Automated behaviour monitoring in dairy cows

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Abstract

Acceleration sensors in a Wireless Sensor Network (WSN) were used to monitor the behaviour of dairy cows. The data processing from 3D acceleration into behaviour classification (lying, standing or walking) was based on a two-steps method: first the distinction between lying and standing/walking was based on the computed average values during standing and the calculated distance from the actual values and the standing average. Secondly the distinction between standing and walking was based on the variance in 10 successive measurements. With this method both on-node data processing and state-based triggering are possible. This classification was tested during one day with three cows were video recordings were available as reference data. The calculated behaviour corresponds highly with the observed behaviour, the distinction between lying and standing/walking is the same during 99.15% of the time. 99.5% Of the observed walking periods have a matching calculated walking period (if measurements are available).

Keywords: Wireless Sensor Networks, classification, dairy cows.

Introduction

Monitoring the behaviour of dairy cows is of importance for different purposes. Changes in daily activity are useful indicators of pain associated with lameness as lame cows are less active (O'Callaghan *et al.*, 2003). Behaviour characteristics as total lying time and lying synchrony are possible indicators for the assessment of dairy cows welfare (Fregonesi & Leaver, 2001). Occurrences of a disease can influence the behaviour (Fourichon *et al.*, 2000). Behaviour monitoring can also be important to meet quality requirements, e.g. to proof that milk originates from cows in pasture.

Behaviour monitoring may be done by visual observations but this method is not practical within the available time of the herdsman and the increasing herd sizes. The application of accelerometers in Wireless Sensor Networks (WSNs) makes it possible to automate the monitoring of behaviour. Behaviour is classified as lying, standing or walking. Nodes attached to legs of a cow can measure the acceleration and send the data to a base station (possibly via other cows). Important aspects for an efficient use of WSNs are:

- on-node data processing: it is more efficient to process data on the node and transmit only the aggregated data in the network as the data transfer in the network is most energy-consuming task;
- state-based triggering: process data only when this is relevant, e.g. reduce the measuring frequency when a cow is lying, as the energy use can be lowered when the frequency and contents of the data processing tasks depend on the current state.

The objective of this paper is to describe a method for behaviour classification in dairy cows that is suitable for on-node data processing and for state-based triggering in a WSN, and to describe the test results.
These results originate from the WASP project ('Wirelessly Accessible Sensor Populations', www.wasp-project.org), where possible applications of WSNs have been investigated. One of the two chosen scenarios in the WASP project was: 'Detection of health problems with focus on claw health and locomotion' (De Mol *et al.*, 2007, Lokhorst *et al.*, 2008).

Material and methods

The acceleration data were collected at the experimental farm "Waiboerhoeve" of Wageningen UR in Lelystad (The Netherlands). A part of the cubicles stall was fenced off and three Holstein-Friesian cows were kept in that part during one day (Figure 1). Each cow was equipped with two nodes: one at the right hind leg and one at the left hind leg (Table 1). The acceleration was measured with 50 Hz in three dimensions: X, Y and Z. Ten successive acceleration measurements comprise one message. The nodes could transmit their messages to four static nodes and one base node in an observation room on the first floor of the stable building. Video data were recorded with three cameras (with fixed position). The video recordings were analysed with dedicated software (Noldus Observer, www.noldus.com) to record the true behaviour of the cows. The observed behaviour was compared with the calculated behaviour based on the acceleration data.

