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PRECISION FARMING IN IMPROVEMENT OF DAIRY CATTLE WELFARE

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Abstract: The welfare of dairy cattle is a complex phenomenon, which requires multilevel, multidimensional and planned approach. Precision livestock farming (PLF) enables farm animal welfare focusing from the group level to monitoring and managing individual animals of different categories, which is enabled by use of new advanced technologies.

The basic principle of precision agriculture is the use of sensor technologies in order to improve the efficiency of given narrow thresholds resource use. A range of precision livestock monitoring and control technologies have been developed, primarily to improve livestock production efficiency, but more precise and delicate use may be very applicable in early detection of certain conditions, for example initial lameness in dairy cows, real-time surveillance when calving, or distant body temperature variations measuring of individual animals, when early and more efficient therapeutic measures could be undertaken. Environmental monitoring and control in barns can improve animal comfort, and automatic milking systems facilitate animal choice and improve human-animal interactions.

According literature data, previous and future investigations are encouraging possibility of PLF mechanisms use into automated barn surveillance systems in order to assess, control and improve dairy cattle welfare in entire production process through prompt reaction.

Key words: cattle, improvement, precision livestock farming, sensors, surveillance, welfare

Introduction

The welfare of dairy cattle is a complex phenomenon, which requires multilevel, multidimensional and planned approach. For instance, Five Domains describe a highly structured approach to assessing animal welfare and is centred on the four internal domains of nutrition, environment, health, and behaviour, with the aggregation of these affects into the fifth domain, mental state (*Mellor, 2017*). These Five Domains are defined by the set of 118 contributing factors, approximately 10 times more than the Welfare Quality framework (*Van Erp-van der Kooij and Rutter, 2020*).

The measures which determinate the animal welfare quality when animal exhausted short–term or long term problems may be physiological, behavioural, or concerned with individual production or disease. Individuals vary in the coping methods which they use, so any one measure may indicate poor welfare and absence of evidence using one measure does not mean that there is no welfare problem (*Broom, 1988*).

During the time, animal welfare not only started to use, but developed multiple methodologies, where empiricism, engagement and ethics join to know what 'matters' for the animal and to ensure, as far as is possible, that what matters is met. In both, animal welfare science has been remarkably successful in providing the evidence and the procedures for defining, identifying, and precise assessing animal welfare, leading to significant legislative and regulatory change (*Amon et al., 2001; Milman et al., 2004; Blokhuis et al., 2008; Melfi, 2009*).

To be more accurate, some precision livestock farming funds (PLF) originate many years before term itself became in use, described in domestic literature, such as certain aspects of animal rearing and health protection (*Hristov et al., 1996; Đuričić et al., 1997; Stanković, 1998; Ostojić Andrić et al., 2011*), genetic and reproduction (*Šahinović et al., 1997; Stanković et al., 2005*), nutrition (*Grubić et al., 2009*) and welfare (*Hristov et al., 2014*). This paper aims to present certain aspects of PLF services in contemporary cattle welfare protection.

Precision livestock farming sensors and different aspects of animal welfare

Most reviews of welfare now start with listing the needs of the animal, including needs to show certain behaviours. This approach has used sophisticated studies of what is important to animals and has replaced the earlier general guidelines described as freedoms. Many measures of welfare are now used and indicate how good or how poor the welfare is (*Broom, 2011*). Therefore, PLF enables farm animal welfare focusing from the group level to monitoring and managing individual animals of different categories, which is enabled by use of new advanced technologies (*Van Erp-van der Kooij and Rutter, 2020*). PLF uses advanced technologies for automatic, real-time monitoring of animal behaviour and health, and their influence on environment and production (*Beckermans, 2017*), in order to detect variableness at an early stage and improve current state of animal health, welfare and efficiency, expecting to improve production sustainability (*Beckermans, 2014*). PLF relies on four elements (*Wathes, 2010*):

1. The continuous sensing of the process responses at an appropriate frequency and scale with a continuous exchange of information with the process controller;
2. A compact, mathematical model, which predicts the dynamic responses of each process output to variation of the inputs and can be and is best estimated online in real time;
3. A target value and/or trajectory for each process output, e.g. a behavioural pattern, pollutant emission or growth rate;
4. Actuators and a model-based predictive controller for the process inputs.

According to *Buller et al. (2018)*, protecting the welfare of farmed animals has entered the public policy mainstream in many countries. The development of animal welfare policy and science faces new challenges, particularly in the context of the increasingly in food security, climate change, and human nutrition, opening numerous practical and ethical questions. These issues have potential impact on the welfare science and policy development and therefore need to be discussed, especially two of them; the first is the growing incorporation of animal welfare into contemporary understandings of sustainability (IFC, 2014), now formally endorsed in the United Nations Committee on World Food Security Draft Recommendation, and the second is intertwining of animal and human health, increasingly represented by the ‘One Health’ and ‘One Welfare’ agendas (*Gibbs, 2014; Pinillos et al., 2016*).

