Quantifying walking and standing behaviour of dairy cows using a moving average based on output from an accelerometer

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Abstract: Manual observations either directly or by analysis of video recordings of dairy cow behaviour in loose housing systems are costly. Therefore progress could be made if reliable estimates of duration of walking and standing could be based on automatic recordings.
In this study we developed algorithms for the detection of walking and standing in dairy cows based on the output from an electronic device quantifying acceleration in three dimensions.
Ten cows were equipped with one movement sensor on each hind leg. The cows were then walked one by one in the alleys of the barn and encouraged to stand and walk in sequences of approximately 20 seconds for period of 10 minutes. Afterwards the cows were stimulated to move/lift the legs while standing in a cubicle. The behaviour was video recorded, and the recordings were analysed second by second for walking and standing behaviour as well as the number of steps taken.
Various algorithms for predicting walking/standing status were compared. The algorithms were all based on a limit of a moving average calculated by using one of two outputs of the accelerometer, either a motion index or a step count, and applied over periods of three or five seconds. Furthermore, we investigated the effect of additionally applying the rule: a walking period must last at least five seconds.
The results indicate that the lowest misclassification rate (10%) of walking and standing was obtained based on the step count with a moving average of three seconds and with the rule applied. However, the rate of misclassification given walking and standing differed between algorithms, thus the choice of algorithm should relate to the specific question under consideration.
In conclusion, the results suggest that the number of steps taken per time unit as well as the frequency and duration of walking and standing can be estimated with a reasonable accuracy.

Keywords: lameness, dairy cows, accelerometer, walking/standing behaviour.

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1 Introduction

In the recent years new methods have been developed for automatic recording of animal behaviour. It has been documented that classification of lying behaviour can be obtained with high accuracy for both cows and calves based on accelerometer technology (Munksgaard et al., 2006; Trénel et al., 2009; Winckler, 2005). Furthermore, it is well documented that cows walk more and show an increased level of activity during oestrus (Kiddy, 1977; López-Gatius et al., 2005), so devices attached to neckbands or legs for continuous recording of activity are therefore commercially available and used for oestrus detection (Firk et al., 2002). However, the output from these devices does not provide sufficient information about the duration of walking and standing.

Detailed information about the duration and frequency of walking and standing periods as well as the number of steps taken is useful in studies of locomotion and lameness, and the effects of housing systems on animal behaviour. Moreover, it may provide important input to algorithms for automatic detection of lameness in cows. For instance, O'Callaghan et al. (2003) found a lower level of daily activity in lame cows compared to sound cows.

The IceTag3D™ is a new sensor which is based on three-dimensional acceleration technology. It provides information for each second about 1) the posture of a cow (standing vs. lying), 2) whether the leg to which the sensor is attached is moving, and 3) the number of steps taken per time unit. Direct use of the recorded number of steps per second to classify walking or standing does, however, provide an inaccurate prediction. Firstly, cows may move their legs without actually moving the body, i.e. without walking. Secondly, cows may walk so slowly that no leg activity is recorded for one or more seconds. Hence, when only one leg carries an IceTag3D™, there may be seconds when no steps are recorded during walking periods, because the cow is moving the legs that are not equipped with a sensor. For experimental purposes it may be possible to use a sensor on each leg and thus improve the level of information. However, for future commercial use and for use in studies with many animals it is more likely that only one sensor is attached to each animal.

The aim of this study was to develop an algorithm for predicting the duration of walking and standing periods based on a moving average of the output from the IceTag3D™ device. Moreover, the step count and lying/standing prediction of the IceTag3D™ device was also validated against video recordings.

2 Materials and methods

2.1 Animals and housing

Ten lactating Holstein cows (4 in first lactation, and 6 in second or later lactation; stage of lactation 168 ± 93 days) were used as experimental animals. They were kept in a group of 47 cows in a loose housing system with cubicles and slatted floors in the alleys and behind the feeding rack (Figure 1). All cows were milked automatically (DeLaval Milking Unit 2008, DeLaval, Vejle, Denmark). A total mixed ration was offered ad libitum from Insentec feed bins (Insentec, Marknesse, the Netherlands).

