At-market sensor technologies to develop proxies for resilience and efficiency in dairy cows

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Abstract

We hypothesize that at-market sensor technologies can be used to develop proxies for complex traits as resilience and feed efficiency (**FE**). This was tested by comparing variables describing sensor data patterns ("curve-parameters") from resilient or FE cows with non-resilient or non-FE cows. Sensor data included data from weighing scales, activity (steps) and rumination activity from neck collars, and milk production from the parlour or the milking robot. Curve-parameters were calculated for each sensor for each lactation for which data was available and included the mean, standard deviation (std), slope, skewness, and the autocorrelation. Data originated from a Wageningen Research farm, and included data from 1,800 cows with calvings between 1995 and 2016. During this time frame, there were 98 lactations with sufficient feed intake recordings to compute FE at lactation level (DMI (kg) / milk yield (kg)), and to rank them accordingly. The 1,800 cows that could be ranked according to their lifetime resilience (ability to re-calf in combination with the number of health and insemination events) based on scores for each of the, in total, 5,771 lactations. Subsequently, the 20% or 10% most and least FE or resilient lactations, respectively, were selected. Curve-parameters of these selected lactations were compared. Results imply that using a single sensor, or a single curve parameter, is likely to be insufficient as a proxy for resilience of efficiency. Future research should focus on studying which combination of curve parameters and sensors are most informative as proxy for these two complex traits.

Keywords: resilience, feed efficiency, precision livestock farming, proxies

Introduction

After the Second World War, the animal production sector faced the challenge to satisfy a consumer market that demanded animal products in abundance and at low cost (Oltenacu and Algers, 2012). A combination of improved management, better feed and successful genetic selection on improved production resulted in the dairy industry being able to more than double the milk yield in many countries over the past 40 years (Oltenacu and Algers, 2012). For example, in the Netherlands, the average yearly milk production increased from 4,200kg per cow in the 1960s to 9,100kg per cow in 2018 (CBS, 2018). However, the increase in milk yield was accompanied by a decline in reproduction performances, an increase in health disorders, an a decline in longevity of dairy cows (Oltenacu and Algers, 2012). Moreover, public perception of animal production changed, with increasing concerns around animal welfare. This combination introduced an international interest in novel traits that improve fitness and health of dairy cows (Egger-Danner et al., 2015; Oltenacu and Algers, 2012). Two of these traits gaining interest are efficiency and resilience. Efficiency is often expressed as feed efficiency (**FE**), and is of great interest for increasing profitability, as well as reducing the environmental footprint of animal production systems (Savietto et al., 2014). Resilience is the ability of animals to be minimally affected in their functioning by an environmental perturbation, or to rapidly return to their normal level of functioning (adapted from Colditz and Hine (2016)). Despite the increasing interest for these traits, breeding for them is hampered by the lack of phenotypic information. Direct inclusion of feed intake in dairy cow breeding goals, for example, is not possible due to the costs associated with acquiring individual animal feed intake measurements on a large scale (Veerkamp, 1998).

The adoption of sensor technologies by dairy farmers is increasing (Steeneveld et al., 2015; Borchers and Bewley, 2015). Farmers are adopting technologies that are deployed for the detection of specific health or fertility events (e.g., heat or mastitis), or that monitor important performance traits (milk yield or SCC). These sensor technologies generate high-frequency repeated measures, e.g. locomotor activity or rumination activity, of individual animals. This means that instead of having snapshots of relevant events during a cow's lifetime (e.g., a mastitis event recorded by the farmer or veterinarian), we now have access to a continuous time-series of the cow's status. With these continuous measurements cows can serve as their own control and allow precise herd level corrections when detecting outliers. Many disease detection models use the concept that disease occurrence is expected in case sensor measurements deviate from the expected values for that cow (e.g., Jensen et al., 2016; Miekley et al., 2012), and therefore focus on the generation of true positive alerts. However, the specific feature of sensor technologies to monitor continuously make them also interesting for phenotyping animals for complex traits such as resilience and efficiency, and with that provide input for breeding programs. To our knowledge, so far, little to no attention has been paid for the possible use of sensor data in this regard.

As a first step in finding out whether these sensor technologies can be used to develop proxies for resilience and efficiency, we studied whether the data patterns were different between resilient (or efficient) and non-resilient (or inefficient) cows. This was done by comparing sensor data patterns between the 10% and 20% most and least resilient or efficient cows, respectively.