Hotzel (2014) considers that animal welfare science should be revolutionizing production systems since no system can be considered as ‘sustainable’ if it does not ensure high quality animal welfare (*Wathes et al., 2013; IFC, 2014*). This is already happening through a growing attention being paid to ‘reflexive interactive design’ and its application, notably to the development of sustainable dairy systems (*Bos, 2008; Bos et al., 2009*) and the technological innovations and improved welfare possibilities associated with precision farming (*Berckmans, 2006; Dawkins, 2014*). It is happening with the expanding incorporation of welfare criteria in environmental certification and assurance schemes, but these are often limited to relatively high-end food supply chains, as well as legislative changes reactions (*Buller and Roe, 2008; Buller, 2018*).

In the very informing study of *Van Erp-van der Kooij and Rutter (2020)*, different types of PLF sensors in use or expected in future to be in use were presented (Table 1).

Table 1. Examples of PLF sensors commercially for use on-farm

Sensor	Location	Measure	Reason
Accelerometer	Leg-mounted	Activity	Oestrus, health
	Neck-mounted	Activity	Oestrus, health, rumination
	Rumen bolus	Activity	Oestrus, health
	Ear tag	Activity	Oestrus, health
	Tail-mounted	Tail posture	Onset of calving
Temperature sensor	Ear tag	Body temperature	Health
	Rumen bolus	Body temperature	Health
pH sensor	Rumen bolus	Body temperature	Health
Milk characteristic	Milking machine, online or inline	Progesterone, BHB, urea, LDH	Pregnancy, ketosis, digestion, mastitis
Milk characteristic	Milking machine	Milk flow, colour, conductivity	Mastitis
Sound analysis	Neck tag	Rumination	Health, stress
Vision	Camera	Body Condition Score	Health, nutrition
Vision	Camera	Face recognition	Identification
Positioning	Beacons and neck tags	Locomotion, behaviour	Health, stress, reproduction
	Wireless sensor network	Locomotion, behaviour	Health, stress, reproduction
Weighing device	Dairy farm, feeder	Weight and feed intake	Growth
Pressure sensor	Floor sensor	Leg pressure	Lameness
Ultrasonic sensor	Foot bath sensor	Claw shape	Lameness, claw health
Vision	Camera	Posture	Lameness
Heart rate sensor	Chest band	Heart rate	Health, stress

(from: *Van Erp-van der Kooij and Rutter, 2020*)

There are several levels of PLF, varying from collecting and analysing data at the group level down to monitoring individual animals, utilising sensors that can be static, moving or animal-mounted (*Rutter, 2012*). The automatic monitoring systems may be based on sound, images and collection of environmental data (*Tullo et al., 2013*), and the technology ranges from monitoring production and fertility to health and behaviour; some systems monitor environmental factors to control climate conditions and there are robotic systems that automate human handling such as milking, feeding and cleaning (*Van Erp-van der Kooij and Rutter, 2020*). Many PLF systems are already commercially available, with further systems in development and likely to be improved and commercialised in the future.

Feeding and drinking sensors - data concerning feeding and water consumption could be collected directly from automatic feeders (*Rushen et al., 2012*) or waterholes (*Meiszberg et al., 2009)*, or indirectly from sensors that monitor behaviour, location or the animals. In dairy cows, feeding behaviour and grazing can be monitored automatically using activity meters, location sensors or sound sensors *(Rutten et al., 2013; Vanrell et al., 2018; Werner et al., 2018)*. Rumination can be monitored by sensors on a neck collar, based on accelerometer data or sound *(Ambriz-Vilchis et al., 2015; Bar and Soloman, 2010)*, and sound may be also analysed to measure behaviour of lying and ruminating time in dairy cows *(Meen et al., 2015)*.

Animal health sensors - Several sensor systems can be used to detect disturbed health condition in farm animals, using animal-mounted sensors or sensors as a part of farm infrastructure. Body temperature can be measured directly - with animal-mounted sensors, or indirectly - with thermographic cameras *(Sellier et al., 2014; Arican et al., 2018)*. Thermographic cameras can be used for mastitis detection in dairy cows *(Hovinen et al., 2008; Bortolami et al., 2015)*. Body temperature can be monitored with rumen boluses in dairy cows, which can also monitor rumen motility and pH, as an indicator for metabolic disease *(Mottram, 2015; Nogami et al., 2017; Arai et al., 2019)*. Accelerometers measuring activity in dairy cows not only detect oestrus but also behavioural changes signalling disease *(Rutter, 2012; Chanvallon et al., 2014; Roelofs and Van Erp-Van Der Kooij, 2015)*, such as lameness *(Sadiq et al., 2017; Vázquez Diosdado et al., 2018; Barker et al., 2018)*. Symptoms of disease can be detected with sound analysis, for example coughing calves *(Vandermeulen et al., 2016)*. Lameness in cows can be detected with force plates or pressure mats *(Maertens et al., 2011)*. In milk samples, beta-hydroxybutyrate (BHB) and lactate dehydrogenase (LDH) can be measured automatically as an indicator for metabolic disease or mastitis in dairy cows *(Asmussen and Foss, 2010)*.

Housing conditions and animal comfort sensors - This type of sensors are used mostly for pig and poultry farms, since these farms are under no influence of the outside environmental conditions *(Van Erp-van der Kooij and Rutter, 2020)*. These farms require automatic control systems, regulating the indoor climate, temperature, relative humidity (RH), air speed and carbon dioxide (CO_2). In dairy farms, commercial climate condition monitoring is in development *(Antanaitis et al., 2016)*.

