The role of Precision Livestock Farming technologies in animal welfare monitoring: a review

Birte L. Nielsen

Universities Federation for Animal Welfare (UFAW), The Old School, Wheathampstead, United Kingdom

NIELSEN, B. L.: The role of Precision Livestock Farming technologies in animal welfare monitoring: a review. Vet. arhiv 92, 251-257, 2022.

ABSTRACT

Precision Livestock Farming is the use of technology to help farmers monitor and manage their animals and their farm. Precision Livestock Farming technologies can be used to improve not only animal welfare and health, but also production. Automated measures reflecting the welfare of an animal can be related to its environment, and to the behaviour and physiology of the animal, as well as its position relative to environmental features. We need to ensure that the automatic measures we record reflect the type of behavioural or physiological changes we are interested in. Other aspects to consider are space and time, in terms of variable environmental conditions and animal-related changes that occur gradually. Different types of equipment can be used for measuring behaviour automatically, and these are either attached to, interacting with, or remote from the animal. A combination of these is often the most efficient method, but it is also more complex to manage. There are also species differences as to what is feasible. Small farms are unlikely to be able to afford the type of equipment used by larger enterprises, and we need to put more effort into finding Precision Livestock Farming technologies that can work for the smallholder. The use of Precision Livestock Farming technologies for efficient animal welfare monitoring in practice requires affordable, reliable, and easy-to-use equipment, providing data that reflect – adequately and in real-time – different aspects of the state of the welfare of animals within the herd.

Key words: Precision Livestock Farming; technology; animal welfare; animal health; monitoring

Introduction

Precision Livestock Farming (PLF) is the use of technology to help farmers monitor and manage their animals and their farm (ROWE et al., 2019). The word 'help' is important here, as PLF is not meant to replace humans, but to function as a tool to improve monitoring and make sure that time is spent on the most useful and important tasks. It is also worth noting that PLF technologies can be used to improve not only animal welfare and health, but also production. The former may lead to the latter, in that improved health and welfare can pave the way for increased production, but the reverse is rarely, if ever, the case. Thus, PLF technologies are tools – and only tools – that farmers can use to monitor their animals, and which provide information for use in decision making and management of the farm. This is important to keep in mind throughout this article, in particular in

*Corresponding author:
Dr. Birte L. Nielsen, Universities Federation for Animal Welfare (UFAW), The Old School, Brewhouse Hill, Wheathampstead AL4 8AN, United Kingdom, Phone: +44 (0) 7841 562420; E-mail: nielsen@ufaw.org.uk

ISSN 0372-5480
Printed in Croatia

connection with the examples of how to use certain techniques in practice.

Although it has been defined above, it might be worth delving into what exactly is meant by Precision Livestock Farming. If we look at the words individually, '*Precision*' refers to some form of frequent, automated measurement, which is sometimes performed in real-time. In other words, this is the collection of data over time, and the accuracy and accessibility may vary dependent on what we are measuring. We know what '*Livestock'* is, although my choice of species used in the examples below reflects conventional farm animals. I should perhaps have included fish to illustrate that, in the 2020s, livestock is more than just cows, pigs, and chickens. Finally, '*Farming'* is of course to do with producing some form of commodity, be it milk, meat, eggs or fur. It also involves the breeding of the specific livestock, and it includes the health and welfare of the animals in our care (Fig. 1). The data of interest relate to variables in the environment surrounding the animal and where the animal is positioned within this environment, as well as animal-based measures of physiology and behaviour. Examples of measurements from these four areas (environment, position, physiology and behaviour) will be given in the following section.

Types of equipment and measurement

An example of the type of measurements we can make is monitoring rumination in a dairy species. Using data from continuous, automatic, real-time measurement from an accelerometer attached to the ear of a goat (*Capra aegagrus hircus*), we can detect periods of activity lasting roughly one minute when the goat is chewing a bolus of roughage, and these are interspersed with very short pauses, occurring when the goat swallows the bolus and brings up another one (for an illustration see Fig. 13.2 in NIELSEN, 2020). However, we were already able to obtain an almost identical picture almost 60 years ago by tracking the jaw movements of a goat by means of pressure changes on rubber-tubes fitted on a halter and connected to ink pens writing on a moving paper roll (BELL and LAWN, 1957). In other words, we tend to think of PLF as a modern concept, but we have actually been able to measure relevant aspects of behaviour – in this example rumination – for many years, even if the methods were somewhat clumsier in those days.