2.2 Device used for recordings of leg movement

The IceTag3D™ device is an electronic sensor that measures animal activity 16 times per second in three dimensions. It comes with a software program (IceTagAnalyzer™) that computes an estimated step count and a motion index per second using internal algorithms. The motion index reflects the average magnitude of acceleration within the second.

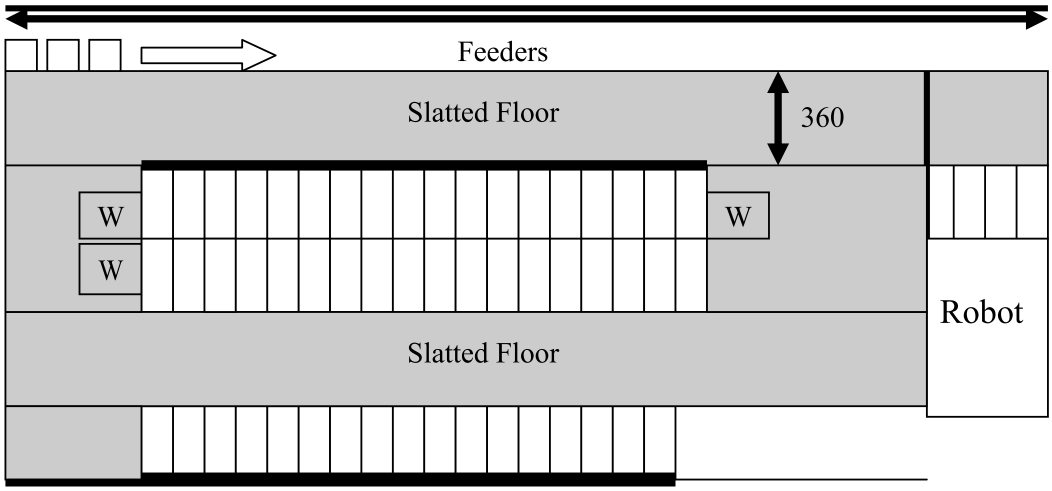

Figure 1: Overview of the housing system.

2.3 Experimental protocol for estimating walking and standing

Each cow was equipped with two IceTag3D™ sensors (one sensor on each hind leg) immediately before initiation of the experiment. The cow was then walked in the alleys of the barn by two people allowing her to move freely. One person walked behind the cow slightly to one side and encouraged her to walk and stand in sequences of approximately 20 seconds. This was continued for approximately 10 minutes. The cow was then led into a cubicle, and the hind legs were touched in order to stimulate moving/lifting the legs without walking approximately 10 times for each cow. None of the cows were lying down during the experiment.

A second person was behind her filming the movement of all four legs with a hand-held video camera, capturing 25 pictures per second (SONY HandyCam HDR-SR10E, Sony Corporation, Tokyo, Japan). Two additional IceTag3D™ devices activated at the same time and on the same computer as the ones attached to the cow were used for time synchronisation of the video recordings with the IceTag3D™ devices on the cow. The following procedure was used: the two IceTag3D™ devices were placed on the floor and filmed in a sequence of alternations between upright and horizontal positioning, each lasting 20 to 30 seconds before initiating the recording of the cow's behaviour. Afterwards, these alternations were identified in the data and related to the timestamp of the video recording showing the positioning of the devices.

All video recordings were analysed by the same person, registering per second the position of the cow (cubicle or alley) and whether the legs or the body were moving. In the data analyses a cow was considered walking within a second when the body of the cow was moving according to the analyses of the video recordings (used as golden standard). For each walking period, the number of steps taken by the cow was defined as the step count for the hind leg taking the first step within the walking period. Occasionally, it was impossible to observe whether the cow was walking or how many steps she took, e.g. because another cow was blocking the camera view. Such periods were excluded from the analysis.