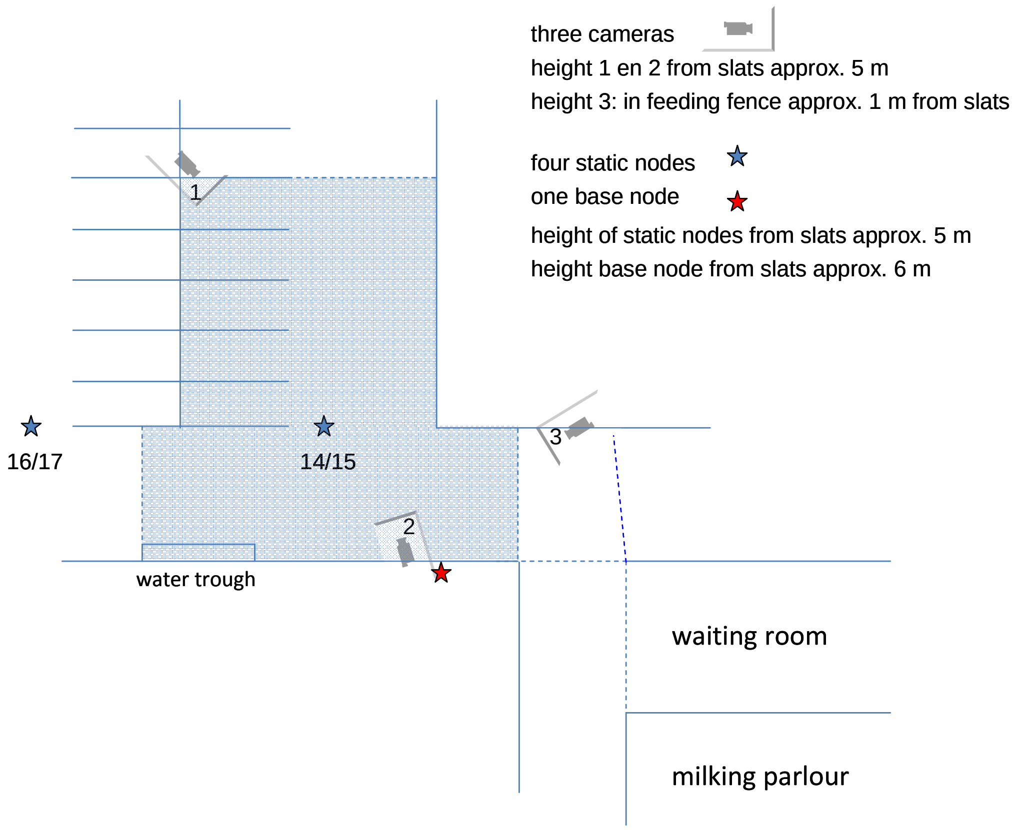

Figure 1. Overview of the situation in the barn during the experimental period.

Table 1. Cows and nodes involved in the experiment.

Nr	Cow ID	Characteristics	Node at left hind leg	Node at right hind leg
1	3246	Spotted cow marked with a X	105	106
3	3272	Black cow marked with a I	101	102
4	3830	Spotted cow marked with a O	103	104

The measured acceleration is used to calculate the behaviour, classified as lying, standing or walking. This is done with a two-steps method:

First a distinction is made between lying and standing/walking. Therefore the accelerometers were used as tilt sensors. If the cow is not accelerating, the only influence is the gravity. This influence will be zero when the sensor is perpendicular to the gravity; a changing value reflects the turning of the sensor in the gravity field. It is possible to calculate the angle when the acceleration sensors are calibrated (as in de Mol *et al.*, 2009a), but here a method is used that does not rely on calibration. The acceleration sensor has limited freedom when the cow is standing (or walking). The range of measurements is small when the leg is vertical. The sensor has a wider range when the cow is lying as the leg can point in any direction then. It is assumed that the variance of the acceleration values is small during standing and the actual values are close to the average values. For any measurement a distinction can then be made between lying and standing by calculating the Euclidian distance with the average values. The behaviour is classified as standing/walking when the distance is below a threshold; the behaviour is lying when the distance is above a threshold. The value of this lying/standing threshold depends on the measurement units and has to be set in practical circumstances.

Secondly, when a cow is standing/walking the distinction between standing and walking is based on the fact that the sensor hardly moves during standing. The behaviour is classified as walking when the variance of ten successive measurements in one or more dimensions is above a threshold and the behaviour is classified as standing otherwise. The value of the standing/walking threshold also has to be chosen.

Results

Observed behaviour

Observations were done on 20 May 2010, starting at 9.00 hr in the morning and ended around 16.00 hr after milking. A still of the video is shown in Figure 2.

Figure 2. Still of the video recording from Camera 1 at 9:01 hr: the three cows in the right part of the boxes are object of research: Cow 3272 is lying, Cow 3246 is standing in a cubicle and Cow 3820 is standing at the feeding fence.

The results of the analysis of the video recordings from 10:00 hr till 11:00 hr with the Noldus Observer software are depicted in Figure 3.