Materials and Methods

Data

Data originated from the Dairy Campus, a Wageningen Research farm, and included data from 1,800 cows, totalling to 5,771 lactations, with calvings between 1995 and 2016. All of these cows were culled at the end of the data collection period. Over this time period, data was collected with a number of sensor technologies. Activity (steps) and rumination activity were monitored through SRC-tags (via Lely Industries, Maassluis, the Netherlands). Data from these tags were available from October 2007 onwards. The barn of this research farm was split into two sections: one with four groups of approximately 64 cows that were milked and weighed in milking robots (Lely Industries, Maassluis, the Netherlands), and one where cows were milked twice daily in a conventional milking parlour where live-weight was recorded before entering the parlour. Cows were allocated to groups based on research requirements, and could therefore be milked part of the time in one of the robots and part of the time in the parlour. In the section were cows were milked in the parlour, two subsections were equipped with roughage intake control (RIC) bins (Insentec, Marknesse, the Netherlands). Feed trials were common good on this research farm, ensuring detailed measures of individual feed intake. For the current study we could use feed intake (DMI (in kg) / cow / day) records from one of the feed trials, where feed intake was monitored throughout entire lactations. All inseminations and health events (disease cases and treatments) were recorded in the farm management system.

Definitions for Resilience and Efficiency

In the current study, efficiency was expressed as FE, which was computed at lactation level as total input (DMI, in kg) over total output (milk yield, in kg). To be eligible for this FE computation, cows were required to have at least one RIC recording per week, for a minimum of 36 subsequent weeks. Due to the experimental setup, the selection did not include heifers lactations, but was restricted to lactations from 2^{nd} – 7^{th} parities.

Friggens and De Haas (2019) stress the importance of having an operational reference measure of resilience when developing a proxy for this trait. They suggest to use the within-cow variance associated with a relevant time-series of measures, which needs to be of sufficiently high-frequency to capture the variance due to perturbations. One option for measures against which to validate these resilience proxies include the ability to re-calve, assuming that impaired resilience will negatively impact reproduction performance (Friggens and De Haas, 2019). It is this option that we explored further in this study. To reflect how good (or bad) this ability was compared to herd mates, a point system was introduced based on a cow's lifetime. This point system included four aspects on top of 500 points for each calving:

(1) age at first calving compared to the herd average. Bonus points were given in case the age at first calving was lower than the herd average, and minus points in case this age was higher. One (bonus or minus) point was assigned for each day difference from the herd average. Bonus or minus points for this aspect were only assigned for first parity lactations;
(2) calving interval compared to the herd average. Bonus points were assigned in case the interval was shorter than the herd average, and minus points in case this interval was longer than the herd average. One (bonus or minus) point was given for each day difference form the herd average, where calving interval is the interval between the previous calving and the current calving. As such, points for this aspect were only assigned for second parity lactations and up;
(3) number of inseminations: because data on inseminations were incomplete and because poor fertility was also reflected in aspect 2 (calving interval), only inseminations carried out in the final lactation were taken into account in this third aspect. We applied 25 minus points in case culled cows were inseminated, assuming that the farmer planned to keep this cow but it was involuntary culled due to fertility issues.
(4) number of events. Minus points were assigned to each event day, excluding preventive events, e.g., hoof trimming. Also inseminations and calvings are ignored since they these events are already accounted for in aspect 2 and 3. For each day during the lactation that a cow was curatively treated one point was subtracted from the score. Moreover, because culling in an early stage after calving was assumed to be involuntary and could mask health problems that were not treated on-farm, one point was subtracted for each day the cow was culled before day 100 after calving. So, in case a cow was culled at 40DIM, 60 points were subtracted from the total score for the last calving.

Cows, or lactations in case of FE, were ranked according to their resilience or efficiency score.