So, what are the types of automated measures we can collect within the four areas mentioned earlier and outlined in the blue triangle of Fig. 1?

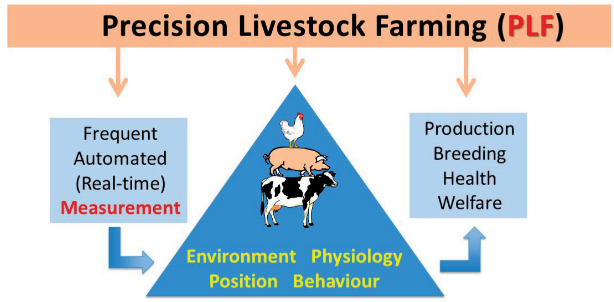

Fig.1. Precision Livestock Framing (PLF) and what the words refer to. Data of use in PLF can be collected from the environment, as well as from the animals themselves in terms of their physiology, position and behaviour. PLF technologies can be used to manage animal health and welfare, as well as production and breeding.

The most common environmental measures relate to the ambient temperature, the relative humidity and the air quality within the barn or pen. If we are farming fish, we would include measures of water quality. It is easy to see how information on these aspects can be useful for us when considering the health and welfare of the animal. If the ambient temperature suddenly rises, we need to check if our animals are suffering from heat shock or if the barn is on fire. Many of us will have stayed in places where there are carbon monoxide alarms to ensure that we are not slowly suffocating without knowing it, and these alarms are an example of environmental monitoring to safeguard our health. Another example of a useful on-farm measure is water consumption, where a decrease may reflect that some drinkers are blocked, or the animal is ill, whereas a sudden increase in water usage can be due to a leakage in the system, which could lead to wet litter. In broiler chickens (*Gallus gallus domesticus*), for example, this may result in footpad dermatitis, which is not conducive to good animal welfare. However, we could ask, since we have measured these things for ages, surely that has nothing to do with the new-fangled idea of PLF? Yes it has, as the example of rumination measures from 60 years ago also showed. All the data we can collect easily and accurately, and which reflect aspects of the wellbeing of our animals, should be considered part of PLF – even if we have been collecting them for ages.

The animal-based measurements relate to physiology, position and behaviour. Physiological measures are often most relevant when we look at changes over time or differences between animals. The measurements can be of bodily fluids, such as blood or urine, of body temperature or rumen pH, measures of heart rate, but also production output, such as milk yield or egg production. Remember, although high production is not necessarily an indicator of high welfare, sudden changes in production measurements can alert us to the animal in question. This is particularly relevant for milk yield, which is often measured automatically twice a day as part of the normal routine.

When it comes to the position of the animal, this is not only being able to find your animal when you need to, such as where is it in the flock or the field. It is also their position relative to specific fixtures (such as the drinker or the grooming brush), as well as to other animals in the group. In terms of behaviour, the posture of the animal is perhaps the simplest measure, and an important one, especially over time as an animal that is lying down most of the time may be lame or have other health issues. However, more specific data on the behaviour of the animal can contribute to a more complete picture, and can include measurements of activity or locomotion, feeding, drinking, and vocalisation, to name but a few.

Different types of equipment can be used for measuring behaviour automatically, and these can be roughly divided into three categories, depending on their proximity to the animal: attached to (e.g. accelerometers); interacting with (e.g. feed troughs placed on weigh scales, or sensors detecting presence), and remote from (e.g. video and sound recording) the animal (Fig. 2). A combination of these is often the most efficient, but also more complex to manage. It would be optimal if different gadgets were able to talk to each other, and there are also species differences as to what is feasible (though many techniques are adaptable).

