтыру және диагностикалау үшін тиімді құрал болып табылады. Бұл зерттеу жұмысының негізгі мақсаты RumiWatch (RWS) – күйіс қайыратын жануарлардың денсаулық жай-күй мониторингі құрылғысының сенімді жұмыс істеуін бағалау. Жүйе хомут, адым өлшегіш және анализдеуші компьютерлік бағдарламадан тұрады. Құрылғы күйіс қайыратын жақтың қозғалысын күйіс қайтарғанда, жеммен азықтанғанда және су ішкенде хомуттағы қысым тетігі арқылы тіркейді.

Зерттеу жұмысы бес Скандинавиялық Қызыл және Голшитиндық сауын сиырларына жүргізілді. Әрбір сиыр RumiWatch құрылғысымен жабдықталды. RWS құрылғысының функционалдылығын тексеру үшін аппараттан алынған деректер және дәлсіздіктер матрицасы әдісімен бейне бақылаулар салыстырылды. Тиімділік көрсеткіштер жүйесі келесідей болды: күйіс қайыру дұрыстығы – 89%, ерекшелігі – 93%. Дегенмен құрылғымен барлық шынайы мінез-құлық анықталмады – сезімталдық 79%-ы көрсетті. Су ішу кезіндегі нәтижелер жоғарғы 98% сенімділікті және 99 % сезімталдықты көрсетті, бірақ 6% төмен дәлділікті және 7% сезімталдық су ішу процесінің дұрыс балансталмауын көрсетеді.

Қорытындылай келе, бұл зерттеу жұмысы RumiWatch құрылғысы жануарлардың күйіс қайтару және жеммен азықтану процесстерін өлшеуде сенімді құрылғы екенін көрсетті, бірақ су ішу процесінде бұл құрылғы сенімсіз болып табылды. Дегенмен, RumiWatch жүйесі практикада қолданылуы үшін әлі де тексеруді қажет етеді.

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor Professor Jaakko Mononen for his guidance, professional help, invaluable patience, advice, support and positive attitude during this long process. I would also like to thank my other supervisor MSc Salla Ruuska for her willingness to help me in the beginning of this work.

Special thanks to our coordinator MSc Roseanna Avento for all the assistance, helpful advice, understanding, encouraging and for her help to keep me motivated during the whole writing process.

I express my sincere gratitude to the University of Eastern Finland for the knowledge and skills I gained during my studies. I express my sincere gratitude also the Kazakh National Agrarian University for the opportunity to engage in this programme and for the financial support.

Many thanks to my family, my friends and my mom for her endless love, support and encouragement during the year I have been in Finland.

Without the people who have helped me in this long process, I would not have finished this thesis.

CONTENTS

ACKNOWLEDGEMENTS 5

1. INTRODUCTION 7

2. LITERATURE REVIEW 8

  2.1 THE DIGESTIVE SYSTEM AND ITS FUNCTIONING IN CATTLE 8

  2.2 THE DAILY TIME BUDGET OF DAIRY COWS 12

  2.3 FEEDING BEHAVIOUR OF CATTLE 13

  2.4 RUMINATION BEHAVIOUR OF CATTLE 14

  2.5 DRINKING BEHAVIOUR OF CATTLE 15

  2.6 AUTOMATED SYSTEMS FOR MEASURING NUTRITIONAL BEHAVIOUR IN CATTLE 15

  2.7 VALIDATING DEVICES FOR AUTOMATED MEASUREMENT OF BEHAVIOUR 17

3. OBJECTIVES 18

4. MATERIALS AND METHODS 19

  4.1 ANIMALS AND DATA COLLECTION 19

  4.2 CALCULATION OF THE RESULTS 20

  4.3 PRESENTATION OF THE RESULTS 21

5. RESULTS 22

6. DISCUSSION 29

7. CONCLUSION 33

REFERENCES 34

1. INTRODUCTION

With the increase in the size of the cattle herds, individual monitoring of animals becomes more difficult, which inevitably requires the introduction of intensive technologies (Zehner *et al*., 2014). Automation of processes in animal husbandry is carried out through the implementation of precision livestock farming (PLF). The basic idea of PLF is the use of the latest advances in the field of electronics, computing and information technology in the management of productive processes of livestock (Wathes *et al*., 2008). Continuous automated monitoring of farm animals will also allow "hearing" complaints of animals long before the appearance of the disease, and providing individual care for the animals that will improve their health, welfare and productivity (Frost *et al*., 1997).

Therefore, the task of PLF is the use of technical means to create optimal conditions for feeding and housing of cattle to facilitate the daily work of farmers and eliminate the need for visual observations of animals (Nielsen 2013). However, modern electronic technologies need to operate correctly and thus research on their functionability is important.

Recently, many technologies for electronic animal identification systems (McAllister *et al*., 2000), for measuring activity (Alsaaod *et al*., 2012) and position (Martiskainen *et al*., 2009) of the animals, as well as for detecting feeding (Chizzotti *et al.*, 2015), and rumination (Braun *et al*.,2013) behaviour of cattle have been tested. One such equipment is the RumiWatch system (RWS), a system for automatic health monitoring in ruminants (Zehner *et al*., 2012). The overall objective of this study is to evaluate how well the RumiWatch system classifies eating, rumination and drinking behaviour in dairy cows as compared to continuous recording based on video recordings.

2. LITERATURE REVIEW

2.1 THE DIGESTIVE SYSTEM AND ITS FUNCTIONING IN CATTLE

Cattle are ruminants, and they are characterized by complex multi-chambered stomachs (Hall and Silver, 2009). The digestive system of ruminants is adapted to receive and process large amounts of roughage (Greathouse, 1964). The stomach of cattle consist of four compartments: the rumen, reticulum, omasum and abomasum (Hall and Silver, 2009; Figure 1). The abomasum is the true stomach and the other three compartments are called the proventriculus (Moran, 2005).