Retrieving curve parameters

For each sensor (activity, rumination activity, milk yield, and live-weight), within-day measurements were aggregated to daily values. These daily values were made relative to the herd mean, and subsequently we summarized these relative values into "curve-parameters" at lactation level (Figure 1). These curve-parameters involved the mean, and autocorrelation (lag1) of the relative curve of each cow (red line; Figure 1), and the slope, skewness, and standard deviation of the regression line through this relative curve of each cow (light blue line; Figure 1). These curve parameters were computed for all lactations (for FE and for resilience) for which we had a sufficient amount of data (at least 200 days with data during 1 – 300 DIM). For resilience only first lactation curves were compared, assuming that these will be more useful to investigate differences between resilient and non-resilient cows than e.g. last lactation curves. For efficiency, which is currently purely calculated on a lactation basis, lactation curves were compared for the lactations for which efficiencies were calculated.

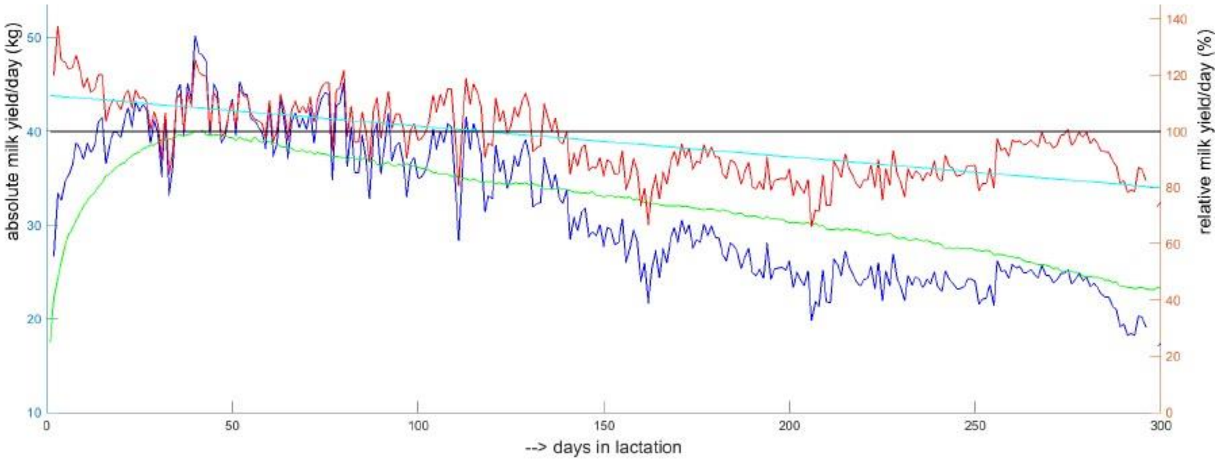

Figure 1: Assessment of curve parameters based on the relative curve (red line), or its regression line (light blue line) of a cow. The absolute values of the cow are in dark blue, the absolute herd mean values in green, and the relative herd mean values in black.

<u>Statistical analyses</u>
The 10% or 20% most and least resilient cows or FE lactations, respectively, were selected, and curve-parameters of these selected lactations were compared between these two groups.

Results and Discussion

A FE score was computed for 98 lactations, with an average of 0.79 kg DM/kg milk, and a range of 0.48 to 1.19 kg DM/kg milk. A resilience score was computed for 1,800 cows with 5,771 lactations, with an average of 1518 points and a range of 31 to 6031 points. Figure 2 demonstrates a distribution plot for both traits (where the scores were classified into ten categories, each category having roughly 600 points for resilience and 0.11kg for FE), indicating that scores for these traits are not normally distributed. Particularly for resilience the distribution was skewed to the left.