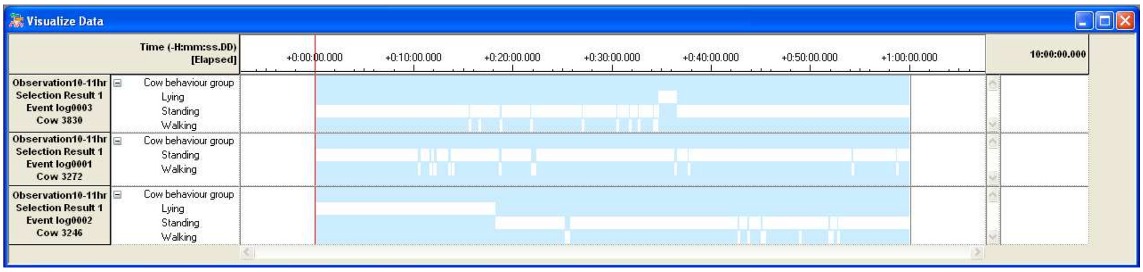

Figure 3. Visualization of the analysis of the video recordings between 10:00 and 11:00 hr of Cow 3830 (upper), 3272 (middle) and 2346 (lower); for each cow the white middle bar represents standing, the higher bar represents lying and the lower outliers represent walking.

<u>Calculated behaviour: lying and standing/walking</u>

The measurements of six nodes have been used to calculate the behaviour of the cows (Table 1). Acceleration was measured with a frequency of 50 Hz, the average value per second was used to calculate the behaviour. As an example the measured values in two dimensions of Node 103 are given in Figure 4. Node 106 stopped functioning after 10:10 hr. The system crashed around 13:15 hr, therefore there is a break in the measurements around that time.

The average value of the acceleration when the cow was observed standing was calculated for each node. For example right lower graph in Figure 4 shows the measured acceleration per second of Node 103 during standing, the average values during standing for the X, Y and Z values were 1818, 2199 and 2468 respectively.