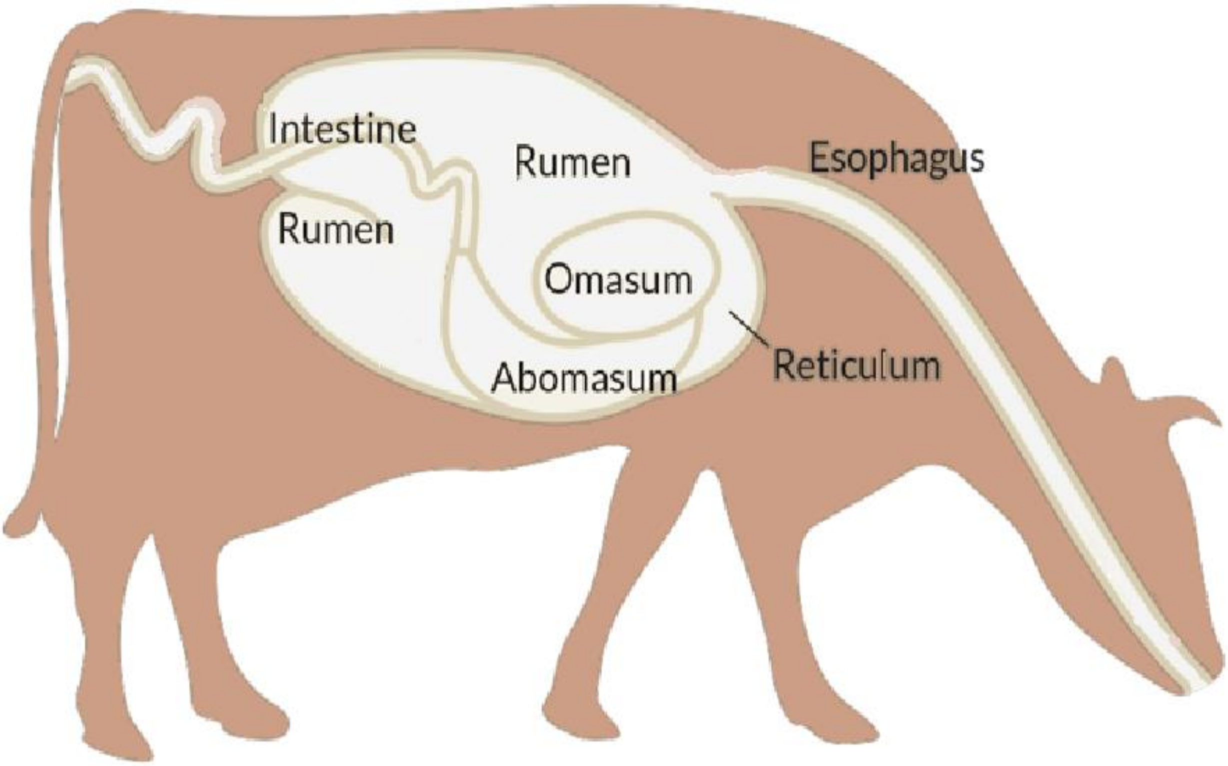

Figure 1. Cattle's digestive tract. (Otwell, 2015, modified)

Before food reaches the rumen, it is crushed by the mechanical action of chewing the grass or other feed just eaten (Moran, 2005). Chewing the cud, or rumination is the process whereby softened but not enough chopped food is brought back up into the mouth for further chewing. The food is chewed, mixed with saliva and swallowed again. The time required for rumination or cud chewing depends on the cellulose content in the feed.

The rumen is the largest compartment of the cattle stomach system (Hall and Silver, 2009; Figure 2). In the rumen, walls continuously move that allows the ingested feed to be mixed with rumen fluid and microbes (Moran, 2005). The internal surface of the rumen is covered with tiny papillae and projections, which allow better absorption of digested nutrients (Greathouse, 1964)**.** The rumen is adaptable to digest large amounts of fiber due to anaerobic microorganisms: protozoa, bacteria and fungi (Hall and Silver, 2009). Some of these microorganisms digest cellulose and starch while others digest sugars. The protozoa and bacteria can digest up to 70-80% of the digestible dry matter in the rumen.

Figure 2. Internal surface of the rumen. (Photo: Wolfemanwm, 2014)

In the rumen, temperature is maintained at a stable level at around 38–42°C. This temperature is necessary for the growth of microbes (Moran, 2005). The range of pH in the rumen under normal conditions is in the range of 6-7.

The main end products of microbial fermentation are:
- Volatile fatty acids: major energy source of the cow
- Ammonia: a building material for microbial protein, which is then digested in the abomasum and small intestine
- Gases: those not used by rumen microbes are mainly removed by belching

From the rumen, the forage mass moves to the reticulum. The reticulum (Figure 3) is a compartment of the stomach lined with a honeycomb-like wall and connected to the rumen (Hall and Silver, 2009). The major function of the reticulum is sorting the forage mass. This function allows small food particles pass on to the omasum, while coarse particles remain in the rumen for further digestion (Greathouse, 1964)**.**

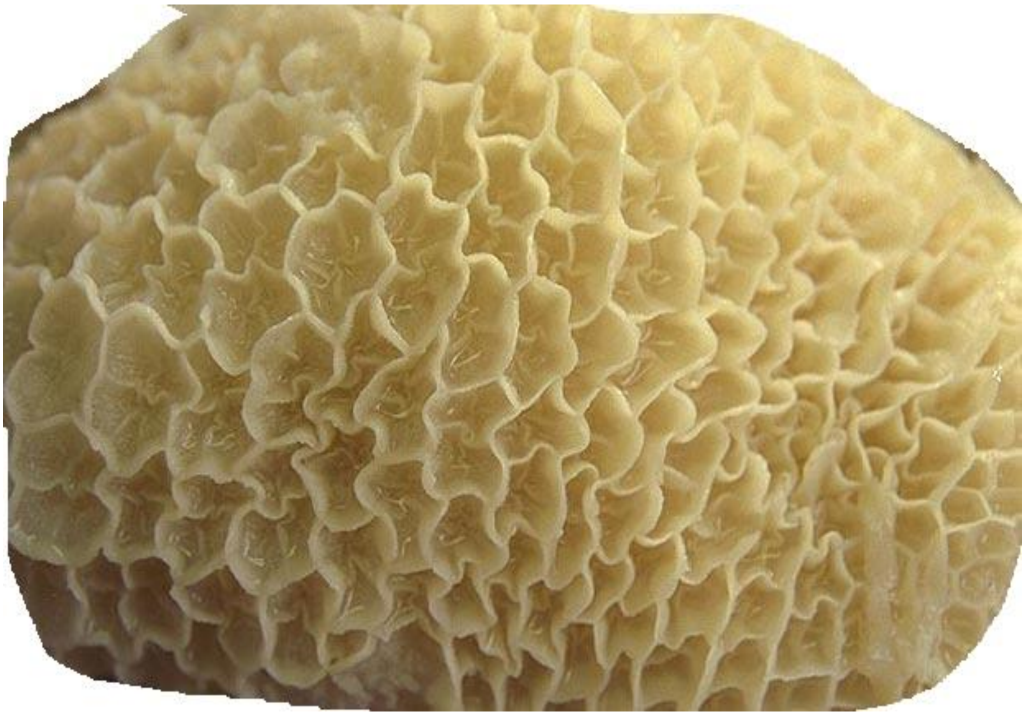

Figure 3. Internal surface of the reticulum. (Photo: Wolfemanwm, 2014)

The omasum (Figure 4) consists of many leaf-like folds (Moran, 2005). One important function of the omasum is to filter food particles. Sufficiently milled particles pass to the abomasum and large particles back to the reticulorumen. The omasum also absorbs some volatile fatty acids and water (Hall and Silver, 2009).

Figure 4. Internal surface of the omasum. (Photo: Wolfemanwm, 2014)

Further, digestion occurs in the abomasum (Figure 5). The abomasum is often mentioned as the "true stomach", because it operates in the same way as the stomach in monogastric animals (Hall and Silver, 2009**.** The abomasum secretes gastric juice that contains hydrochloric acid and enzymes (pepsin). These enzymes carry out the digestion of protein and some of fat, starch or cellulose. Then feed material are passed to the small intestine (Greathouse, 1964)**.**

Figure 5. Internal surface of the abomasum. (Photo: Wolfemanwm, 2014)

In the small intestine, the process of digestion of different nutrients of the feed is carried out by bile, pancreatic and intestinal juices (Moran, 2005). Absorption of most nutrients also occurs in the small intestine. Secondary fermentation especially of fiber occurs in the large intestine. Absorption of water, ammonia and minerals also occurs there. Non-digested components of feed in the large intestine pass through to the rectum and are then removed as faeces.