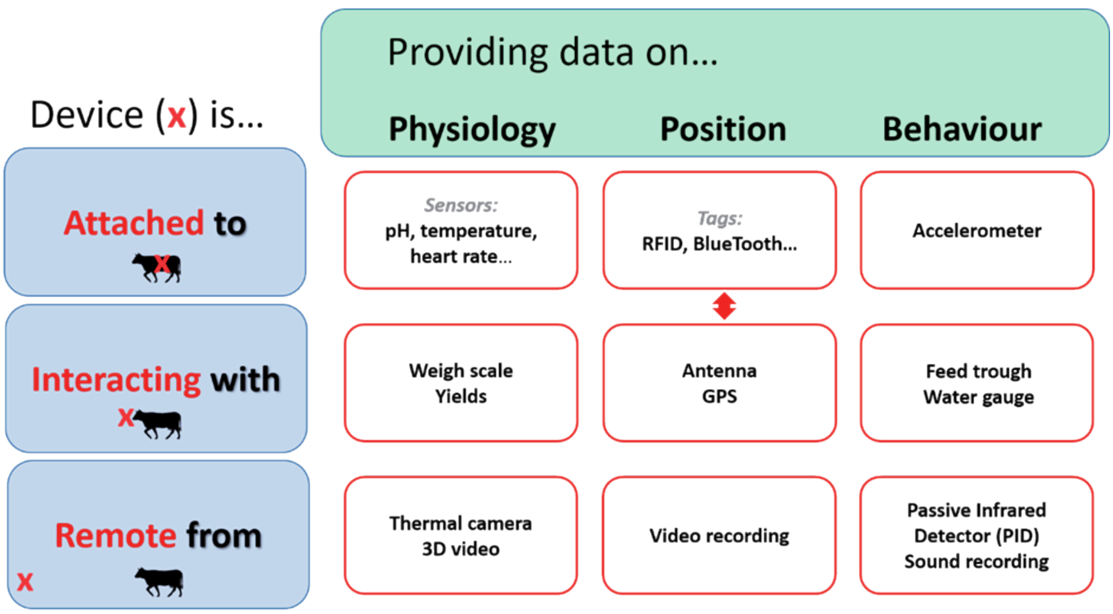

Fig. 2. Examples of devices used to collect animal-based data for Precision Livestock Farming (PLF). The devices can be placed on or away from the animals, and the same device may provide information on different aspects of animal welfare.

Examples of Precision Livestock Farming technology

In order to illustrate some of these PLF technologies, I will give a handful of examples, starting with one that is well known: in recent years there has been an explosion in accelerometers available to monitor behaviour automatically. Accelerometers are found in all smartphones and they measure changes in locomotion, in other words acceleration, in three dimensions. The commercial versions, which include IceTags and Hobo loggers, use pre-set algorithms to interpret the data collected. One use of accelerometer data was given in the rumination example above, but accelerometers are also used to detect lying behaviour and lameness, especially in ruminants (e.g. ZOBEL et al., 2015; THORUP et al., 2016).

As mentioned earlier, production data can be used to monitor animals, since perturbations and sudden changes in the milk yield curve of a dairy cow (*Bos taurus*) for instance, can help to identify health issues (HØJSGAARD and FRIGGENS, 2010; CODREA et al., 2011). In a similar manner, CHAPINAL and TUCKER (2012) used the fluctuations in weight measured on a weighing platform. They found that lame cows take more steps *per* minute with the rear legs than non-lame cows. In other words, by monitoring these weight changes over time, we may be able to spot lame cows if their step-pattern changes suddenly or gradually. Another way to detect lameness in dairy cows is by using 3D cameras providing automatic registration of the back posture of the cow as it moves to the milking parlour. The camera can be fitted above the corridor, as the 3D function still allows it to measure the curvature of the back, which becomes more rounded as the cow becomes lame (PIETTE et al., 2020). The authors found a good association between the data obtained from the 3D camera and results from less frequent and more labour-intensive manual scoring.

One method for measuring activity is Passive Infrared Detectors (PIDs). These are familiar to us as when the light comes on automatically when you enter a room, as they sense movement as a temperature difference relative to the background. This is why your porch light may not come on in the summer because your body temperature is not sufficiently different from that of the background. It is also the reason why you may have to wave your arms to turn the light back on when it suddenly gets dark in the room because you have stayed still for too long. Using PIDs that had been modified so that the measurements can be downloaded as data expressed in mV (PEDERSEN and PEDERSEN, 1995), we tracked the total activity of groups of broiler chickens (*Gallus gallus domesticus*) logged every minute (NIELSEN et al., 2004), revealing low activity during the dark period, and bursts of activity when the lights come on and the chickens rush to the feed troughs (NIELSEN, 2003). As far as I know, this system has not been made commercially available, but PIDs offer the possibility of monitoring activity automatically and in real-time, without the need for tags or sensors on the animals.