Animal behaviour sensors - Behaviours of animals can be monitored using location or activity data from animal-mounted sensors in dairy cows *(Meunier et al., 2018; Pastel et al., 2018)*. In dairy farms, activity sensors developed for heat detection are also used for behaviour monitoring and for reporting deviations in behaviour *(Van Erp-Van der Kooij et al., 2016;)* [25, 76–79]. Lying, walking, eating and standing behaviour of dairy cows can be measured quite accurately with activity meters on a leg, neck or ear tag *(Van Erp-Van der Kooij et al., 2016)* [25, 76, 80]. It is also possible to detect some abnormal and damaging behaviour, which is mostly used in pig and poultry production *(Van Erp-van der Kooij and Rutter, 2020)*. For instance, it has been reported that lame cows reveal changes to both feeding and lying behaviour. They are slower to respond to food being made available *(Yunta et al., 2012)* and feed faster, although for a reduced overall duration per day *(Norring et al., 2014)*. Changes in lying behaviour are also described, although there are discrepancies between studies *(Barker et al., 2018)*; increased lying was described by *Singh et al. (1993)* and *Blackie et al. (2011)*, no difference by *Ito et al. (2010)* and *Yunta et al. (2012),* and decreased lying by *Cook et al. (2008)*. Therefore, automated individual cow behaviours monitoring could be useful in the early detection of lameness.

Distress detecting sensors – According to Van Erp-*van der Kooij and Rutter (2020)*, different stress calls in cows can be recognised. The rise in heat production during stress can be measured using a thermographic camera in cows *(Stewart et al., 2005; Stewart et al., 2017).* Finally, automatic heart rate measurements, corrected for activity, can be used to measure stress *(Behmann et al., 2016).*

Measures used in on-farm welfare assessment systems are often classified into resource-based measures: housing systems, space allowances, animal management practises, and animal-based measures: low incidence of disease or injury, normal behaviour *(Main et al., 2003)*. Animal-based measures provide more direct assessment of the state of the animals *(Barnett and Hemsworth, 2009)* and nowadays PLF has an important role in the welfare assessment.

PLF implications on animal welfare

The creation of an automated assessment of animal welfare was attempted through integration and combining of certain measures *(Van Erp-van der Kooij and Rutter, 2020)*, but still no system offers everything that could be achieved by using a full combination of all systems operating together, and almost without exception, the different technologies operate 'stand-alone' and will not communicate with each other *(Caja et al., 2016).*

PLF has the potential to monitor, manage and control many aspects of livestock production, simultaneously and automatically *(Wathes et al., 2008)*. Regarding calving prediction, recognition and early detection enable timely assistance, which is necessary to ensure the survival of cows and their offspring *(Lopes et al., 2016).* There are some calving detection sensors on the market, which resort to the detection of different changes that occur around or during calving.

According to *Saint-Dizier and Chastand-Maillard (2015)*, these sensors should point out variations of rectal and vaginal temperatures (0.4 to 0.6 ºC and 0.6-0.7 ºC respectively lower on the day of calving than 48 hours before), for both beef and dairy cattle. On the calving day, their behaviour changes, the animals tend to isolate themselves from the rest of the herd, have increased activity and lie down and stand up more often, increased movements by the tail close to parturition and rising of the tail head as early as 5 days before parturition. There are decreases of feeding, drinking and rumination activity which also should be noticed.

Bioacoustics has been used to evaluate conditions such as stress and welfare through screams, calls and vocalizations, and to assess health by monitoring coughs and sneezes *(Ferrari et al., 2010)*. Furthermore it is a simple, cheap and non-invasive technology. Respiratory diseases, such as bovine respiratory disease (BRD), are one of the most prevailing pathologies in young categories and early recognition of cough sounds is being used as a method of diagnosing respiratory diseases. Cough sounds can only be assessed during a visit to the farm and an automatic monitoring tool for animals' coughs can contribute to improved farm management through opportune treatments *(Vandermeulen et al., 2016)*.

Use of different types of imaging, such as infrared thermographic imaging (IRT), magnetic resonance (MR), computer tomography (CT) are accurate and saving time but expensive and in logistic aspect demanding methodology for diagnostic of certain primarily health disorders. According to *Arican et al. (2018),* thermographic examination may have potential as a detection tool for laminitis. MR transversal images provided excellent depiction of anatomical structures and many biometric researches in the bovine hoof can be easily investigated, especially during the initial active phase of laminitis. However, the usefulness of IRT, MRI, CT in evaluating laminitis in different situations remains still open. Diagnostic imaging technique such as radiography and ultrasonography provide limited information for evaluation of the bovine digits and claw. Radiography has limited value to evaluation of soft tissue.