2.2 THE DAILY TIME BUDGET OF DAIRY COWS

Most animals, including dairy cattle, possess a circadian timing of behavior patterns. Changes that occur during the day and are repeated every day at approximately same time comprise the circadian rhythms of animals (Harvatine, 2012). Ruminants are crepuscular animals and mostly active during sunrise and sunset (Linnane *et al*., 2001).

According to Jensen (2002), the daily rhythm of dairy cattle is characterized by alternating phases of feeding, rumination and resting, the two latter of which typically overlap. A simplified daily time budget for lactating dairy cattle proposed by Grant and Albright (2000) for cows in a free stall environment usually consist of following behavioural patterns:

- Eating: 3-5 hours per day (9-14 meals/day)
- Resting (lying): 12-14 hours per day
- Social interactions: 2-3 hours per day
- Ruminating: 7-10 hours per day (both standing and lying)
- Drinking: 0.5 hours per day
- Time spent outside the pen: 2.5-3.5 hours per day (for travel to and from the parlor, milking, and other management practices)

2.3 FEEDING BEHAVIOUR OF CATTLE

One of the main concern of all animals is collecting food (Albright, 1993).The feeding behavior of the cattle mainly includes grazing on pasture or visits to a feeder and feeding table in animal barns (Nielsen, 1999). The lips, teeth, and tongue are major organs for the prehension of feed (Albright, 1993).The ruminants eat by collecting feed up with the tongue and taking it into the mouth. Feeding behaviour depends on the physical consistency of the diet. In barn condition, dairy cattle are usually offered forages, which are in moderately small particles. Hence, chewing movements are more frequent than biting actions.

Usually, the longest grazing periods occur at the beginning and end of daylight (Albright, 1993). Grazing includes the search for forage, and selecting and taking chosen forage into the mouth (Lyons and Machen, 2000). Cattle graze by wrapping their tongues around the grass and cutting it off with their lower teeth and upper dental pad. The number of bites taken per minute usually ranges from 30 to 70. As a rule, the animals walk at a relatively slow pace while they graze (Ekesbo, 2011). Dairy cattle graze approximately 8-9 hours a day (Mosavat and Chamani, 2013).

The diurnal rhythm of feeding behaviour in modern housing systems is mainly affected by the feed delivery, milking times (DeVries, 2013) and type of feed (Albright, 1993). In addition, as Albright (1993) established, in barn conditions, dominance hierarchy also affects to feeding behaviour. In a competitive situation, particularly if the cows are kept in groups and there is not enough available space for them to eat simultaneously, the lower ranking cows spend less time eating than the more dominant cow.

2.4 RUMINATION BEHAVIOUR OF CATTLE

Rumination is a natural behaviour in ruminants characterized by the complex process of digestion (food undergoes mastication in the oral cavity twice). It usually begins after ingestion of feed when the contents of the rumen becomes softened and liquefied (Broom and Fraser, 2007; Beauchemin, 1991). During the day rumination periods occurs 10-20 times, each period lasting from one minute to two hours (Beauchemin, 1991).

A cow spends about one-third (6-7 hours) of the day ruminating (Welch, 1982). A regular pattern of mastication, normally about 50-55 jaw movements per minute occur during the rumination process (Beauchemin, 1991). Rumination starts when the animal is relaxed and calm. This is one of the main reasons why rumination mostly occurs at night. However, cattle also display distinct period of rumination in the daytime. Cattle ruminate mainly in a lying position but may ruminate also in a standing position. Rumination can also overlap with some other activities, such as walking, nursing, scratching, defecating and urinating.

Rumination behaviour is influenced by several factors, such as the content of the feed, stress, health status and cattle management environment (Grant and Albright, 2001; Calamari *et al*., 2014).

Gregorini *et al*. (2012) have established empirically that rumination is a key component of rumen digestion controlling digestion rate and outflow of digesta from the rumen, dry matter intake, and the physical breakdown of plant material in the rumen. In the framework of research devoted to the health problems of dairy cattle, some studies reported that changes in rumination might be used as an indicator of animal health (Ambriz-Vilchis *et al*., 2015; Vanhoudt *et al*., 2015). Undoubtedly, when the animal stops rumination this is an evidence of serious health problem (Goldhawk *et al*., 2013).

2.5 DRINKING BEHAVIOUR OF CATTLE

The water content in the body of dairy cattle is 56-81%. Water is the most important nutrient, and all metabolic processes take place in the water phase of the body (Pinheiro Machado Filho *et al*., 2004). Water plays a key role in major biological functions, including digestion, temperature regulation, fetal development and milk production (Murphy, 1992).
Drinking behaviour is influenced by many factors such as water quality (Willms *et al.*, 2002), climate (Murphy *et al*., 1983; Meyer *et al*., 2004), nutrition (Dado and Allen, 1994), milk yield (Dahlborn *et al*., 1998; Meyer *et al*., 2004) and body weight (Meyer *et al*., 2004). Thirst is a very strong motivation stimulating drinking behaviour. Cattle drink by dipping their muzzles into the water and sucking it into the mouth, keeping their nostrils above the surface of the water (Eskebo, 2011; Mills and Marchant-Forde, 2010).

Adult cattle require at least 50 liters of water per day, and lactating dairy cows require up to 100-150 liters per day. During the day cows drink 7-12 times in short bouts consuming 10 to 20 liters of water per a bout (Eskebo, 2011). Typically, cattle drink after sunrise and again late in the afternoon (Mills and Marchant-Forde, 2010). Animals prefer to drink also after milking and during feeding (Subcommittee on Dairy Cattle Nutrition, 2001). Interestingly, according to Mills and Marchant-Forde (2010) animals do not necessarily always drink every day. In mild climates, cattle may not drink water within a few days, especially if the pasture is lush.

2.6 AUTOMATED SYSTEMS FOR MEASURING NUTRITIONAL BEHAVIOUR IN CATTLE

Automation is one of the main trends in modern animal husbandry (Nielsen, 2013). In recent years, one of the main efforts of developers and manufacturers farm animal technology has been creating equipment for livestock that allow maximally automate the care of the herd and provide effective tools for collecting and analyzing information about the condition of the animals for the farmers (Wathes *et al*., 2008). This is enabled by modern electronics, sensors, special software and efficient computers.

Stobbs and Cowper described already in 1972 a simple device which recorder jaw movements of ruminants during rumination and grazing. The device consisted of a micro-switch and mercury switch. A micro-switch powered by the movement of the jaw, registers both the total number of bites, and bites during grazing, on a numerical recorder assembly. A mercury switch permitted jaw movements during grazing to be recorded when the animal's head is in a grazing position. Examples of the more recent types of sensors that already are or will probably become available in the future in practical use are accelerometers and pedometers, which enable classifying behavioural patterns in dairy cows (Vázquez Diosdado *et al*., 2015), jaw balloons and pressure transducers that distinguish two types of activities: ruminating and eating (Bels, 2006), and microphones that measure rumination activity (Galli *et al*., 2006).

A 3D activity logger that registers the position of the cow’s head is a very recent example of an equipment for measuring grazing time of cattle (Nielsen, 2013). The device simply tries to differentiate non-grazing behavior from grazing at pasture. The device is based on a 3D accelerometer sensor attached to and halter (around the cows head and muzzle), and it measures the changes in inclination of the head every fifth second. All data is stored in the device until downloaded to the computer. Ultimately, the device simply tries to differentiate grazing behaviour from non-grazing behavior at pasture based on the position of an animal’s head.