Finally, sound recordings have been used to identify different types of coughing in growing pigs (*Sus scrofa domesticus*). Spectrograms of these cough types differ sufficiently to be able to identify the disease category behind the cough (GUTIERREZ et al., 2010). Sound recordings have also been used to identify where in the pig shed the coughing animals can be found, by using three or more microphones so the position of a sound can be triangulated and the pen in which coughing occurs identified (EXADAKTYLOS et al., 2008).

Additional methods and considerations

Some of the technological developments that we see in PLF are due to developments in other industries, not least professional sports. The statistics on distance run and the number of passes provided during football matches for individual players (*Homo sapiens*) arise from data accumulated by automatic tracking devices carried by each player (as well as in the ball) during a game. This technique also allows density maps to be constructed, and these data can deliver information in real time on the positioning of a player in team sports (although it has yet to be refined to detect an off-side in football). There is not a great deal of difference between a football team moving on a football field, and a herd of dairy cows moving about in a cow shed, apart from fewer goals and more milk in the latter. As professional sports develop these techniques, they are bound to become cheaper, smaller and more accessible, which can only be a benefit to PLF.

But what do we do if we cannot afford to equip the whole team or herd or group? One solution is the use of sentinels, where only a fraction of the herd or high-risk individuals, such as runts, are fitted with a given piece of equipment, which could be accelerometers. Like the canary in the mine, they act as warning signals if the welfare of the animals is starting to deteriorate. We may also be able to make some measurements before the animals even enter the herd, thereby preventing undesirable interventions later. One example is the sexing of eggs in the laying hen (*Gallus gallus domesticus*) industry. This can now be done prior to hatching (GALLI et al., 2018), allowing male embryos to be destroyed sooner and before the bird becomes a sentient being. Another example is the sorting of semen in cattle (e.g. RATH and JOHNSON, 2008), which can allow more females to be born from dairy breeds (*Bos taurus*), whilst male semen from beef bulls can be used to produce more efficient meat producing offspring. Again, the welfare aspect of this is that some (but not all) of the male offspring of dairy breeds are surplus to requirements and killed at an early age, sometimes as young as 5 days old which is the legal age needed for transport to the slaughterhouse in the European Union. Some calves may also be killed on-farm, but the methods for killing are variable and not always humane. However, the viability of the calves born from sex-sorted semen still gives rise to concern (MIKKOLA et al., 2015; MIKKOLA and TAPONEN, 2017).

There are also measures we can make after slaughter to prevent future flock-members suffering the same fate. An example is footpad dermatitis in broiler chickens (*Gallus gallus domesticus*), a painful ailment caused mainly by wet litter (e.g. DUNLOP et al., 2016). There are now systems in place to automatically assess footpad dermatitis in the slaughter line (VANDERHASSELT et al., 2013). This can lead to producers being punished economically until they bring their house in order – most often by restrictions being imposed on the permitted stocking density so they cannot produce as many birds *per* square meter as before.

So how do animal producers decide what PLF equipment to invest in? The type of equipment depends on what they want to measure, and what the environment allows them to install. The size of the equipment also needs to be taken into consideration, which depends on where it can be placed and what species they are dealing with. Finally, we cannot avoid looking at the price, both in terms of the cost relative to the benefit, and the quality of the data we obtain. In terms of the data, we again need to consider what to measure, and how to detect changes over time. It comes down to issues such as how often we can collect the data – is it real-time, or at intervals? The sampling rate we employ depends on the accuracy we want, the battery life, and data storage capacity. Is the transmission of data automatic or manual, and at the end of the day, how do want to use it – are we looking for alerts or are they for use as a decision-making tool. A combination of these inputs is often the most efficient, but more complex to manage.

Conclusion and perspectives

We need to ensure that the automatic measures we record reflect the type of behavioural or physiological changes we are interested in. In terms of behavioural measures, this can be done by observing the animals concurrently with recording the automatic data to check that the two methods correspond to a certain degree. It should be kept in mind that the PLF method is unlikely to provide the same accuracy as continuous observation of behaviour. However, as long as the PLF data can detect changes, within or between individuals, sufficiently well to indicate a potential welfare issue, this is not a problem. One way to ensure this is to reverse the method of gadget development: meticulous study of behaviour at key moments, such as tail biting, can provide information on what to measure and when (DIANA et al., 2019). Other aspects to consider are space and time, in terms of variable environmental conditions and animal-related changes that occur gradually (VÁZQUEZ-DIOSDADO et al., 2019).