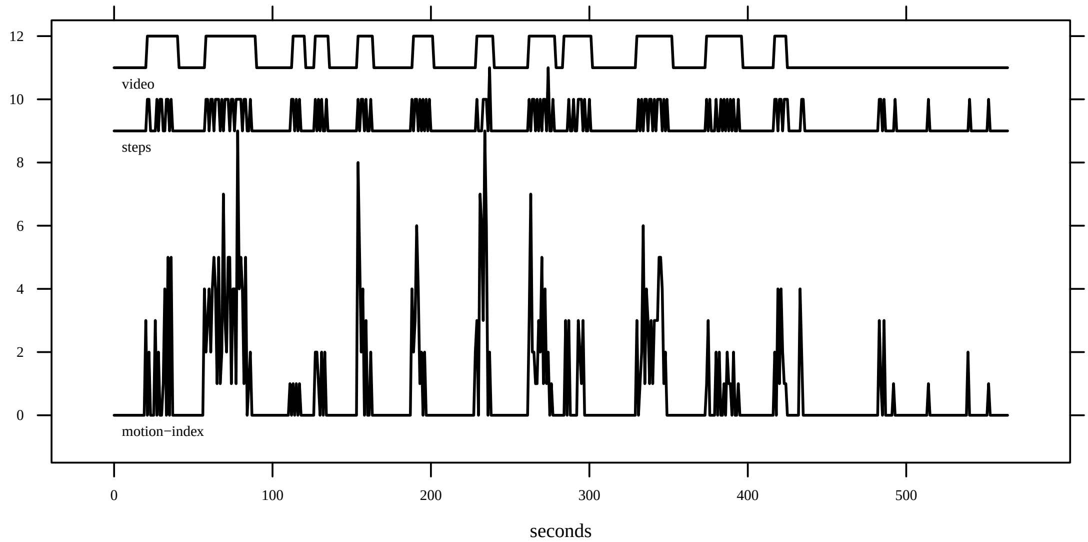

Figure 2: Walking and standing status according to the video recordings (shifted 11 units vertically) plotted together with the corresponding IceTag3D™ step count (shifted nine units vertically) and motion index for a single cow in the experiment. A high value in the video recordings indicates that the cow is walking.

2.4 Experimental protocol for validating the prediction of lying/standing

In order to validate the lying/standing prediction of the IceTagAnalyzer™ software, data was downloaded from a larger group of cows on three different days (day 1 $n = 62$, day 2 $n = 59$, day 3 $n = 56$ cows), while the tags were still attached to the cows. In total 177 records were given where also the position of the cow (standing or lying) was recorded manually. The last recording of data from the IceTag3D™ before downloading was then compared with the position of the cow.

3 Statistical analysis

Visual inspection of the data showed that the step count and the motion index can be zero within walking periods (the walking cow is moving legs without a IceTag3D™ device) and positive within standing periods (a standing cow is lifting a leg with an IceTag3D™ device attached), cf. Figure 2. Hence, when attached to only one leg the IceTag3D™ step count or motion index does not provide an accurate estimate of the walking/standing status of a cow per second. To improve this walking/standing classification we used the following algorithms.