Delagarde and Lamberton (2015) introduced, in turn, the Lifecorder Plus device to detect behavioral patterns (ruminating, drinking, walking) and grazing activities of cattle at pasture. Based on the uniaxial accelerometer fixed on the neck or leg the device registers the level of physical activity for each 4-s period.

Chizzotti *et al*. (2015) presented another device, Intergado, for measuring individual feed intake and feeding behaviour of dairy cattle. The system consists of an ear tag containing a unique passive transponder and radio frequency identification antenna is located inside the rubberized mat near the feeder. The equipment record the animal identification number, bunk number, changes in the feed weight at the beginning and end of each single bunk visit.

Kononoff *et al*. (2002) have demonstrated an electronic system IGER that monitors several behavioural patterns of ruminants such rumination, eating and resting behaviour. The system consists of a noseband sensor and a special computer program that allows recording and differentiates jaw movements through its amplitude, frequency, and shape.

2.7 VALIDATING DEVICES FOR AUTOMATED MEASUREMENT OF BEHAVIOUR

The main criterion of modern technologies is reliability or correct functioning of the devices (Nielsen, 2013). There are different statistical methods to evaluate the devices for automated measurement of animal behaviour.

Linear regression method is a statistical analysis model for a basic predictive task, usually based on two variables, where the independent variable is usually denoted as “x” and the dependent variable denoted as “y” (Schneider *et al*., 2010). In studies where a device measuring time spent on a behaviour is validated, x represents “the truth” (i.e. result from gold standard, such as continuous recording from a video recording) and y represents the result given by the device to be validated (Daigle and Siegford, 2014). The hypotheses are that $y = x$ (i.e. $a = 1$ and $b = 0$ for the regression line $y = ax + b$) and the coefficient of determination = $R^2 = 1$ (i.e. that the device to be validated gives exactly the same results as the gold standard). For instance, Schirmann *et al*. (2009) and Ruuska *et al*. (2016) used regression method in validating devices for measuring nutritional behaviour of cattle.

The confusion matrix method, in turn, is based on information about actual and predicted classifications done by a classification model (or “classifier”) (Kohavi and Provost, 1998). Table 1 displays an example of confusion matrix for a simple binary class situation. The table contains information of how many times the system correctly and incorrectly evaluated the data of the given class (Patro and Patra, 2015). The rows of the matrix present the true situation (gold standard), whereas the column present the predictions made by the classifier. The classifications options are: TP - true positive rate (e.g. grazing is recognized as grazing), FN - false negative rate *(*e.g. grazing is not recognized), FP - false positive rate (e.g. non-grazing recognized as grazing) and TN - true negative rate (e.g. non-grazing recognized as non-grazing). Martiskainen *et al*. (2009), Nielsen (2013) and Wolfger *et al*. (2015) have used confusion matrix approach in validating devices for measuring the behaviour of cattle.

Table 1. Confusion matrix for a binary class situation (Patro and Patra, 2015).

Actual class	Predicted class	
	Yes	No
Yes	TP	FN
No	FP	TN

3. OBJECTIVES

Eating and ruminating are major components of the daily behaviour of dairy cows. Studies have shown that the use of devices for monitoring feeding behaviour can be a reliable and suitable technology for surveillance of cattle health and welfare. Such automated systems can be part of an automatic livestock management tool for the efficient monitoring and control of welfare and comfort of cattle in farms. However, this necessitates that the behavioural data produced by the devices is reliable, i.e. validation studies are required.

The main aim of this thesis was to study the reliability of the functioning of the RumiWatch System (RWS). RWS is a sensor-based device that measures ruminating, feeding and drinking behaviour in dairy cattle by registering the cow's jaw movements through a pressure sensor. RWS has been validated earlier by using the regression method (Ruuska *et al*., 2016). The present validation study utilized the confusion matrix approach, and a second and more general aim was to find out, whether the confusion matrix method is useful in the validation work of RWS or other devices for measuring the behaviour of animals.

4. MATERIALS AND METHODS

4.1 ANIMALS AND DATA COLLECTION

The study was conducted at the Maaninka Research Station of MTT Agrifood Research Finland, now Natural Resources Institute Finland (Luke). Five non-lactating cows (Nordic Red and Holstein) were included in the study. The experimental animals were equipped with RumiWatch noseband sensors (Itin + Hoch GmbH, Liestal, Switzerland). The animals were kept in a loose housing system, but for the experimental period, the cows were moved to tied stalls. The cows were fed grass silage delivered two times a day, and water was available ad libitum from individual water cups.

The RWS (Figure 6) consists of a halter with a noseband sensor comprising of a vegetable oil-filled silicon tube with a built-in pressure sensor, a data logger and the corresponding evaluation software (and an optional pedometer but pedometer data was not used in this study). The data logger registers the pressure at a frequency of 10 signals per second (i.e., 10 Hz). For automatic measurement, a generic algorithm divides individual jaw movements into ruminating, eating, drinking or other activities. Measurement data of the sensors were transferred daily to a computer operating the specific evaluation software for further processing of the data.

The behavioral analyses from the videos, needed for the validation or RWS, had been completed earlier by two trained observers who had recorded from the videos the four behaviour categories needed in this study, i.e. eating (E), rumination (R), drinking (D) or “other behaviour” (O), with continuous recording (see more details in Ruuska *et al*., 2016)

Figure 6. Two cows equipped with Rumi-Watch system. (Photo: Kajava, S. 2013)

4.2 CALCULATION OF THE RESULTS

Before calculating the results, the data required pre-processing. RWS data of 5 cows with originally a total of 48 hours of data per each cow obtained from the RumiWatch system was used. First 12 hours of data were extracted from each cow. These 12 hours of data had detailed behavioral observations in order to be able to compare the behaviour classification of RumiWatch to video-based continuous recording.

In the RWS data there was behavioral classification for every second, in other words the original 152800 (48 h) rows of data for each cow had to be reduced to 43200 rows of data (12 h, one row for each second). This was done manually with the Excel program. Then the video-data was combined with RWS data manually by adding the behaviour classification from the video analyses (i.e. gold standard) beside the RWS classification for each of the seconds.

There were altogether 16 possible combinations of RWS and video data: EE, ER, ED, EO, RE, RR, RD, RO, DE, DR, DD, DO, OE, OR, OD, OO. Frequencies for all these combinations were calculated with SPSS statistical software. Each of the combinations (i.e. RWS observations) fell into one of the four "trueness categories": true positive (TP), true negative (TN), false positive (FP) or false negative (FN). For each animal was created confusion matrices that included the number of RWS observations in each of these four categories for each of the four behaviour patterns. Based on frequencies four indicators were calculated that describe the performance (Nielsen, 2013; Zhu *et al.*, 2010; Sokolova and Lapalme, 2009) of RWS as a classifier for these four behaviours:

Accuracy = ((TN + TP)/ (TN+TP+FN+FP)) × 100, i.e. overall effectiveness of the classifier.

Sensitivity = (TP/ (TP + FN)) × 100, i.e. effectiveness of the classifier to identify positive cases.

Specificity = (TN/ (TN + FP)) × 100, i.e. effectiveness of the classifier to identify negative cases.