In order to to evaluate the potential application of thermographic imaging compared to SCC and bacteriological culture for infection detection in cow affected by subclinical mastitis, *Bortolami et al. (2015)* took thermographic images from each functional udder quarter and nipple. Authors found that infrared thermography was correlated to SCS ($p<0.05$) but was not able to discriminate between positive and negative cows. The association found between SCS and temperatures suggests the use of thermographic imaging as a screening tool helpful in the evaluation of an inflammation status of the udder, but seems to have a poor diagnostic value. Similar results regarding thermal imaging in assessing body temperature of calves were published by *Bell et al. (2019),* suggesting that accurate measures of core body temperature using thermal imaging cannot be achieved under commercial farm conditions and that further research is needed.

Another approach to animal status assessment traditionally includes manual and visual scoring, but the large number of man-hours required for these methods involves high costs, and use of a sensor attached to the animals can be invasive and may alter the outcome *(Cangar et al., 2008)*. For this reason, the use of automatically collected images to analyse farming systems is becoming more and more common *(Tullo et al., 2013)*. Early detection of certain symptoms of health disorders might be useful when immediate therapy is required, such as real-time rumen temperature monitoring by utilizing an ingestible biosensor *(Kim et al., 2019)*. It proved to be right and that mastitis is accompanied with a high rise in body temperature.

PLF can combine audio and video information into on-line automated tools that can be used to control, monitor and model the behaviour of animals and their biological response *(Tullo et al., 2013)*. The PLF approach can easily be applied to different aspects of management, with a focus on the animals and/or the environment, and at different scales, from the individual to the entire flock/herd *(Wathes, 2010)*.

The human-animal relationship is important for animal welfare and could be measured automatically. An integrated approach to animal welfare assessment should be possible, but this approach needs to be further defined and validated *(Van Erp-van der Kooij and Rutter, 2020)*.

The greatest uptake of PLF technologies to date has been in intensive animal production systems, but *Van Erp-van der Kooij and Rutter (2020)* deem that there is a risk for the technological intensification of production may be neglected animal welfare enhancement by promoting positive experiences *(Stevenson, 2017)* and decreased contact between farmer and animals, therefore disturbing the human-animal relationship and decrease the opportunities to directly observe the health and well-being of the animals *(Hostiou et al., 2017)*. Over-relining on PLF might cause missing of other diseases signs *(Wathes et al., 2008)*. Farmers often do not understand PLF systems and need to be maintained and calibrated *(Hartung et al., 2017)*. Therefore, automated detection system must work on any farm in any conditions, and data standardisation is strongly dependent on manual labelling, which is necessary for data analysis and model development. Key indicators and standards must be clear and precise *(Tullo et al., 2013)*.

PLF systems should improve welfare by optimising feeding and systematically monitoring growth and/or weight measurements *(Wathes et al., 2008)*, by early detection of disease, such as lameness or mastitis, as well as by improving housing conditions with devices such as robot scrapers and automated climate control systems *(Blokhuis, 2010)*. *Webster (2016)* is right claiming that giving animals the ability to make choices that promote their own quality of life could help improve welfare, which could be managed through individual feeding, robotic milking or voluntary showering facilities. PLF systems may increase welfare if the farmer responds adequately to the PLF system alerts; however, good tools do not automatically guarantee good utilisation by a stockperson *(Van Erp-van der Kooij and Rutter, 2020).*

Conclusion

The welfare of dairy cattle is a complex phenomenon, which requires multilevel, multidimensional and planned approach. Precision livestock farming (PLF) enables farm animal welfare focusing from the group level to monitoring and managing individual animals of different categories, which is enabled by use of new advanced technologies. A number of developed PLF sensors increase as investigations advance, although welfare assessment systems are not efficient enough yet and further research is needed. PLF is a useful tool for the farmer to monitor and improve animal welfare, upgrading living conditions for the cows and to detect early symptoms of health disorders. According literature data, previous and future investigations are encouraging possibility of PLF mechanisms use into automated barn surveillance systems in order to assess, control and improve dairy cattle welfare in entire production process through early reaction.

Precizna poljoprivredna proizvodnja za poboljšanje dobrobiti mlečnih goveda

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Rezime

Dobrobit mlečnih goveda je složen fenomen koji zahteva višestepeni, višedimenzionalni i planski pristup. Precizno uzgajanje stoke (PLF) omogućava fokusiranje dobrobiti domaćih životinja sa grupnog nivoa na praćenje i upravljanje pojedinim životinjama različitih kategorija, što je moguće upotrebom novih naprednih tehnologija.
Osnovni princip precizne poljoprivrede je upotreba senzorskih tehnologija u cilju poboljšanja efikasnosti korišćenja resursa u okviru zadatih uskih graničnih vrednosti parametara. Razvijen je niz preciznih tehnologija za nadzor i kontrolu životinja, prvenstveno radi poboljšanja efikasnosti stočarske proizvodnje, ali se one

mogu upotrebiti preciznije i delikatnije u ranom otkrivanju određenih stanja, na primer početne hromosti kod muznih krava, nadzor u realnom vremenu u vreme teljenja ili za daljinsko merenje telesne temperature za pojedinačna grla, u cilju ranog i efikasnijeg preduzimanja terapijskih mera. Monitoring i kontrola parametara životne sredine u štalama mogu poboljšati udobnost životinja, a sistemi za automatsku mužu olakšavaju odabir grla i poboljšavaju interakcije ljudi i životinja.
Prema literaturnim podacima, sprovedena i buduća istraživanja ohrabruju mogućnost upotrebe PLF mehanizama u automatizovanim sistemima za nadzor štala u cilju procene, kontrole i poboljšanja dobrobiti mlečnih goveda u celom proizvodnom procesu mogućnošću brzog reagovanja.