3.1 Classifying walking and standing based on a moving average

Prediction of the walking/standing status was based on a moving average of either the motion index or the step count running over periods of either three or five seconds. More precisely, within a given second the average of the values of the IceTag3D™ variable at that second and at one or two seconds before and after was calculated. The classification was then based on a limit on the moving average,

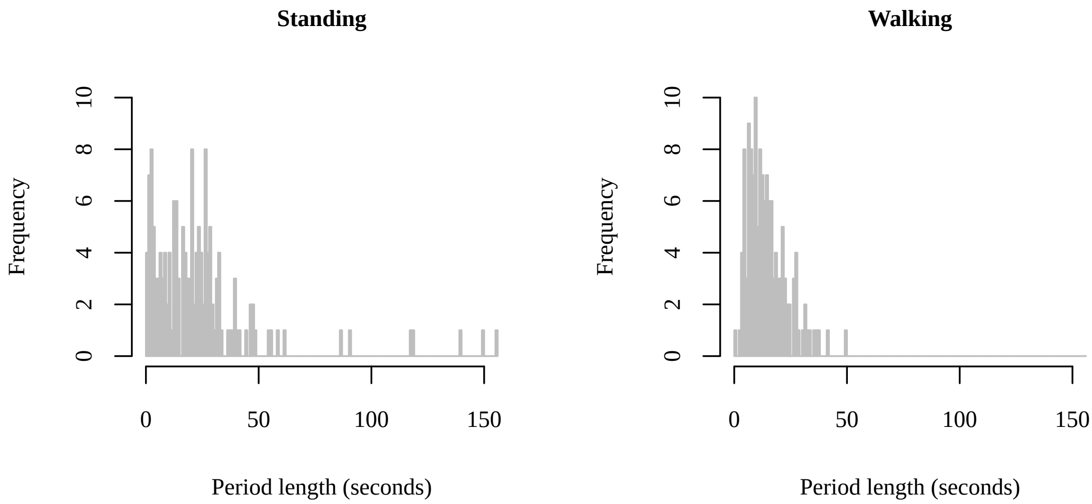

Figure 3: Density plot of the duration of walking and standing periods based on video recordings.

i.e. if the moving average at a particular second was larger than a limit, τ, the cow was classified as walking in that second; otherwise it was classified as standing.

Using the raw IceTag3D™ data (step count or motion index per second) for the classification corresponds to using a zero limit ($\tau = 0$) and a moving average running over periods of one second, whereas using a non-zero limit ($\tau > 0$) and a moving average period longer than one second addresses the problems outlined above. A moving average period of three or five seconds removes erroneous standing seconds during walking periods, where the walking cow is moving the legs without an IceTag3D™ device. A positive limit ($\tau > 0$) on the moving average removes erroneous walking seconds during standing periods, where the standing cow is lifting a leg.

3.2 Classification based on a moving average and a post-processing rule

Even with a positive limit on the moving average the algorithms may still predict very short walking periods. Hence, for each of the algorithms outlined above we furthermore investigated the effect of a final post-processing of the walking/standing classifications by applying the rule: a walking period must last at least five seconds.

3.3 Statistical measures

To quantify the performance of the classification algorithms the following misclassification rates were considered:

$$\theta = \frac{\text{\#sec. misclassified}}{\text{\#sec.}}$$

$$\theta_W = \frac{\text{\#walking sec. misclassified}}{\text{\#walking sec.}}$$

$$\theta_S = \frac{\text{\#standing sec. misclassified}}{\text{\#standing sec.}}$$

Table 1: Overall (across cows) misclassification rates for the optimal limit of four different walking/standing classification algorithms applied to IceTag3D™ data from left and right hind leg.

		Motion index						Step count					
Avg.[a]	Leg[b]	θ[c]	τ[d]	θ_W[e]	θ_S[f]	μ_W[g]	μ_S[h]	θ	τ	θ_W	θ_S	μ_W	μ_S
3	left	12	0.5	19	9	10	17	12	0	15	11	9	15
3	right	12	0.5	17	10	10	16	11	0	12	11	9	14
5	left	13	0.5	15	11	13	19	11	0.35	25	4	10	22
5	right	13	0.4	14	12	13	19	11	0.35	24	4	9	20

[a] The moving average period length (s).
[b] Left or right hind leg.
[c] Overall misclassification rate (%).
[d] Optimal limit (minimal value among multiple candidates).
[e] Misclassification rate in walking periods (%).
[f] Misclassification rate in standing periods (%).
[g] Mean length of walking period (s). Equals 15 s for the video observations.
[h] Mean length of standing period (s). Equals 25 s for the video observations.