Precision = (TP/ (TP+FP)) ×100, i.e. the trueness of the cases classified as positive by the classifier.

4.3 PRESENTATION OF THE RESULTS

A confusion matrix results combining results from all the animals were built to summarize and illustrate the types of misclassification by RWS and the performance indicators were calculated from this matrix. The results (the confusion matrices and performance indicators) are presented also for each of the five individual animal.

5. RESULTS

In terms of the performance indicators (Table 2), for the rumination behaviour, accuracy was 89%, and RWS was especially good in differentiating “not ruminating” from ruminating (specificity 93%). However, it was slightly worse in recognizing all true rumination cases (sensitivity 78%), and classified some of the other behaviours erroneously as rumination (precision 79%). For eating behaviour, accuracy was much lower than for ruminating, resulting mainly from poor precision and to some extent from lower specificity. Instead, RWS’s sensitivity was slightly higher for eating than ruminating. In the case of drinking, accuracy and specificity were very high but precision and sensitivity extremely low.

Table 2. RWS performance indicators based on confusion matrix combining the results from all animals (see Table 3).

Measuring behavioural patterns	RumiWatch Performance Indicators in %			
	Sensitivity	Specificity	Precision	Accuracy
Rumination Behaviour	77.81	92.92	79.48	88.98
Eating Behaviour	82.26	82.12	50.94	66.99
Drinking Behaviour	7.36	98.84	5.55	97.99
Other Behaviour	68.55	86.66	85.98	76.72

The confusion matrix for the data combined from all the animals shows the main ways of misclassifications (Table 3). In the case of ruminating, the main ways of misclassification were that other behaviour (8684 cases) and eating behaviour (2622 cases) were classified as ruminating. The situation was similar in the case of eating in the sense that classifying other behaviour (26245 cases) as easting was the most frequent misclassification, followed by ruminating (3960 cases).

Drinking was misclassified as eating quite frequently (1319 cases), but seldom as ruminating (11 cases). For the drinking behaviour, the main ways of misclassification by RWS were that especially other behaviour (2184 cases) but not so much eating (270 cases) or ruminating (30 cases) were misclassified as drinking.

For the other behaviour category it was mainly ruminating (8509 cases) and eating (4166 cases), and no so often drinking (509 cases) that were misclassified to this category. (Note that these "reading instructions" are the same for the Tables 8-12 that present the confusion matrices for the individual animals).

Table 3. The confusion matrix obtained from the behaviour pattern classifications by of RWS for the all animals. The true positive values are bolded.

RumiWatch Data	Video Data			
	Rumination Behaviour	Eating Behaviour	Drinking Behaviour	Other Behaviour
Rumination Behaviour	**43822**	2622	11	8684
Eating Behaviour	3960	**32730**	1319	26245
Drinking Behaviour	30	270	**146**	2184
Other Behaviour	8509	4166	509	**80881**

There were some differences in the performance indicators between the individual animals (Tables 4-7). The top three results (highest accuracies) for ruminating, eating and other behaviours were obtained for the animals 79, 3355 and 102. The accuracies for ruminating and other behaviours were worst for animal 4293, whereas animal 154 had the worst accuracy for eating.

Table 4. RWS performance indicators for rumination behaviour for individual animals.

RumiWatch Performance Indicators in %	Animals №				
	79	3355	102	154	4293
Sensitivity	98.42	91.03	91.07	52.26	51.22
Specificity	94.57	99.01	97.90	96.60	76.15
Precision	88.69	97.04	93.34	81.85	44.04
Accuracy	95.73	96.92	96.24	86.54	69.46

Table 5. RWS performance indicators for eating behaviour for individual animals.

RumiWatch Performance Indicators in %	Animals №				
	79	3355	102	154	4293
Sensitivity	83.56	96.87	90.90	83.39	53.88
Specificity	91.59	86.33	80.43	68.77	84.61
Precision	77.27	64.98	38.77	36.37	40.36
Accuracy	89.54	88.52	81.69	71.35	79.63

Table 6. RWS performance indicators for other behaviour for individual animals.

RumiWatch Performance Indicators in %	Animals №				
	79	3355	102	154	4293
Sensitivity	83.86	81.20	71.90	63.26	46.86
Specificity	97.13	97.05	97.15	85.06	53.58
Precision	95.70	96.79	97.68	85.61	56.73
Accuracy	91.40	88.75	81.35	72.33	49.78

Table 7. RWS performance indicators for drinking behaviour for individual animals.

RumiWatch Performance Indicators in %	Animals №				
	79	3355	102	154	4293
Sensitivity	1.95	5.23	13.11	11.21	0(N/A)
Specificity	98.99	99.41	98.10	98.20	99.49
Precision	2.05	6.30	6.78	7.35	0(N/A)
Accuracy	97.96	98.70	97.21	97.10	99.02

* N/A – not available

The individual confusion matrices (Tables 8-12) indicate some details of the reasons for the differences between the individual animals. The variation between the animals was smallest for eating and drinking, and for these two behaviours, the combined confusion matrix (Table 2) pretty much tells the story.

Individual results demonstrate, that for four animals (3355, 79, 102, 154: Tables 8-11, respectively) this misclassifying eating and other behaviour categories as ruminating varied but the misclassification rate was low. Instead, in the case of the fifth animal (4293: Table 12) misclassifying other behaviour category as ruminating was very frequent, accounting for 7573 out of the total of 8684 misclassifications of this type in the combined confusion matrix (Table 2). The other behaviour category was frequently misclassified as ruminating and eating was frequently misclassified to the other behaviour category. This was mainly due to two animals, animal 4293 (Table 12) having plenty of both types of errors and animal 154 (Table 11) having mainly the former errors.

Table 8. The confusion matrix of behaviour pattern classifications by RWS for Animal № 3355. The true positive values are bolded.

RumiWatch Data	Video Data			
	Rumination Behaviour	Eating Behaviour	Drinking Behaviour	Other Behaviour
Rumination Behaviour	**10299**	30	0	284
Eating Behaviour	805	**8685**	147	3729
Drinking Behaviour	0	13	**17**	240
Other Behaviour	210	237	161	**18362**

Table 9. The confusion matrix of behaviour pattern classifications by RWS for Animal № 79. The true positive values are bolded.

RumiWatch Data	Video Data			
	Rumination Behaviour	Eating Behaviour	Drinking Behaviour	Other Behaviour
Rumination Behaviour	**12854**	1261	0	378
Eating Behaviour	20	**9207**	367	2322
Drinking Behaviour	0	117	**9**	314
Other Behaviour	186	433	85	**15665**

Table 10. The confusion matrix of behaviour pattern classifications by RWS for Animal № 102. The true positive values are bolded.

RumiWatch Data	Video Data			
	Rumination Behaviour	Eating Behaviour	Drinking Behaviour	Other Behaviour
Rumination Behaviour	**9608**	274	0	411
Eating Behaviour	719	**4712**	291	6433
Drinking Behaviour	0	59	**59**	752
Other Behaviour	223	139	100	**19438**

Table 11. The confusion matrix of behaviour pattern classifications by RWS for Animal № 154. The true positive values are bolded.