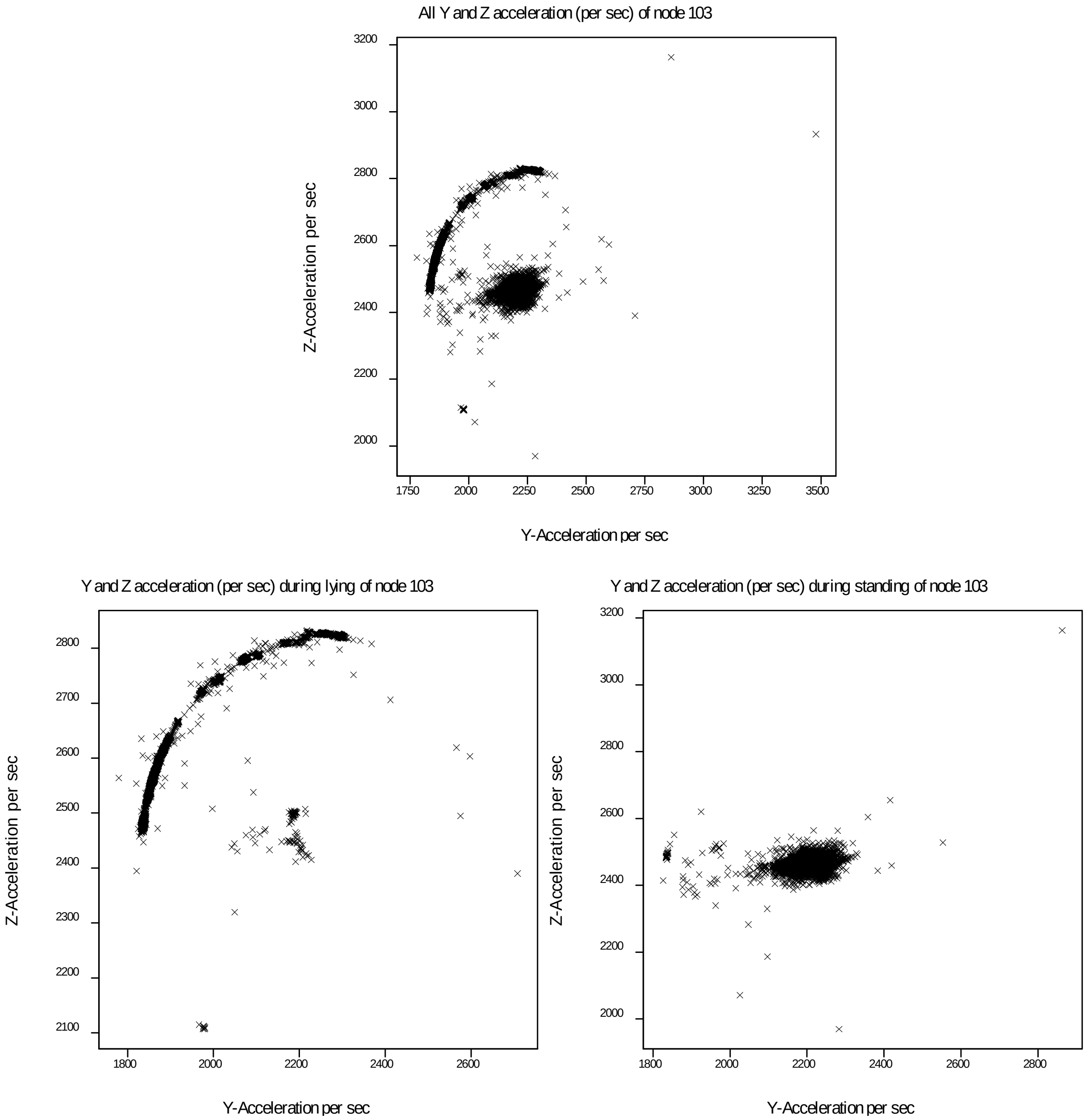

Figure 4. All measured acceleration values for the Y and Z dimension of Node 103 (upper graph); divided into measurements during lying (lower left graph) and during standing/walking (lower right graph).

The calculated behaviour is standing when the Euclidian distance with the average during standing is less than a threshold, otherwise lying. The value of this threshold that has been applied in this research is 300 (for all nodes).

Comparison of calculated and observed behaviour: lying and standing/walking

There is a great similarity between the observed and calculated behaviour, as can be seen in Figure 5, 6 and 7. Some small deviations occur when:

– there are outliers in the calculated behaviour where the behaviour is deviating during 1 second; these outliers could be filtered out easily;