Ključne reči: goveda, poboljšanje, precizno stočarstvo, senzori, nadzor, dobrobit

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References

AMBRIZ-VILCHIS V., JESSOP N.S., FAWCETT R.H., SHAW D.J., MACRAE A.I. (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, 1750–1758.
AMON T., AMON B., OFNER E., BOXBERGER J. (2001): Precision of assessment of animal welfare by the'TGI 35 L'Austrian needs index. Acta Agriculturae Scandinavica, Section A-Animal Science, 51, S30, 114-117.
ANTANAITIS R., ZILAITIS V., JUOZAITIENE V., STOSKUS R., TELEVICIUS M. (2016): Changes in reticulorumen content temperature and pH according to time of day and yearly seasons. Polish Journal of Veterinary Sciences, 19, 4, 771–776.
ARAI S., OKADA H., SAWADA H., TAKAHASHI Y., KIMURA K., ITOH T. (2019): Evaluation of ruminal motility in cattle by a bolus-type wireless sensor. Journal of Veterinary Medical Science 81, 12, 1835–41.
ARICAN M., HATIPLOGU F., EROL H., KANAT O., YAVUZ O., PARLAK K., COK O. (2018): Comparison of Thermographic Imaging and Other Diagnostic

Techniques in Diagnosis of Cattle with Laminitis. Acta Scientiae Veterinariae, 46, 1, 7.
ASMUSSEN T., FOSS A.S. (2010): Herd navigator or "how to benefit from frequent measurements". In: ICAR 37th Annual Meeting. Riga: ICAR; 291–293.
BAR D., SOLOMAN R. (2010): Rumination collars: what can they tell us. In: The First North American Conference on Precision Dairy Management, Toronto, Canada, 2.
BARKER Z.E., VÁZQUEZ DIOSDADO J.A., CODLING E.A., BELL N.J., HODGES H.R., CROFT D.P., AMORY J.R. (2018): Use of novel sensors combining local positioning and acceleration to measure feeding behavior differences associated with lameness in dairy cattle. Journal of Dairy Science, 101, 7, 6310–21.
BARNETT J.L., HEMSWORTH P.H. (2009): Welfare monitoring schemes: using research to safeguard welfare of animals on the farm. Journal of Applied Animal Welfare Science, 12, 114-131.
BEHMANN J., HENDRIKSEN K., MÜLLER U., BÜSCHER W., PLÜMER L. (2016): Support Vector machine and duration-aware conditional random field for identification of spatio-temporal activity patterns by combined indoor positioning and heart rate sensors. GeoInformatica, 20, 4, 693–714.
BELL D.J., MACRAE A.I., MITCHELL M.A., MASON C.S., JENNINGS A., HASKELL M.J. (2020): Comparison of thermal imaging and rectal temperature in the diagnosis of pyrexia in pre-weaned calves using on farm conditions. Research in Veterinary Science, 131, 259-265.
BERCKMANS D. (2006): Automatic on-line monitoring of animals by precision livestock farming. In Livestock Production and Society; Wageningen Academic Publishers: Wageningen, The Netherlands, 287–295.
BERCKMANS D. (2008): Automatic real-time monitoring of locomotion and posture behaviour of pregnant cows prior to calving using online image analysis. Computers and Electronics in Agriculture 64, 1, 53-60.
BERCKMANS D. (2014): Precision livestock farming technologies for welfare management in intensive livestock systems. OIE Revue Scientifique et Technique, 33, 1, 189–96.
BERCKMANS D. (2017): General introduction to precision livestock farming. Animal Frontiers. 7, 1, 6–11.
BLOKHUIS H.J. (2010): The Welfare Quality® project and beyond: safeguarding farm animal well-being. Acta Agriculturae Scandinavica Section A Animal Science 60, 3, 129–40.
BLOKHUIS H.J., KEELING L.J., GAVINELLI A., SERRATOSA J. (2008): Animal welfare's impact on the food chain. Trends in Food Science & Technology, 19, S79–S87.