RumiWatch Data	Video Data			
	Rumination Behaviour	Eating Behaviour	Drinking Behaviour	Other Behaviour
Rumination Behaviour	**5124**	898	0	238
Eating Behaviour	2416	**6354**	381	8320
Drinking Behaviour	0	51	**61**	718
Other Behaviour	2265	317	102	**15974**

Table 12. The confusion matrix of behaviour pattern classifications by RWS for Animal № 4293. The true positive values are bolded.

RumiWatch Data	Video Data			
	Rumination Behaviour	Eating Behaviour	Drinking Behaviour	Other Behaviour
Rumination Behaviour	**5937**	159	11	7373
Eating Behaviour	0	**3772**	133	5441
Drinking Behaviour	30	30	**0**	160
Other Behaviour	5625	3040	61	**11442**

6. DISCUSSION

The main aim of this study was to assess the reliability of RWS, a new device for measuring nutritional behaviour in dairy cows. According to the performance indicators calculated from the confusion matrices, RWS was fairly good for classifying ruminating and eating behaviours but poor in classifying drinking behaviour.

However, performance indicators must be interpreted with some cautiousness. Extreme examples are the high accuracy and specificity for the drinking behaviour. Drinking behaviour is not very common (Eskebo, 2011) and in the present study, RWS did not succeed in measuring it: sensitivity and precision were very low. However, the accuracy and specificity were very high. When classification data is highly imbalanced (Sokolova and Lapalme, 2009) and the number of negative cases is much greater than the number of positive cases, accuracy can be misleadingly high. This is so-called accuracy paradox (Valverde-Albacete and Peláez-Moreno, 2014). Therefore, it is better to use all performance indicators together (Kubat *et al.*, 1998). Here only RWS's extremely poor precision and sensitivity revealed the major problems of its ability to recognize drinking.

The performance indicators and confusion matrix demonstrate some inter-individual differences. For three animals, obtained results were better than for the remaining two animals. There may be several possible reasons for this: malfunctions in the equipment, improper attachment of equipment, or there were differences between the individual cows in the movements of their jaws. The true reasons remains unclear.

Ruuska *et al.* (2016) studied the reliability of RWS earlier by using the same data (or almost the same: data from six animals in their study) as in the present study, but they used regression analyses. Results from regression model measurement were presented as the coefficients of determination (R^2), the slopes and the intercepts for ruminating drinking and eating. They concluded that RWS is good for measuring ruminating ($R^2 = 0.94$) and eating ($R^2 = 0.93$) behaviours, but not for drinking ($R^2 = 0.20$), which is in parallel with the present study.

However, using the method based on a confusion matrix approach gives more detailed information than regression model method. Confusion matrix method shows what kind of misclassification a classifier does (Kubat *et al.*, 1998). This information might be very important to the engineers who are developing RWS to further improve the algorithm of this classifier system, for example in determining what kind of behaviours in the “other behaviour” category are misclassified as eating or ruminating. These behaviours might include behaviours that are related to use of the mouth for other behaviours than eating or ruminating by cattle, such as licking the feeding table (Morgan and Doyle, 2015) or licking other animals (Tresoldi *et al*., 2015).

Even though the RWS was reliable for measuring ruminating and eating behaviours, the confusion matrix results revealed plenty of cases when true ruminating was misclassified as eating as well as cases when true eating was misclassified as ruminating. Obviously, the RWS is far from perfect in telling these two behaviour patterns from each other, although the jaw movements while doing these behaviours are different (Beauchemin, 1991). During rumination a repetitive pattern of mastication is separated by short pauses and mastication is deliberate (50-55 chews per min). During eating mastication does not display a repetitive pattern, rate of mastication changes with time and the pauses during the meal are irregular.

Comparison of the data from the RWS and video observation revealed an overestimation of eating time. There were 31524 false positive cases for eating (Table 2), corresponding to 525 min in the 60-hour data set. This overestimation was also detected by Ruuska *et al*. (2016): the intercept in the regression equation for eating behaviour was higher than 0 (1.35 min/h).

The reliability of RWS has been validated also by Zehner *et al.* (2012). Interestingly, they concluded that the results of drinking behaviour displayed a specific pressure profile for water intake and intake was clearly distinguishable from rumination and feed intake, which is in contrast with results of the present study. However, the Zehner *et al.* did not present any numbers or statistical tests to prove their claim.

An experiment similar to the present study was conducted by Braun *et al*. (2013). The device has the same construction like a RumiWatch system and was designed to monitor ruminating and eating time in cattle. Equipment represents a pressure sensor that mounted on a halter and registers animal’s jaw movements. The results from the sensor were very promising. The total time spent eating per day from visual observation and from the system were 445.0 minutes and 445.4 minutes, respectively. For rumination, the respective figures were 389.3 and 388.3 minutes. These results are in agreement with results obtained from RWS. Thus, it seems that devices based on pressure sensors are good results for measuring ruminating and eating behaviours.

Many other technologies have been used in devices for monitoring nutritional behaviour of cattle. Schirmann *et al*. (2009) assessed the reliability of the Hi-Tag microphone device, which recorded the total time spent ruminating during 2-h periods. They used linear regression and the Bland and Altman (plot) method. According to the results, rumination times (35.1 ± 3.2 min) from the electronic system were highly correlated with direct observation ($R^2 = 0.87$), indicating that this monitoring system was a useful tool for monitoring rumination in dairy cows. However, RWS can be regarded as more useful because it allows measuring both ruminating and eating activity.

Martiskainen *et al*. (2009) used a support vector machine (SVM) method while developing an accelerometer device for measuring and recognizing several behavioural patterns (ruminating, feeding, standing, lying) in dairy cows. For the evaluation of the results, they used the confusion matrix approach. Obtained results indicated that the device was fairly good in classifying some of the behavioural patterns. For ruminating and eating precision, values were 86% and 81%, respectively, i.e. slightly higher than in the present study (79% and 51%).

Vázquez Diosdado *et al*. (2015) also used a tri-axial accelerometer while developing decision-tree classification algorithm for classifying behavioural activities of dairy cattle, (feeding, standing and lying). To test the performance of the algorithm, the confusion matrix approach was used. The results from tri-axial accelerometer showed high values for feeding behaviour (99% sensitivity and 93% precision). Values from RWS for feeding behaviour were lower (82% sensitivity and 51% precision). The differences in results from the devices might be explained by the fact that the RWS in addition to feeding behaviour has the ability to measure rumination, unlike the tri-axial accelerometer of Vázquez Diosdado *et al*., and the present results show that RWS is far from perfect in differentiating these two behaviours from each other.

Nielsen (2013) validated a 3D activity logger that registers the position of the cow's head every fifth second, for measuring a grazing time of cattle. In this study, data from the device and visual observation were compared by using the confusion matrix method. The results obtained from the device were: sensitivity 83.6% and 85.5% (for 5 s and 5 min interval), specificity 79.9% and 82.1%, precision 74.6% and 77.6%. The results were improved (in particular specificity: 90.2-90.7% ; and precision: 85.8-86.8%) when Nielsen used additional information from the another sensor (IceTag3D), that registers leg movement, lying and standing position of the cow. These results show that 3D activity logger is a suitable device for automatic registers of grazing behaviour of cattle.