For instance, the misclassification θ denotes the percentage of the seconds misclassified (not in agreement with the video analysis). These misclassification rates were calculated separately for each cow and for different limits (τ).

4 Results

4.1 Duration of walking and standing periods

The duration of the walking and standing periods obtained from the video recordings showed some variation since the handler could not completely control the cows (Figure 3). In total, after deleting periods with missing data, the data included 156 standing periods (mean duration 25 seconds, sd 26 seconds and range 1-156 seconds) and 139 walking periods (mean duration 15 seconds, sd 9 seconds and range 1-50 seconds).

4.2 Classification of walking and standing using a moving average

4.2.1 Minimising the overall misclassification rate

The overall (across cows) misclassification rate, θ, for a range of values of a common limit, τ, shows multiple optimal values of τ (Figure 4). The misclassification rate in the cubicles decreased with increasing limit, because the cows were never walking in the cubicles, and increasing the limit predicts more standing seconds. In the alleys, where the cows are both walking and standing, the misclassification was minimal at a lower value and increased with increasing limit. In the combined data set (cubicles and alleys) an optimal value of τ could be defined, e.g. the smallest of the multiple optimal values, although it may produce different misclassification rates in the cubicles and alleys (Figure 4).

In general, a lower optimal limit and overall misclassification rate was found for algorithms based on the step count, whereas the effect of different moving average period lengths was very small (Table 1). The misclassification rate was quite different for walking and standing periods, e.g. 24% vs. 2%, respectively, for the algorithm based on a moving average of the step count over periods of five