BOJKOVSKI J., BOROZAN S., HRISTOV S., STANKOVIĆ B., JOKSIMOVIĆ-TODOROVIĆ M., DAVIDOVIĆ V. (2007): Uticaj kontaminacije sredine na zdravstveno stanje farmskih životinja. „Dobrobit životinja i biosigurnost na farmama”, Poljoprivredni fakultet, Zemun, 251-258.
BORTOLAMI A., FIORE E., GIANESELLA M., CORRO M., CATANIA S., MORGANTE M. (2015): Evaluation of the udder health status in subclinical mastitis affected dairy cows through bacteriological culture, somatic cell count and thermographic imaging. Polish Journal of Veterinary Sciences, 18, 4, 799–805.
BOS A.P. (2008): Instrumentalization theory and reflexive design in animal husbandry. Social Epistemology, 22, 29–50.
BOS A.P., GROOT KOERKAMP P.W.G., GOSSELINK J.M.J., BOKMA S. (2009): Reflexive interactive design and its application in a project on sustainable dairy husbandry systems. Outlook on Agriculture, 38, 137–145.
BROOM D.M. (1988): The scientific assessment of animal welfare. Applied Animal Behaviour Science, 20, 1-2, 5-19.
BROOM D.M. (2011): A history of animal welfare science. Acta biotheoretica, 59, 2, 121-137.
BULLER H. (2018): Public Opinion and the Retailer. In Animal Welfare in a Changing World; BUTTERWORTH A., Ed.; CABI: Wallingford, UK, 100–109.
BULLER H., BLOKHUIS H. JENSEN P., KEELING L. (2018):Towards farm animal welfare and sustainability. Animals, 8(6), 81.
BULLER H., BLOKHUIS H., JENSEN P., KEELING L. (2018):Towards farm animal welfare and sustainability. Animals, 8, 6, 81.
BULLER H., ROE E. (2008): Food and Animal Welfare; Bloomsbury Press: London, UK.
CAJA G., CASTRO-COSTA A., KNIGHT C.H. (2016): Engineering to support wellbeing of dairy animals. Journal of Dairy Research, 83, 2, 136–47.
CANGAR Ö., LEROY T., GUARINO M., VRANKEN E., FALLON R., LENEHAN J., MEE J., BLACKIE N., AMORY J.R., BLEACH E., SCAIFE J. (2011): The effect of lameness on lying behaviour of zero grazed Holstein dairy cat-tle. Applied Animal Behaviour Science, 134, 85–91.
CHANVALLON A., COYRAL-CASTEL S., GATIEN J., LAMY J.M., RIBAUD D., ALLAIN C., CLÉMENT, P., SALVETTI P. (2014): Comparison of three devices for the automated detection ofestrus in dairy cows. Theriogenology, 82, 5, 734–41.
COOK N.B., MARIN M.J., MENTINK R.L., BENNETT T.B., SCHAEFER M.J. (2008): Comfort zone-design free stalls: Do they influence the stall use behavior of lame cows? Journal of Dairy Science, 91, 4673–4678.
DAWKINS M.S. (2014): Precision Farming and Animal Welfare. Sci. Parliam. 71, 14–15.

ĐURIČIĆ B., MILOŠEVIĆ B., RADOJIČIĆ S., OBRENOVIĆ S., ARANĐELOVIĆ S., KNEŽEVIĆ D., VUKŠA P., STANKOVIĆ B., MIĆOVIĆ M. (1997): Aerosol vaccination: drop size influence on postvaccinal immunity in chickens vaccinated against Newcastle disease. Proceedings of XIth International Congress of the World Veterinary Poultry Association, 203, Budapest, Hungary, 18-22nd August 1997.

FERRARI S., PICCININI R., SILVA M., EXADAKTYLOS V., BERCKMANS D., GUARINO M. (2010): Cough sound description in relation to respiratory diseases in dairy calves. Preventive Veterinary Medicine 96, 3-4, 276-280.

GIBBS E.P.J. (2014): The evolution of One Health. Veterinary Record, 174, 85–91.

GRUBIĆ, G., NOVAKOVIĆ, Ž., ALEKSIĆ, S., SRETENOVIĆ, L., PANTELIĆ, V., OSTOJIĆ-ANDRIĆ, D. (2009): Evaluation of the body condition of high yielding cows. Biotechnology in Animal Husbandry, 25, 1-2, 81-91.

HARTUNG J., BANHAZI T., VRANKEN E., GUARINO M. (2017): European farmers' experiences with precision livestock farming systems. Animal Frontiers, 7, 1, 38–44.

HOSTIOU N, FAGON J, CHAUVAT S, TURLOT A, KLING-EVEILLARD F, BOIVIN X, ALLAIN C. (2017): Impact of precision livestock farming on work and human-animal interactions on dairy farms. A review. Biotechnology, Agronomy, Society and Environment 21, 4, 268–75.

HÖTZEL M.J. (2014): Improving farm animal welfare: Is evolution or revolution needed in production systems. In Dilemmas in Animal Welfare; Appleby, M., Sandoe, P., Weary, D., Eds.; CABI: Wallingford, UK, 67–84.

HOVINEN M., SIIVONEN J., TAPONEN S., HÄNNINEN L., PASTELL M., AISLA A.M., PYÖRÄLÄ S. (2008): Detection of clinical mastitis with the help of a thermal camera. Journal of Dairy Science, 91, 12, 4592–4598.

HRISTOV S, STANKOVIĆ B, OSTOJIĆ-ANDRIĆ D. (2014): Different approaches to assess the welfare of dairy cows with some results in Serbia. Proceedings of the International Symposium on Animal Science 2014, September 2014, Belgrade – Zemun, 320-328.

HRISTOV S., ANOJČIĆ B., VUČINIĆ M., STANKOVIĆ B. (1996): Uticaj prašine vazduha na organizam životinja. VII Savetovanje DDDDD, Zbornik radova, 268-275.

INTERNATIONAL FINANCE CORPORATION. Improving Animal Welfare in Livestock Operations; IFC: Washington, WA, USA, 2014.51.