A recent research was carried out by Wolfger *et al***.** (2015) to validate an ear-tag accelerometer (SensOor) for recording ruminating, feeding, resting and active time in beef cattle. Sensitivity and specificity for rumination and feeding behaviors were 49-96%, and 95-76%, respectively**,** displaying that accelerometer predicted feeding better than rumination behaviour. In comparing with these results RWS was good in classifying both ruminating (sensitivity 78%, specificity 93%) and feeding (sensitivity 82%, specificity 82%) behaviours**.**

To summarize, the comparison of the results from the validation study in the present thesis to other studies shows that the ability of RWS to measure eating and ruminating time in cattle is superior to some and inferior to some other devices and methods for measuring these behaviours**.**

7. CONCLUSION

The RWS in this study was proved to be a relatively useful device for measure ruminating and eating behaviour (but not for drinking). RWS might become a valuable tool for researchers and farmers in the future, but further validation is desirable. Confusion matrix approach is useful in the validation work RWS and other devices for measuring animal behaviour.

REFERENCES

Albright, J. 1993. Feeding Behavior of Dairy Cattle. *Journal of Dairy Science*, 76(2), pp.485-498.

Alsaaod, M., Römer, C., Kleinmanns, J., Hendriksen, K., Rose-Meierhöfer, S., Plümer, L. and Büscher, W. 2012. Electronic detection of lameness in dairy cows through measuring pedometric activity and lying behavior. *Applied Animal Behaviour Science*, 142(3-4), pp.134-141.

Ambriz-Vilchis, V., Jessop, N., Fawcett, R., Shaw, D. and Macrae, A. 2015. Comparison of rumination activity measured using rumination collars against direct visual observations and analysis of video recordings of dairy cows in commercial farm environments. *Journal of Dairy Science*, 98(3), pp.1750-1758.

Beauchemin, K. 1991. Ingestion and Mastication of Feed by Dairy Cattle. *Veterinary Clinics of North America: Food Animal Practice*, 7(2), pp.439-463.

Bels, V. 2006. Feeding in domestic vertebrates. Wallingford, UK: CABI Pub.

Braun, U., Trösch, L., Nydegger, F. and Hässig, M. 2013. Evaluation of eating and rumination behaviour in cows using a noseband pressure sensor. *BioMed Central Veterinary Research*, 9(1), p.164.

Broom, D., and Fraser, A. 2007. Domestic animal behaviour and welfare. Wallingford, UK: CABI.

Calamari, L., Soriani, N., Panella, G., Petrera, F., Minuti, A. and Trevisi, E. 2014. Rumination time around calving: An early signal to detect cows at greater risk of disease. *Journal of Dairy Science*, 97(6), pp.3635-3647.

Chizzotti, M., Machado, F., Valente, E., Pereira, L., Campos, M., Tomich, T., Coelho, S. and Ribas, M. 2015. Technical note: Validation of a system for monitoring individual feeding behavior and individual feed intake in dairy cattle. *Journal of Dairy Science*, 98(5), pp.3438-3442.

Dado, R. G., and Allen, M. S. 1994. Variation in and relationships among feeding, chewing, and drinking variables for lactating dairy cows. *Journal of Dairy Science*, 77, pp.132-144.

Dahlborn, K., Akerlind, M., and Gustafson, G. 1998. Water intake by dairy cows selected for high or low milk-fat percentage when fed two forages to concentrate ratios with hay or silage. *Swedish Journal of Agricultural Research*, 28, pp.167-176.

Daigle, C. and Siegford, J. 2014. When continuous observations just won't do: Developing accurate and efficient sampling strategies for the laying hen. *Behavioural Processes*, 103, pp.58-66.

Delagarde, R. and Lamberton, P. 2015. Daily grazing time of dairy cows is recorded accurately using the Lifecorder Plus device. *Applied Animal Behaviour Science*, 165, pp.25-32.

DeVries, T. 2013. Impact of Feeding Management on Cow Behaviour, Health, and Productivity. *WCDS Advances in Dairy Technology*, 25, pp.193-201.

Ekesbo, I. 2011. Farm animal behaviour. Wallingford, Oxfordshire, UK: CABI.

Frost, A.R., Schofield, C.P., Beaulah, S.A., Mottram, T.T., Lines, J.A., Wathes, C.M., 1997. A review of livestock monitoring and the need for integrated systems. *Computers and Electronics in Agriculture*, 17, pp.139-159.

Galli, J., Cangiano, C., Demment, M. and Laca, E. 2006. Acoustic monitoring of chewing and intake of fresh and dry forages in steers. *Animal Feed Science and Technology*, 128(1-2), pp.14-30.

Goldhawk, C., Schwartzkopf-Genswein, K. and Beauchemin, K. 2013. Technical Note: Validation of rumination collars for beef cattle. *Journal of Animal Science*, 91(6), pp.2858-2862.

Grant, R. and Albright, J. 2001. Effect of Animal Grouping on Feeding Behavior and Intake of Dairy Cattle. *Journal of Dairy Science*, 84, pp.E156-E163.

Grant, R. J., and Albright, J. L. 2000. Feeding behaviour. in D'Mello J.P.F. (ed*.). Farm Animal Metabolism and Nutrition*, CABI International, Wallingford, UK. pp.365-382

Greathouse, T. 1964. Principles of ruminant digestion. Urbana, IL: University of Illinois, College of Agriculture, Cooperative Extension Service, and the U.S. Dept. of Agriculture.

Gregorini, P., DelaRue, B., McLeod, K., Clark, C., Glassey, C. and Jago, J. 2012. Rumination behavior of grazing dairy cows in response to restricted time at pasture. *Livestock Science*, 146(1), pp.95-98.

Hall, J.B., Silver, S., 2009. Nutrition and Feeding of the Cow-calf Herd: Digestive System of the Cow. *Virginia Cooperative Extension*, 400-010, pp. 1-4.

Harvatine, K. 2012. Circadian Patterns of Feed Intake and Milk Composition Variability. In: Proceedings of Tri-State Dairy Nutrition Conference, Michigan State University, Michigan, pp.43-56.

Jensen, P. (2002). The ethology of domestic animals. Wallingford, Oxon, UK: CABI Pub.

Kohavi, R. Provost, F. 1998. Glossary of terms. *Machine Learning*, 30, pp. 271-274.

Kononoff, P., Lehman, H. and Heinrichs, A. 2002. Technical Note – A Comparison of Methods Used to Measure Eating and Ruminating Activity in Confined Dairy Cattle. *Journal of Dairy Science*, 85(7), pp. 1801-1803.

Kubat, M., Holte, R.C., Matwin, S. 1998. Machine Learning for the Detection of Oil Spills in Satellite Radar Images. *Machine Learning*, 2(3), 195-215.

Linnane, M.I., Brereton, A.J., Giller, P.S. 2001. Seasonal changes in circadian grazing patterns of Kerry cows (Bos Taurus) in semi-feral conditions in Killarney National Park, Co. Kerry, Ireland. *Animal Behaviour Science*, 71, pp.277-292.

Lyons, R.K. and Machen R.V. 2000. Interpreting Grazing Behavior. *Texas Agricultural Extension Service,* The Texas A&M University System, L-5385:10-00.

Martiskainen, P., Järvinen, M., Skön, J., Tiirikainen, J., Kolehmainen, M. and Mononen, J. 2009. Cow behaviour pattern recognition using a three-dimensional accelerometer and support vector machines. *Applied Animal Behaviour Science*, 119(1-2), pp.32-38.