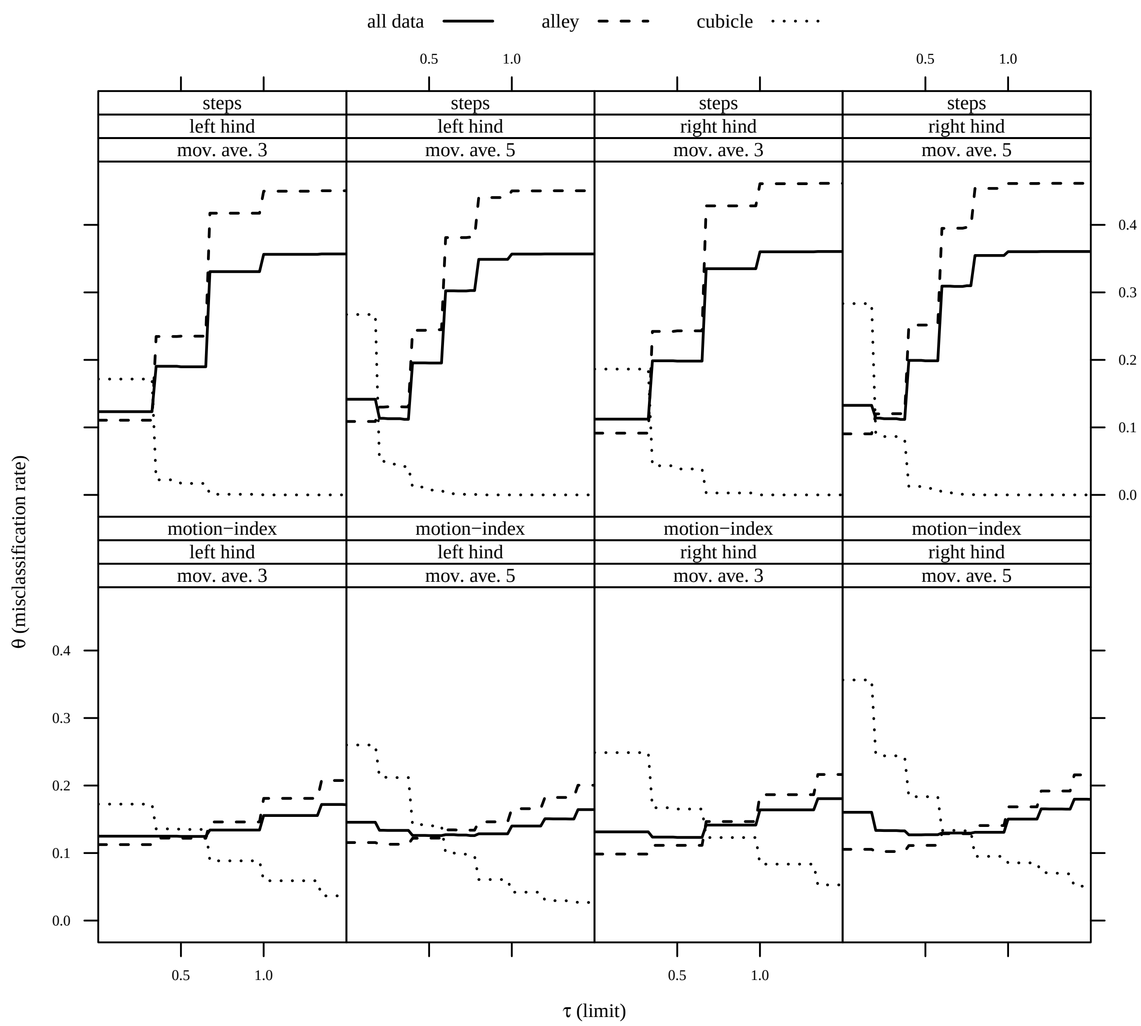

Figure 4: The overall misclassification rate of different walking/standing classification algorithms (moving average over a period of 3 or 5 seconds) applied to IceTag3D^{TM} data (motion-index or step count) from left and right hind leg and presented for different subsets of the data (alley data only; cubicle data only; all data).

Table 2: Mean and standard deviation of cow-specific optimal limits and misclassification rates of four different walking/standing classification algorithms applied to IceTag3D™ data from left and right hind leg.

		Motion index				Step count			
Avg.[a]	Leg[b]	μ_θ[c]	ρ_θ[d]	μ_τ[e]	ρ_τ[f]	μ_θ	ρ_θ	μ_τ	ρ_τ
3	left	11	3	0.34	0.34	12	2	0.06	0.17
3	right	11	2	0.53	0.43	11	2	0	0
5	left	11	3	0.63	0.39	10	2	0.21	0.14
5	right	11	3	0.5	0.35	11	1	0.23	0.15

[a] The moving average period length (s).
[b] Left or right hind leg.
[c] Mean of the cow-specific misclassification rates.
[d] Standard deviation of the cow-specific misclassification rates.
[e] Mean of the cow-specific optimal (minimal among multiple candidates) limits.
[f] Standard deviation of the cow-specific optimal (minimal among multiple candidates) limits.

seconds applied to IceTag3D™ data from right hind leg. The predicted mean durations of walking and standing periods were smaller than the corresponding values from the video recordings.

4.2.2 Cow specific optimal limits and misclassification rates

The optimal limit, i.e. the limit leading to the lowest misclassification for an individual cow, was calculated (Table 2). The variation in the cow-specific optimal misclassification rates was small, and both mean and the standard deviation of the rates were almost independent of the moving average period length. The variation in the cow-specific optimal limits was higher with the motion index than with the step count. Furthermore, for the algorithm based on the moving average over periods of three seconds of the step count from the right hind leg it was possible to select a common optimal limit ($\tau = 0$).

4.3 Post-processing the walking/standing algorithms with a rule for the minimum length of walking periods

A rule stating that the minimum duration of a walking period should be at least five seconds was applied after the calculation of the moving average.