ITO K., VON KEYSERLINGK M.A.G., LEBLANC S.J., WEARY D.M. (2010): Lying behavior as an indicator of lameness in dairy cows. Journal of Dairy Science, 93, 3553–3560.

KIM H., MIN Y., CHOI B. (2019): Real-time temperature monitoring for the early detection of mastitis in dairy cattle: Methods and case researches. Computers and Electronics in Agriculture, 162, 119-125.
LOPES S.I., BEXIGA R., ARAÚJO J.P., CERQUEIRA J.L., ABREU C., PAREDES C., ALONSO J.M. (2016): Precision livestock farming for reproductive performance optimization: a survey. In Food futures: ethics, science and culture, Wageningen Academic Publishers, 3197-3211.
MAERTENS W., VANGEYTE J., BAERT J., JANTUAN A., MERTENS K.C., DE CAMPENEERE S., PLUK A, OPSOMER G, VAN WEYENBERG S, VAN NUFFEL A. (2011): Development of a real time cow gait tracking and analysing tool to assess lameness using a pressure sensitive walkway: The GAITWISE system. Biosystems Engineering, 110, 1, 29–39.
MAIN D.C.J., KENT J.P., WEMELSFELDER F., OFNER E., TUITTENS F.A.M. (2003): Applications for methods of on-farm assessment. Animal Welfare Journal, 12, 445-456.
MEEN G.H., SCHELLEKENS M.A., SLEGERS M.H.M., LEENDERS N.L.G., VAN ERP-VAN DER KOOIJ E., NOLDUS L.P.J.J. (2015): Sound analysis in dairy cattle vocalisation as a potential welfare monitor. Computers and Electronics in Agriculture, 118, 111–115.
MEISZBERG A.M., JOHNSON A.K., SADLER L.J., CARROLL J.A., DAILEY J.W., KREBS N. (2009): Drinking behavior in nursery pigs: determining the accuracy between an automatic water meter versus human observers. Journal of Animal Science, 87, 12, 4173–80.
MELFI V.A. (2009): There are big gaps in our knowledge, and thus approach, to zoo animal welfare: A case for evidence-based zoo animal management. Zoo Biology: Published in affiliation with the American Zoo and Aquarium Association, 28, 574–588.
MELLOR D.J. (2017): Operational details of the five domains model and its key applications to the assessment and management of animal welfare. Animals, 7(8):1–20.
MEUNIER B., PRADEL P., SLOTH K.H., CIRIÉ C., DELVAL E., MIALON M.M., VEISSIER I. (2018): Image analysis to refine measurements of dairy cow behaviour from a real-time location system. Biosystems Engineering, 173, 32–44.
MILLMAN S., DUNCAN I., STAUFFACHER M., STOOKEY J.M. (2004): The impact of applied ethologists and the International Society for Applied Ethology in improving animal welfare. Applied Animal Behaviour Science, 86, 299–311.
MOTTRAM T. (2015): Precision livestock farming in rumen sensing, feed intake and precise feeding. In: HALACHMI I, ed. Precision livestock farming applications. Wageningen: Wageningen Academic Publishers, 291-298.

NOGAMI H., ARAI S., OKADA H., ZHAN L., ITOH T. (2017): Minimized bolus-type wireless sensor node with a built-in three-axis acceleration meter for monitoring a Cow's Rumen conditions. Sensors (Switzerland), 17, 4, 1–10.

NORRING M., HÄGGMAN J., SIMOJOKI H., TAMMINEN P., WINCKLER C., PASTELL M. (2014): Short communication: Lameness impairs feeding behavior of dairy cows. Journal of Dairy Science, 97, 4317–4321.

OSTOJIĆ ANDRIĆ D., ALEKSIĆ S., HRISTOV S., NOVAKOVIĆ Ž., PETROVIĆ M.M., NIKŠIĆ D., STANIŠIĆ N. (2012): Serbia in the implementation of SEUROP standard for beef carcass classification: Legislation, parameters and evaluation criteria: Part A. Biotechnology in Animal Husbandry, 28, 1, 47-58.

PASTELL M., FRONDELIUS L., JÄRVINEN M., BACKMAN J. (2018): Filtering methods to improve the accuracy of indoor positioning data for dairy cows. Biosystems Engineering, 169, 22–31.

PINILLOS R.C., APPLEBY M.C., MANTECA X., SCOTT-PARK F., SMITH C., VELARDE A. (2016): One Welfare - A platform forimproving human and animal welfare.Veterinary Record, 179, 412–413.

ROELOFS J.B., VAN ERP-VAN DER KOOIJ E. (2015): Estrus detection tools and their applicability in cattle: recent and perspectival situation. Animal Reproduction, 12, 3, 498–504.

RUSHEN J., CHAPINAL N., DE PASSILLÉ A.M. (2012): Automated monitoring of behavioural-based animal welfare indicators. Animal Welfare, 21, 3, 339–50.

RUTTEN C.J., VELTHUIS A.G.J., STEENEVELD W., HOGEVEEN H. (2013): Invited review: sensors to support health management on dairy farms. Journal of Dairy Science 96, 4, 1928–52.

RUTTER S.M. (2012): A "smart" future for ruminant livestock production? Cattle Practice, 20, 3, 186–93.