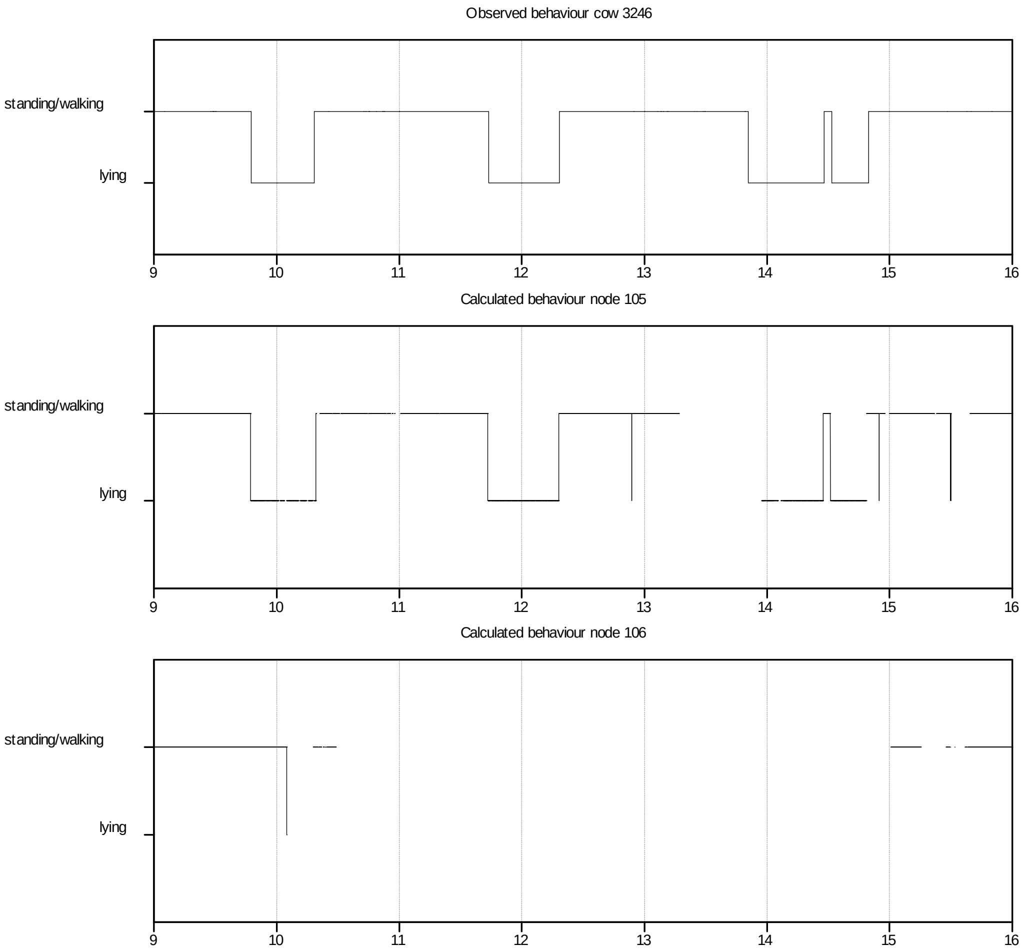

Figure 5. Comparison of observed behaviour of Cow 3246 (upper graph), calculated behaviour of Node 105 attached to the left hind leg of Cow 3246 (middle graph) and calculated behaviour of Node 106 attached to the right hind leg of Cow 3246 (lower graph).

– there are deviations around the moment of behaviour change, the observed moment of change is a few seconds earlier or later than the calculated moment;

– there are no accelerations measurements available on the moment of behaviour change (e.g. Cow 3830 around 10:40 hr).

Major deviations occur when the sensor is not working properly, e.g. the results of Node 106 after 10:10 hr are unreliable; this node did not function any more after 10:10 hr. The results of the comparison of the observed and calculated behaviour are given in Table 2. From these results, it can be concluded that the calculated behaviour is the same as the observed behaviour in 99.15% of the time. The results of Node 106 are not used in this overall result.