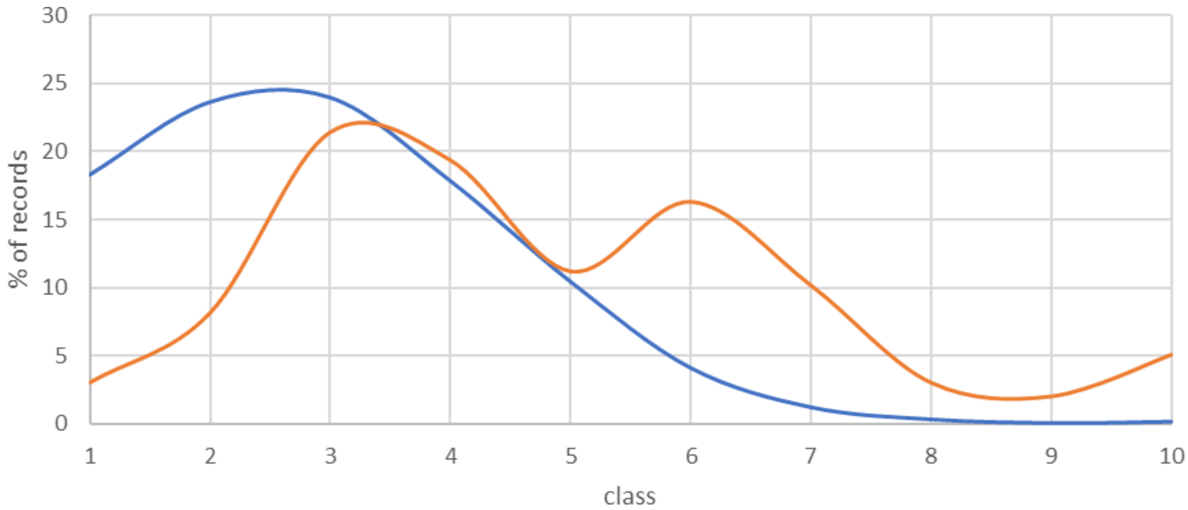

Figure 2: Percentage of values of the datasets for resilience (blue line) and feed efficiency (orange line), divided into 10 classes based on the range of values.

Unfortunately, there were limitations with the data, and in particular with the feed intake data. Feed intake was not recorded on a daily basis during an entire cow's lifetime, but only during feeding trials. Because of this limitation, we lacked feed intake data from heifers (since they were not included in feeding trials), but even more so, we also lacked information on feed intake over lactations from the same cow. Consequently, we were limited to lactation FE and have ignored other output than milk production, particularly growth which certainly should be taken into account when comparing heifer efficiencies with cow efficiencies. In contrast, resilience was computed based on information on an entire cow's lifetime, but our scores are based on preliminary assumptions that need to be investigated further. Ability to re-calve as an indication for resilience suggests that resilience on a lactation basis is decreasing when an animal is aging, since the percentage of re-calvers is highest for heifers and gradually decreases thereafter. Moreover, production levels do influence a farmer's culling decisions, and thus, low producing cows may be unable to express their true resilience and be negatively affected in our resilience scoring system. Preferably, a resilience score should be unbiased by production and we need to determine methods to avoid or remove production effects. It would be of great interest to study whether cows that are FE are also resilient, but we were unable to do so because of FE being limited to lactation level. Future research should think of a definition of efficiency in absence of feed intake recordings.
Table 1 summarizes the mean values (and their range) for the computed curve parameters for the 20 (20%) resp. 25 (10%) most and least FE or resilient cows, respectively. Not surprisingly, the group of lactations with the lowest score for FE has a lower mean milk production that those that belong to most FE. Moreover, the least FE lactations appear to be from cows that are, on average, heavier, less active and have a lower rumination activity than those that belong to the most FE lactations. However, there is an overlap in mean value for all sensors between these two groups. When looking at resilience, the difference in average daily milk production between the most and least resilient cows is not that pronounced as for FE. In fact, the difference between the two groups of resilience is, generally speaking, less pronounced overall. Whether this difference between groups is truly less pronounced should be studied in more detail: for the current study we applied a point system for four aspects to define resilience. But the value for bonus or minus points within each of these aspects was chosen intuitively. We have not yet conducted a

sensitivity analyses to study whether the resilience ranking is robust (that is, independent from the value assigned to bonus or minus points). Future, research should verify this. Moreover, we did not have sensor data from before October 2007, and therefore there might have been some bias in the selection of informative lactations.

The current study only computed curve parameters for the first lactation (resilience) or the lactation for which FE could be determined, and results imply that there is a large overlap between the curve parameters of the two groups of cows. However, a recent study reported on the utilisation of sensor information as indicators for resilient cows (van Dixhoorn et al., 2018). During that particular study, van Dixhoorn et al. (2018) tested different sensor data properties from sensors monitoring activity, behaviour, and rumen and ear temperature. Data properties from these sensors recorded during the period from up to two weeks *before* calving were used as predictor for a total deficit score. This deficit score summarized the health status of a cow up to six weeks after calving, and was used as proxy for resilience. The study demonstrated that sensor data recorded during the dry period was informative for a resilience proxy after calving. Although Van Dixhoorn et al. (2018) included a limited number of cows (n = 20) and used a short-term resilience proxy (transition period), results from their study suggest that taking into account curve parameters from the previous lactation and particularly the dry period may be informative for lifetime resilience and lactation FE. This would also mean that sensor data should be collected during the dry period too, which is currently not standard procedure on commercial dairy farms.