RUTTER S.M. (2012): A "smart" future for ruminant livestock production? Cattle Practice, 20, 3, 186–93.

SADIQ M.B., RAMANOON S.Z., MOSSADEQ W.M.S., MANSOR R., SYED-HUSSAIN S.S. (2017): Association between lameness and indicators of dairy cow welfare based on locomotion scoring, body and hock condition, leg hygiene and lying behavior. Animals, 7(11):1–17.

ŠAHINOVIĆ R., STANČIĆ B., STANKOVIĆ B. (1997): In vitro maturation of porcine follicular oocytes after 24 and 48 hours. 5th KOK and 3rd Symposium on the Animal Reproduction, 150, 2-6th September, Ohrid, Macedonia, 1997.

SAINT-DIZER M., CHASTAND-MAILLARD S. (2015): Methods and on-farm devices to predict calving time in cattle. Veterinary Journal, 205, 349-356.

SELLIER N., GUETTIER E., STAUB C. (2014): A review of methods to measure animal body temperature in precision farming. American Journal of Agricultural Science and Technology, 2, 2, 74–99.
SINGH S.S., WARD W.R., LAUTENBACH K., MURRAY R.D. (1993): Behaviour of lame and normal dairy cows in cubicles and in a straw yard. Veterinary Record, 133, 204–208.
STANKOVIĆ B. (1998): Uticaj prašine u vazduhu poreklom iz prostirke na uspeh vakcinacije pilića putem aerosola. Magistarska teza, Fakultet veterinarske medicine, Beograd.
STANKOVIĆ B., PETRUJKIĆ T., HRISTOV S., RELIĆ R. (2005): Freezing the boars semen: Some limitations and perspectives. Savremena poljoprivreda, 54, 1-2, 139-144.
STEVENSON P. (2017): Precision livestock farming: could it drive the livestock sector in the wrong direction? In: 8th European Conference on Precision Livestock Farming; Nantes, France, 736–45.
STEWART M., WEBSTER J.R., SCHAEFER A.L., COOK N.J., SCOTT S.L. (2005): Infrared thermography as a non-invasive tool to study animal welfare. Animal Welfare 14, 4, 319–25.
STEWART M., WILSON M.T., SCHAEFER A.L., HUDDART F., SUTHERLAND M.A. (2017): The use of infrared thermography and accelerometers for remote monitoring of dairy cow health and welfare. Journal of Dairy Science, 100, 5, 3893–901.
TULLO E., FONTANA I., GUARINO M. (2013): Precision livestock farming: an overview of image and sound labelling. In European Conference on Precision Livestock Farming 2013: (PLF) EC-PLF, KU Leuven. 30-38.
VAN ERP-VAN DER KOOIJ E., RUTTER S. M. (2020): Using precision farming to improve animal welfare. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 15(051).
VAN ERP-VAN DER KOOIJ E., VAN DE BRUG M, ROELOFS J. (2016): Validation of Nedap Smarttag Leg and neck to assess behavioural activity level in dairy cattle. In: Kamphuis C, Steeneveld W, editors. Precision fairy farming 2016. Leeuwarden: Wageningen Academic Press; 321–326.
VANDERMEULEN J., BAHR C., JOHNSTON D., EARLEY B., TULLO E., FONTANA I., GUARINO M., EXADAKTYLOS V., BERCKMANS D. (2016): Early recognition of bovine respiratory disease in calves using automated continuous monitoring of cough sounds. Computers and Electronics in Agriculture; 129, 15–26.
VANRELL S.R., CHELOTTI J.O., GALLI J.R., UTSUMI S.A., GIOVANINI L.L., RUFINER H.L., MILONE D.H. (2018): A regularity-based algorithm for

identifying grazing and rumination bouts from acoustic signals in grazing cattle. Computers and Electronics in Agriculture, 151, 392–402.
VÁZQUEZ DIOSDADO J.A., BARKER Z.E., HODGES H.R., AMORY J.R., CROFT D.P., BELL N.J., CODLING E.A. (2018): Space-use patterns highlight behavioural differences linked to lameness, parity, and days in milk in barn-housed dairy cows. PLOS One 13, 12, 1–23.
WATHES C.M. (2010): The prospects for precision livestock farming. Journal of the 327 Royal Agricultural Society of England 171, 26-32.
WATHES C.M., BULLER H., MAGGS H., CAMPBELL M.L. (2013): Livestock production in the UK in the 21st century: A perfect storm averted? Animals, 3, 574–583.
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, 2–10.
WEBSTER J. (2016): Animal welfare: freedoms, dominions and "a life worth living". Animals, 6, 6, 2–7.
WERNER J., LESO L., UMSTATTER C., NIEDERHAUSER J., KENNEDY E., GEOGHEGAN A., SHALLOO L., SCHICK M. O'BRIEN B. (2018): Evaluation of the RumiWatchSystem for measuring grazing behaviour of cows. Journal of Neuroscience Methods, 300, 138–46.
YUNTA C., GUASCH I., BACH A. (2012): Short communication: Lying behavior of lactating dairy cows is influenced by lameness especially around feeding time. Journal of Dairy Science, 95, 6546–6549.