4.3.1 The overall optimal limits and misclassification rates

The overall optimal limits and misclassification rates were generally smaller (Table 3) than with the corresponding algorithms without the rule for minimum length of walking periods (Table 1). The better performance was due to that smaller optimal limits could be selected, i.e. removing less leg liftings interpreted as walking, because the thereby increased number of falsely predicted small walking periods was afterwards removed by the rule for minimum length of walking periods. Finally, the predicted mean duration of walking and standing periods were also closer to the values from the video recordings than with the corresponding algorithms without the rule for minimum length of walking periods.

Table 3: Overall (across cows) misclassification rates for the optimal limit of four different walking/standing classification algorithms applied to IceTag3D™ data from left and right hind leg and post-processed by converting predicted walking periods of less than five seconds into standing periods.

		Motion index						Step count					
Avg.[a]	Leg[b]	θ[c]	τ[d]	θ_W[e]	θ_S[f]	μ_W[g]	μ_S[h]	θ	τ	θ_W	θ_S	μ_W	μ_S
3	left	10	0	15	7	14	23	10	0	19	6	13	24
3	right	10	0	14	8	14	23	9	0	17	4	13	24
5	left	12	0.4	15	11	13	21	11	0.25	28	2	13	30
5	right	12	0.4	15	11	14	21	11	0.2	27	3	12	28

[a] The moving average period length (s).
[b] Left or right hind leg.
[c] Overall misclassification rate (%).
[d] Optimal limit (minimal value among multiple candidates).
[e] Misclassification rate in walking periods (%).
[f] Misclassification rate in standing periods (%).
[g] Mean length of walking period (s). Equals 15 s for the video observations.
[h] Mean length of standing period (s). Equals 25 s for the video observations.

4.3.2 Cow specific optimal limits and misclassification rates

The cow-specific optimal limits and misclassification rates were also generally smaller (Table 4) than with the corresponding algorithms without the rule for minimum length of walking periods (Table 2), and the best performance was again obtained when selecting a moving average with a period length of 3 seconds. Moreover, for the moving average algorithm applied to the step count over periods of three seconds, a zero limit was found to be optimal for each cow, i.e. the limit $\tau = 0$ achieved the optimal cow-specific misclassification rate for all 10 cows both on the right and left hind leg.

4.4 Validation of the IceTagAnalyzer™ output

The step count prediction of the IceTagAnalyzer™ software was validated on the 10 experimental cows by comparing with manual step counts based on the video recordings. The range of steps within a walking period from the video recordings was 2-20 (median: 11.5), and the range of step counts in these periods was 1-26 (median: 7). The difference between the video recorded and IceTagAnalyzer™ predicted step counts ranged from -2 to 5 steps with a median of zero steps.

The lying/standing prediction of the IceTagAnalyzer™ software was validated on the 177 recordings from a larger group of cows for which the actual lying/standing status was recorded manually. In two out of the 177 recordings the cows were visually scored as lying while recorded as standing by the IceTag3D™, and in one case a cow was scored as standing while the data from the IceTag3D™ predicted it was lying. Thus in total the misclassification was 1.7% (3/177).

5 Discussion

In this study we developed different algorithms for predicting the duration of walking and standing behaviour of dairy cows kept in loose-housing by the use of data from an IceTag3D™ sensor. The lowest overall misclassification compared to visual observations occurred when the classification was

Table 4: Mean and standard deviation of cow-specific optimal limits and misclassification rates of four different walking/standing classification algorithms applied to IceTag3D™ data from left and right hind leg and post-processed by converting predicted walking periods of less than five seconds into standing periods.