Table 1: Mean values (and their range) for curve parameters based on sensor data patterns from the most (highest) and least (lowest) feed efficient or resilient cows, including the absolute number of lactations

Sensor	Efficiency				Resilienc
Curve parameter	Number of lactations		Mean (range)		Number
	highest	lowest	highest	lowest	highest
milk production					
Mean	20	20	105.6 (93.4 - 126.5)	61.0 (46.9 - 72.4)	25
Autocorrelation (lag1)	20	20	0.7 (0.4 - 0.9)	0.8 (0.2 - 1.0)	25
Standard deviation	20	20	12.7 (7.0 - 19.1)	12.0 (6.0 - 26.6)	25
Slope	20	20	-0.0 (-0.2 - 0.1)	-0.1 (-0.3 - 0.1)	25
Skewness	20	20	-1.9 (-4.3 - -0.1)	0.9 (-1.9 - 9.3)	25
body weight					
Mean	20	20	101.3 (84.8 - 118.9)	109.9 (94.8 - 129.0)	25
Autocorrelation (lag1)	20	20	0.8 (0.6 - 1.0)	0.8 (0.6 - 1.0)	25
Standard deviation	20	20	2.8 (1.4 - 7.7)	3.7 (1.7 - 8.2)	25
Slope	20	20	-0.0 (-0.1 - 0.0)	0.0 (-0.0 - 0.1)	25
Skewness	20	20	-0.3 (-2.0 - 0.9)	-0.7 (-2.0 - 0.3)	25
Activity					
Mean	20	20	116.0 (75.1 - 177.9)	110.8 (79.4 - 154.4)	25
Autocorrelation (lag1)	20	20	0.6 (0.2 - 1.0)	0.7 (0.3 - 0.9)	25
Standard deviation	20	20	18.5 (8.9 - 39.3)	17.0 (10.1 - 33.3)	25
Slope	20	20	0.0 (-0.2 - 0.3)	0.0 (-0.1 - 0.2)	25
Skewness	20	20	0.7 (-2.2 - 4.2)	0.6 (-1.5 - 2.9)	25
rumination activity					
Mean	20	20	105.4 (75.0 - 134.3)	99.6 (82.9 - 110.8)	25
Autocorrelation (lag1)	20	20	0.3 (-0.0 - 0.9)	0.3 (0.0 - 0.6)	25
Standard deviation	20	20	13.6 (9.5 - 27.6)	12.5 (10.1 - 17.5)	25
Slope	20	20	0.0 (-0.0 - 0.2)	0.0 (-0.0 - 0.1)	25
Skewness	20	20	-1.1 (-2.4 - 0.3)	-0.7 (-1.5 - 0.0)	25

The large overlap in average values for curve parameters indicate that the use of one single sensor to define resilience or efficiency is highly likely to be insufficient, and that a combination of curve parameters of different sensors is expected to be of more value. The combination of sensors (and curve parameters) proved its value in past research already: the detection of clinical mastitis improves in case the electrical conductivity is combined with other (sensor) data (e.g., Hogeveen et al., 2010), and combining information from different sensors outperformed the automated detection of lameness compared to using a single sensor (e.g., Kamphuis et al., 2013). Moreover, for a complex trait like resilience, Van Dixhoorn et al. (2018) concluded that the combination of static and dynamic sensor data proved the best option as indicators for resilience. Identifying which combination of curve parameters and sensors is a challenging next step in our study to use sensor information as proxy for resilience and efficiency.

Conclusion

This study used lactation FE as proxy for efficiency, and applied a point system based on four aspects to score lifetime resilience in dairy cows. Based on these definitions, there is a strong indication that the average daily milk production differs between FE and non-FE cows. Differences in curve parameters for other sensors between the two groups of efficient or resilient cows are less pronounced, and have a large overlap. This result implies that using a single sensor, or a single curve parameter, is likely to be insufficient as a proxy for resilience of efficiency. Future research should focus on studying which combination of curve parameters and sensors are most informative as proxy for these two complex traits.

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