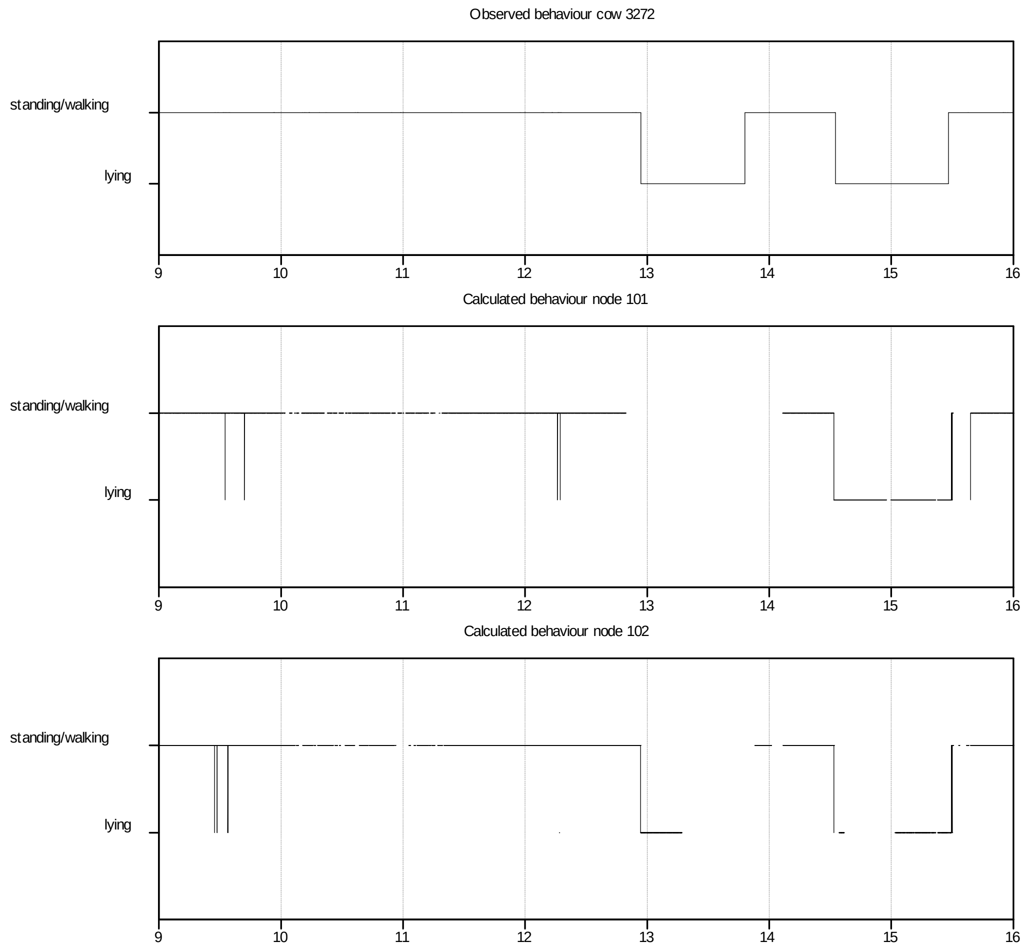

Figure 6. Comparison of observed behaviour of Cow 3272 (upper graph), calculated behaviour of Node 101 attached to the left hind leg of Cow 3272 (middle graph) and calculated behaviour of Node 102 attached to the right hind leg of Cow 3272 (lower graph).

Table 2. Comparison of observed and calculated lying and standing/walking behaviour (per second) per cow/node.

Cow	Node	measurements	calculated behaviours	calculated = observed	calculated ≠ observed	similarity
3246	105, left	22783	20121	19874	247	98.8%
	106, right	8900	6140	5178	962	84.3%
3272	101, left	23047	17968	17870	98	99.5%
	102, right	20578	17752	17620	132	99.3%
3830	103, left	20921	17550	17408	142	99.2%
	104, right	22797	16976	16829	147	99.1%