McAllister, T., Gibb, D., Kemp, R., Huisma, C., Olson, M., Milligan, D. and Schwartzkopf-Genswein, K. 2000. Electronic identification: Applications in beef production and research. *Canadian Journal of Animal Science*, 80 (3), pp.381-392.

Meyer, U., Everinghoff, M., Gadeken, D., and Flachowsky, G. 2004. Investigations on the water intake of lactating dairy cows. *Livestock Production Science*, 90, pp.117-121.

Mills, D. and Marchant-Forde, J. 2010. The encyclopedia of applied animal behaviour and welfare. Wallingford, UK: CABI.

Patro, V. M., and Patra, M. R. 2015. A Novel Approach to Compute Confusion Matrix for Classification of n-Class Attributes with Feature Selection. *Transactions on Machine Learning and Artificial Intelligence*, 3 (2), pp. 52-64.

Moran, J. (2005). Tropical dairy farming. Collingwood, VIC, Australia: Land Links.

Morgan, J. and Doyle, R. 2015. Cow talk. Melbourne: CSIRO Publishing.

Mosavat, N. and Chamani, M. 2013. A Review: Comparison between Grazing Behavior of Cattle and Sheep. *Global Journal of Biodiversity Science and Management,* 3(2), pp.138-140

Murphy, M. 1992. Water Metabolism of Dairy Cattle. *Journal of Dairy Science*, 75(1), pp.326-333.

Murphy, M. R., C. L. Davis, and G. C. McCoy. 1983. Factors affecting water consumption by Holstein cows in early lactation. *Journal of Dairy Science*, 66, pp.35-38.

Nielsen, B. L. 1999. On the interpretation of feeding behaviour measures and the use of feeding rate as an indicator of social restraint. *Applied Animal Behaviour Science*, 63, pp.79-91.

Nielsen, P. P. 2013. Automatic registration of grazing behaviour in dairy cows using 3D activity loggers. *Applied Animal Behaviour Science,* 148, pp.179-184.

Otwell, 2015. Methane markers in Beil, L. (2015) *Getting creative to cut methane from cows-Less-burpy bovines means fewer greenhouse gases* [online] https://www.sciencenews.org/article/getting-creative-cut-methane-cows . Available 29.8.016

Pinheiro Machado Filho, L.C., Teixeira, D.L., Weary, D.M., von Keyserlingk, M.A.G., Hötzel, M.J. 2004. Designing better water troughs: Dairy cows prefer and drink more from larger troughs. *Applied Animal Behaviour Science*, 89, pp.185-193.

Ruuska, S., Kajava, S., Mughal, M., Zehner, N. and Mononen, J. 2016. Validation of a pressure sensor-based system for measuring eating, rumination and drinking behaviour of dairy cattle. *Applied Animal Behaviour Science*, 174, pp.19-23.

Schirmann, K., von Keyserlingk, M.A.G., Weary, D.M., Veira, D.M., Heuwieser, W. 2009. Technical note: validation of a system for monitoring rumination in dairy cows. *Journal of Dairy Science*, 92, pp.6052-6055.

Schneider, A., Hommel, G., Blettner, M. 2010. Linear regression analysis – part 14 of a series on evaluation of scientific publications. *Deutsches Ärzteblatt International*, 107(44), pp.776-782.

Sokolova, M. and Lapalme, G. 2009. A systematic analysis of performance measures for classification tasks. *Information Processing & Management*, 45(4), pp.427-437.

Stobbs, T.H., Cowper, J.L. 1972. Automatic measurements of the jaw movements of dairy cows during grazing and rumination. *Tropical Grasslands*, 6, pp.107-112.

Subcommittee on Dairy Cattle Nutrition; Committee on Animal Nutrition; Board on Agriculture and Natural Resources; Division on Earth and Life Studies; National Research Council 2001. *Nutrient Requirements of Dairy Cattle: Seventh Revised Edition*. Washington, D.C.: National Academy Press.

Tresoldi, G., Weary, D., Pinheiro Machado Filho, L. and von Keyserlingk, M. 2015. Social Licking in Pregnant Dairy Heifers. *Animals*, 5(4), pp.1169-1179.

Valverde-Albacete, F. and Peláez-Moreno, C. 2014. 100% Classification Accuracy Considered Harmful: The Normalized Information Transfer Factor Explains the Accuracy Paradox. *PLoS ONE*, 9(1), p.e84217.

Vanhoudt, A., van Winden, S., Fishwick, J. and Bell, N. 2015. Monitoring cow comfort and rumen health indices in a cubicle-housed herd with an automatic milking system: a repeated measures approach. *Irish Veterinary Journal*, 68(12), pp. 1-7.

Vázquez Diosdado, J., Barker, Z., Hodges, H., Amory, J., Croft, D., Bell, N. and Codling, E. 2015. Classification of behaviour in housed dairy cows using an accelerometer-based activity monitoring system. *Animal Biotelemetry*, 3(15), pp.1-14.

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*, 64, pp.2-10.

Welch. J.G. 1982. Rumination. Particle Size and Passage from the Rumen. *Journal of Animal Science*, 54, pp.885-894.

Willms, W., Kenzie, O., McAllister, T., Colwell, D., Veira, D., Wilmshurst, J., Entz, T. and Olson, M. 2002. Effects of Water Quality on Cattle Performance. *Journal of Range Management*, 55(5), p.452.

Wolfemanwm, 2014. Internal surface of the abomasum [online] https://commons.wikimedia.org/w/index.php?curid=30912369 Available 29.8.2016

Wolfemanwm, 2014. Internal surface of the omasum [online] https://commons.wikimedia.org/w/index.php?curid=30912369 Available 29.8.2016

Wolfemanwm, 2014. Internal surface of the reticulum [online] https://commons.wikimedia.org/w/index.php?curid=30912367 Available 29.8.2016

Wolfemanwm, 2014. Internal surface of the rumen [online] https://commons.wikimedia.org/w/index.php?curid=30912369 Available 29.8.2016

Wolfger, B., Timsit, E., Pajor, E., Cook, N., Barkema, H. and Orsel, K. 2015. Technical note: Accuracy of an ear tag-attached accelerometer to monitor rumination and feeding behavior in feedlot cattle. *Journal of Animal Science*, 93(6), p.3164.

Zehner N., Hürlimann M., Nydegger F., Schick M., Bolt R., Hoch M. 2014. Application of a chewing sensor (RumiWatch) for automic heat detection in dairy cows: a pilot study. Paper presented at: International Conference of Agricultural Engineering (Zurich), 6-10 July.

Zehner, N., Niederhauser, J.J., Nydegger, F., Grothmann, A., Keller, M., Hoch, M., Haeussermann, A., Schick, M. 2012. Validation of a new health monitoring system (RumiWatch) for combined automatic measurement of rumination, feed intake, water intake and locomotion in dairy cows. Paper presented at: International Conference of Agricultural Engineering (Valencia, Spain), July 8-12.

Zhu, W., Zeng, N., Wang, N. 2010. Sensitivity, Specificity, Accuracy, Associated Confidence Interval and ROC Analysis with Practical SAS® Implementations. In: NESUG proceedings: *Health Care and Life Sciences*, Baltimore, Maryland. [online] http://www.lexjansen.com/cgi-bin/xsl_transform.php?x=shl&c=nesug Available 2.9.2016