		Motion index				Step count			
Avg.[a]	Leg[b]	μ_θ[c]	ρ_θ[d]	μ_τ[e]	ρ_τ[f]	μ_θ	ρ_θ	μ_τ	ρ_τ
3	left	9	3	0.23	0.29	10	3	0	0
3	right	9	3	0.21	0.4	8	2	0	0
5	left	10	3	0.62	0.43	10	2	0.16	0.09
5	right	10	3	0.45	0.37	11	2	0.12	0.1

[a] The moving average period length (s).
[b] Left or right hind leg.
[c] Mean of the cow-specific misclassification rates.
[d] Standard deviation of the cow-specific misclassification rates.
[e] Mean of the cow-specific optimal (minimal among multiple candidates) limits.
[f] Standard deviation of the cow-specific optimal (minimal among multiple candidates) limits.

based on a moving average of 3 seconds based on the step count in combination with a rule stating that the length of a walking period is at least five seconds. As shown, the step count provided by the IceTag3D™ corresponded with a high accuracy to the steps counted from video recordings.

It is easy to define when a cow is standing still without moving her legs. However, there is no commonly accepted scientific definition of whether or not a cow is walking or just standing but moving her legs. In our study, cows in cubicles were per definition standing (no cows were lying down during this part of the study).

Compared to the video recordings, the estimates of walking and standing based on data from the IceTag3D™ showed an overall misclassification around 10%. The misclassification in the walking periods was higher than in the standing periods. However, misclassification is probably more likely to occur in the beginning or the end of a period, and the standing periods were on average longer than the walking periods, which may explain the better results obtained for standing periods. With an accelerometer attached to the neck of the cow Martiskainen et al. (2009) found a higher walking/standing misclassification rate than in the present study, and a rather inaccurate classification of lying down. Previous versions of the IceTag have been validated to give very accurate measures of lying versus standing (Munksgaard et al., 2006) in agreement with the results presented in this paper.

We found a large variation in the cow-specific optimal limits for the moving average algorithm based on the motion index. This variation was smaller when considering a moving average based on the step count. Indeed, when applying the rule that cows never walk for less than 5 seconds, the variation was zero. Thus, the most robust algorithm will be a moving average of 3 seconds based on the step count combined with the walking period rule.

During walking the cow lifts the leg and swings it forward before it is placed on the ground again (Phillips, 2002). Thus, theoretically it should be possible to give a more precise estimate of whether the leg is moving forward, if the accelerometer could be placed in a fixed position on the leg of the cow. However, with the IceTag3D™ both experience from the Netherlands (van Reenen, personal communication) and our own experience suggest that injuries will develop within a few days if the device is attached so tight that it cannot move up and down and around the leg. Thus, there is a need for developing a better system of attachment in order to get the full advantage of the information from a three dimensional accelerometer.

The choice of algorithm in our study resulted in differences in the misclassification rates in walking and standing periods. Therefore, the choice of algorithm should be carefully considered in relation to the relevant question under consideration. However, using a moving average of three seconds with the rule applied, the variation in the optimal limit between cows was reduced. A limit of zero could be used for all cows to obtain the lowest misclassification, and the approach provided good estimates of the duration of walking and standing periods. Furthermore, the duration of the walking periods included in our study corresponds well with the median duration of walking periods reported by Martiskainen et al. (2009), who used data obtained without human interference.

Comparison of the number of steps counted from video recordings with the step count provided by the IceTag3D™ showed high correspondence, when the cows were walking. When the cows were in the cubicles, lifting of a leg would occasionally lead to a single step, but not always. Thus, a direct use of the step count from the IceTag3D™ will not give an accurate estimate of the number of steps taken during walking. The number of "false" steps, i.e. steps that is counted due to the cow lifting her leg, will probably vary between cows and depend on the environment. Thus, sorting data into steps belonging to a period of walking, and steps belonging to periods of standing will improve the correct step counts. Estimating the number of steps per time unit of walking can be an important variable since stride length can differ on different types of flooring (Platz et al., 2008), and lame cows may have shortened stride length (Flower and Weary, 2006).

In conclusion, our results suggest that the IceTag3D™ provides data that can be used to estimate the number of steps per time unit and to estimate the frequency and duration of walking and standing with a reasonable high accuracy.

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