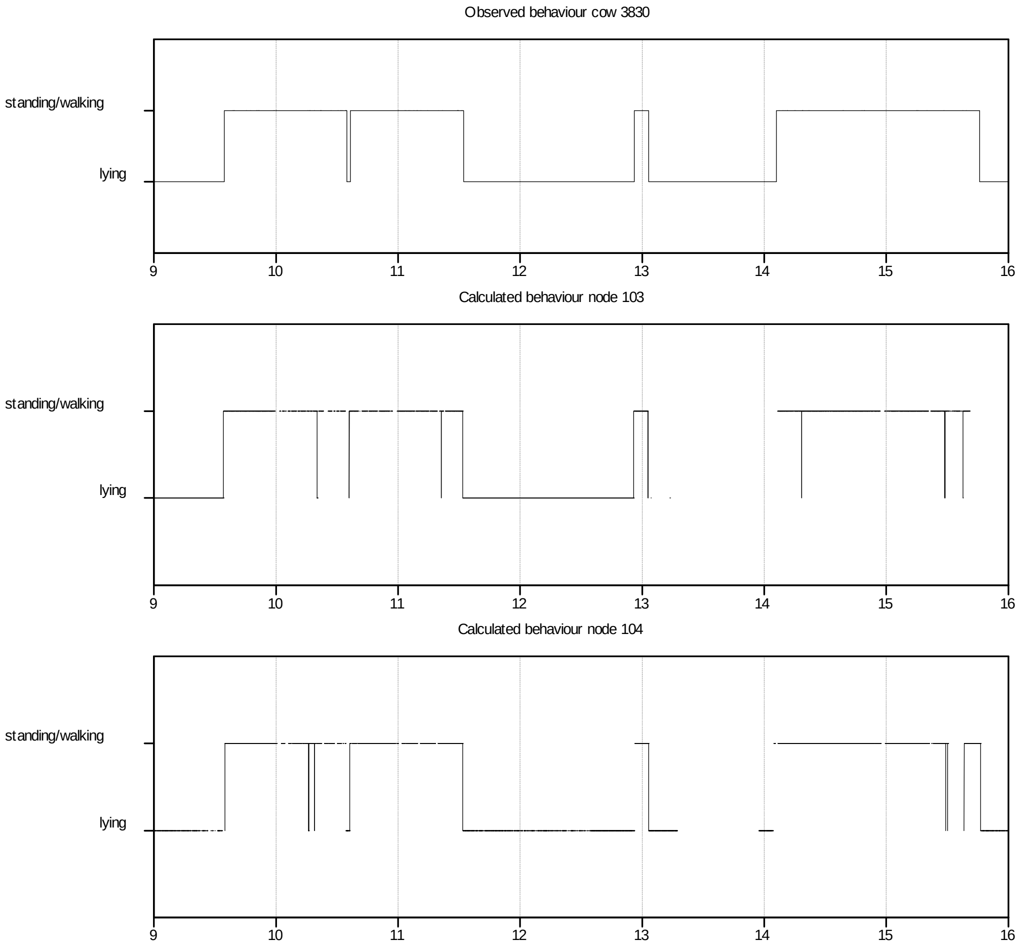

Figure 7. Comparison of observed behaviour of Cow 3830 (upper graph), calculated behaviour of Node 103 attached to the left hind leg of Cow 3830 (middle graph) and calculated behaviour of Node 104 attached to the right hind leg of Cow 3830 (lower graph).

<u>Calculated behaviour: standing and walking</u>

During standing/walking, the behaviour is subdivided in standing and walking based on the variance of ten successive measurements. The cow is walking when the variance is higher than a threshold (in one or more dimensions), otherwise standing. In this research the applied value for this threshold is 400. The values for standing and walking are averaged per second for the further analysis. An example of the results is given in Figure 8, where the observed and calculated standing and walking behaviour of Cow 3830 during 10 minutes is depicted. The walking values are only included in the analysis when the one-second average exceeds 0.5, that is when walking is detected during a major part of the time.

In general, the observed walking intervals do not overlap with the calculated walking intervals due to imperfect time synchronization. But it is quite easy to match observed walking intervals with calculated walking intervals by shifting the time line a bit.