Small farms are unlikely to be able to afford the type of equipment used by larger enterprises, and we need to put more effort into finding PLF technologies that can work for the smallholder. One solution is the use of sentinels, where only a fraction of the herd or high-risk individuals are fitted with a given piece of equipment. The use of PLF technologies for efficient animal welfare monitoring in practice requires affordable, reliable and easy-to-use equipment, providing data that reflect – adequately and in real-time – different aspects of the state of the welfare of animals within the herd.

Conflicts of Interest
The author declares no conflict of interest.

Acknowledgements
This paper was presented at the 1st RAWC Scientific Conference 2020 "Better Science for Better Animal Welfare", postponed and held online, 24-25 June 2021.

References

BELL, F. R., A. M. LAWN (1957): The pattern of rumination behaviour in housed goats. Br. J. Anim. Behav. 5, 85-89.
DOI: 10.1016/s0950-5601(57)80002-1

CHAPINAL, N., C. B. TUCKER (2012): Validation of an automated method to count steps while cows stand on a weighing platform and its application as a measure to detect lameness. J. Dairy Sci. 95, 6523-6528.
DOI: 10.3168/jds.2012-5742

CODREA, M. C., S. HØJSGAARD, N. C. FRIGGENS (2011): Differential smoothing of time-series measurements to identify disturbances in performance and quantify animal response characteristics: an example using milk yield profiles in dairy cows. J. Anim. Sci. 89, 3089-3098.
DOI: 10.2527/jas.2010-3753

DIANA, A., L. CARPENTIER, D. PIETTE, L. A. BOYLE, D. BERCKMANS, T. NORTON (2019): An ethogram of biter and bitten pigs during an ear biting event: first step in the development of a Precision Livestock Farming tool. Appl. Anim. Behav. Sci. 215, 26-36.
DOI: 10.1016/j.applanim.2019.03.011

DUNLOP, M. W., A. F. MOSS, P. J. GROVES, S. J. WILKINSON, R. M. STUETZ, P. H. SELLE (2016): The multidimensional causal factors of 'wet litter' in chicken-meat production. Sci. Total Environ. 562, 766-776.
DOI: 10.1016/j.scitotenv.2016.03.147

EXADAKTYLOS, V., M. SILVA, S. FERRARI, M. GUARINO, C. J. TAYLOR, J.-M. AERTS, D. BERCKMANS (2008): Time-series analysis for online recognition and localization of sick pig (*Sus scrofa*) cough sounds. J. Acoust. Soc. Am. 124, 3803-3809.
DOI: 10.1121/1.2998780

GALLI, R., G. PREUSSE, C. SCHNABEL, T. BARTELS, K. CRAMER, M.-E. KRAUTWALD-JUNGHANNS, E. KOCH, G. STEINER (2018): Sexing of chicken eggs by fluorescence and Raman spectroscopy through the shell membrane. PLoS ONE 13, e0192554.
DOI: 10.1371/journal.pone.0192554

GUTIERREZ, W. M., S. KIM, D. H. KIM, S. C. YEON, H. H. CHANG (2010): Classification of porcine wasting diseases using sound analysis. Asian-Aust. J. Anim. Sci. 23, 1096-1104.
DOI: 10.5713/ajas.2010.90483

HØJSGAARD, S., N. C. FRIGGENS (2010): Quantifying degree of mastitis from common trends in a panel of indicators for mastitis in dairy cows. J. Dairy Sci. 93, 582-592.
DOI: 10.3168/jds.2009-2445

MIKKOLA, M., J. TAPONEN (2017): Quality and developmental rate of embryos produced with sex-sorted and conventional semen from superovulated dairy cattle. Theriogenology 87, 135-140.
DOI: 10.1016/j.theriogenology.2016.08.013

MIKKOLA, M., M. ANDERSSON, J. TAPONEN (2015): Transfer of cattle embryos produced with sex-sorted semen results in impaired pregnancy rate and increased male calf mortality. Theriogenology 84, 1118-1122.
DOI: 10.1016/j.theriogenology.2015.06.012

NIELSEN, B. L. (2003): Use of passive infrared detectors (PIDs) to monitor bursts of activity in groups of broilers. Arch. Geflügelk. 67, 42-44.

NIELSEN, B. L. (2020): Asking Animals: An Introduction to Animal Behaviour Testing. CABI, Wallingford, 178 pp.

NIELSEN, B. L., J. B. KJÆR, N. C. FRIGGENS (2004): Temporal changes in activity measured by passive infrared detection (PID) of broiler strains growing at different rates. Arch. Geflügelk. 68, 106-110.

PEDERSEN, S., C. B. PEDERSEN (1995): Animal activity measured by infrared detectors. J. Agric. Engng. Res. 61, 239-246.
DOI: 10.1006/jaer.1995.1051

PIETTE, D., T. NORTON, V. EXADAKTYLOS, D. BERCKMANS (2020): Individualised automated lameness detection in dairy cows and the impact of historical window length on algorithm performance. Animal 14, 409-417.
DOI: 10.1017/s1751731119001642

RATH, D., L. A. JOHNSON (2008): Application and commercialization of flow cytometrically sex-sorted semen. Reprod. Domest. Anim. 43, Suppl. 2, 338-346.
DOI: 10.1111/j.1439-0531.2008.01182.x

ROWE, E., M. S. DAWKINS, S. G. GEBHARDT-HENRICH (2019): A systematic review of precision livestock farming in the poultry sector: is technology focussed on improving bird welfare? Animals 9, 614.
DOI: 10.3390/ani9090614

THORUP, V. M., B. L. NIELSEN, P.-E. ROBERT, S. GIGER-REVERDIN, J. KONKA, C. MICHIE, N. C. FRIGGENS (2016): Lameness affects cow feeding but not rumination behavior as characterized from sensor data. Front. Vet. Sci. 3, 37.
DOI: 10.3389/fvets.2016.00037

VANDERHASSELT, R. F., M. SPRENGER, L. DUCHATEAU, F. A. M. TUYTTENS (2013): Automated assessment of footpad dermatitis in broiler chickens at the slaughter-line: evaluation and correspondence with human expert scores. Poult. Sci. 92, 12-18.
DOI: 10.3382/ps.2012-02153

VÁZQUEZ-DIOSDADO, J. A., V. PAUL, K. A. ELLIS, D. COATES, R. LOOMBA, J. KALER (2019): A combined offline and online algorithm for real-time and long-term classification of sheep behaviour: novel approach for precision livestock farming. Sensors 19, 3201.
DOI: 10.3390/s19143201

ZOBEL, G., D. M. WEARY, K. LESLIE, N. CHAPINAL, M. A. G. VON KEYSERLINGK (2015): Validation of data loggers for recording lying behavior in dairy goats. J. Dairy Sci. 98, 1082-1089.
DOI: 10.3168/jds.2014-8635

Received: 23 Februry 2022
Accepted: 15 April 2022

NIELSEN, B. L.: Tehnologije preciznog stočarstva u praćenju dobrobiti životinja: pregledni rad. Vet. arhiv 92, 251-257, 2022.

SAŽETAK

Precizno stočarstvo uključuje primjenu tehnologija koje stočarima pomažu pri praćenju i upravljanju njihovim životinjama i farmom. Tim se tehnologijama mogu unaprijediti ne samo zdravlje i dobrobit životinja nego i proizvodnja. Automatizirani načini mjerenja koji pokazuju dobrobit životinje mogu se odnositi na njezin okoliš, ponašanje i fiziologiju, kao i na njezin položaj s obzirom na značajke okoliša. Cilj je mjerenjem osigurati dobivanje ponašajnih i fizioloških promjena koje nas zanimaju. Drugi aspekti koje treba uzeti u obzir jesu prostor i vrijeme, s obzirom na promjenjive uvjete okoliša i promjene vezane uz životinju do kojih s vremenom dolazi. Za automatizirano mjerenje ponašanja mogu se upotrijebiti različiti tipovi opreme koji se mogu postaviti na životinju, koji su na neki način povezani sa životinjom ili mogu biti udaljeni od nje. Premda je najzahtjevnija, kombinacija ovih metoda obično je i najučinkovitija. Izvodivost osim toga ovisi i o vrsnim razlikama. Male farme obično si ne mogu priuštiti opremu kao što to mogu velike te je potrebno uložiti više napora u pronalaženje tehnologijskih rješenja kojima će se moći koristiti male farme. Njihova primjena za učinkovito praćenje dobrobiti životinja zahtijeva dostupnu i sigurnu opremu kojom se lako rukuje i kojom se pravodobno dobivaju odgovarajući podaci upotrebljivi za različite aspekte dobrobiti zivotinja unutar stadu.

Ključne riječi: precizno stočarstvo; tehnologija; dobrobit životinja; zdravlje životinja; praćenje