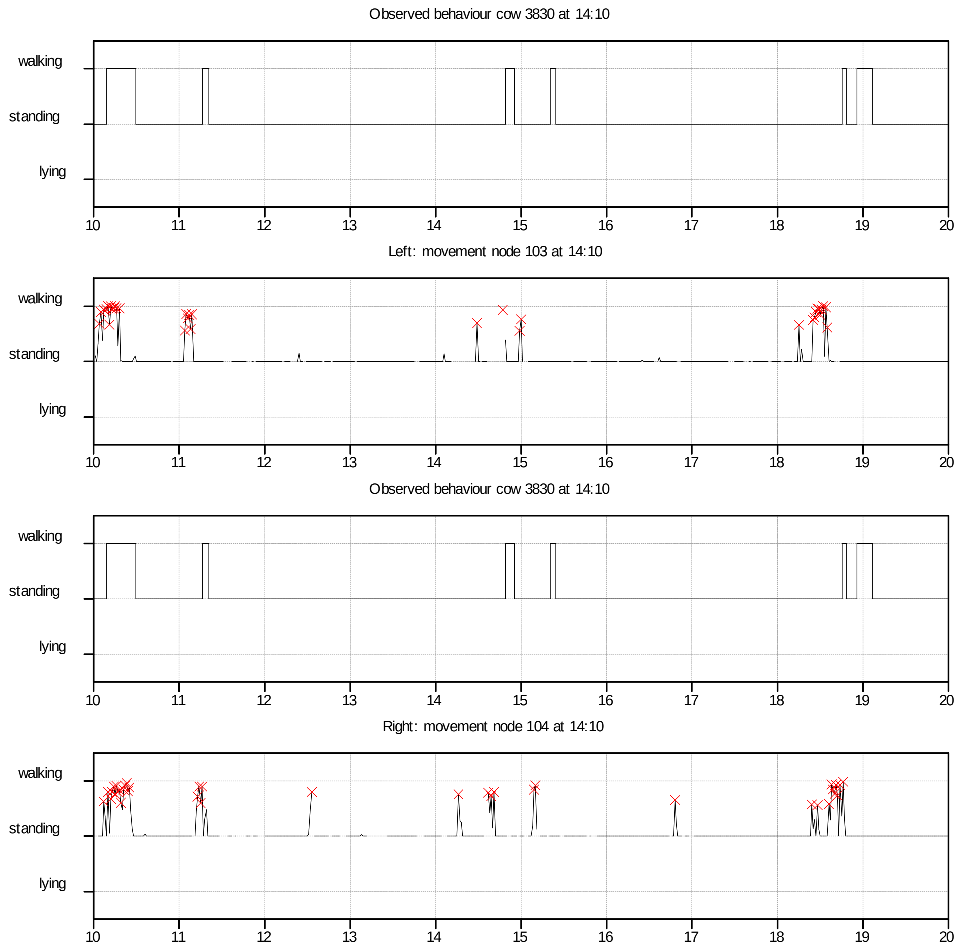

Figure 8. Comparison of observed standing and walking behaviour of Cow 3830 (first and third graph), calculated behaviour of Node 103 attached to the left hind leg of Cow 3830 (second graph) and calculated behaviour of Node 104 attached to the right hind leg of Cow 3830 (fourth graph), all during a 10 minutes interval from 14:10 till 14:20 hrs. The calculated walking values are averaged per second and a cross is added when the one-second average exceeds 0.5.

<u>Comparison of calculated and observed behaviour: standing and walking</u>

Results of the comparison of the observed and calculated standing and walking behaviour are included in Table 3.

In total 151 walking periods have been observed. With the left-side nodes all walking periods match with calculated moving periods if measurements available (there are no measurements available in 13 cases). With the right-side nodes all but one walking periods match (no measurements in 26 cases), there is one non-matching case for Node 104 attached to Cow 3830. So if measurements are available, 99.5% of the observed walking periods have a matching calculated moving period.

There are a lot of moving periods that do not match with an observed walking period. Mostly these are very short intervals. These probably correspond with leg movement during standing (or during the process of lying down or standing up). These non-matching periods may better be classified as 'moving legs' instead of 'walking'.

The method used is suitable for on-node processing as it needs only one message of ten successive measurements. The results make clear that the method can be used for state-based triggering as moving behaviour is (almost) always detected during walking (and also sometimes during standing).

Table 3. Comparison of observed and calculated standing and walking behaviour (per second) per cow/node.

Cow	Node	percentage of moving time during standing /walking	number of walking periods			number of calculated moving periods not walking
			total number	with matching calculated walking periods	without measure-ments	
3246	105, left	7.2%	26	19	7	349
	106, right	6.2%		8	18	138
3272	101, left	4.8%	44	40	4	230
	102, right	4.8%		41	3	248
3830	103, left	3.0%	51	49	2	35
	104, right	4.1%		45	5	66

Discussion

The calculated behaviour is the same as the observed behaviour during most of the time. Small differences can be filtered out (if they last only one second), have less influence (exact time of behaviour change) or were caused by the off-line calculation method. During this experiment the calculations were done off-line, the calculations will be done on node level during practical implementation to reduce the effects of packet loss during signal transmission and to reduce the radio traffic (Lokhorst *et al.*, 2010).

During this experiment the observed behaviour was known and has been used to calculate the average value during standing. This is not possible in practical circumstances. But the average value might as well be calculated during periods when the cow is known to be standing, e.g. during milking or in the waiting room before milking. Therefore this method is also applicable when the observed behaviour is not known.

The nodes were attached to outer side of the hind leg. In practical circumstances, the node might rotate around the leg (to the inner side). This did not happen in this experiment and the effects on behaviour classification are not known yet. This should be studied. The effects will be temporarily if the standing averages are updated regularly (e.g. during each milking).

Defect sensors will give bad behaviour classifications (e.g. Node 106). It will not always be clear when a sensor is defect. This might be solved by determining the trustworthiness of the sensor data (Gomez *et al.*, 2011).

When a cow is walking this can be recognized by the described method to distinguish standing from moving. This relation is one-way: moving is always detected during walking, but moving does not imply walking as there can be other similar leg movements. So this method is suitable for state-based triggering, moving detection can be the starting point of locomotion analysis (de Mol *et al.*, 2009b) as the cow may be walking then.

The time synchronization between the video recordings and the acceleration recordings was a practical problem in this research. Incorrect timing leads to false behaviour classifications around the moment of behaviour change. It also makes is necessary to include a time shift to match observed and calculated walking intervals. So imperfect time synchronization made it more difficult to show the evidence of the methods used, but it is no problem at all for the practical application: the interval lengths are correct and the exact moment of walking is irrelevant (but the number and length of walking periods can be relevant).

Conclusions

The proposed method for the behaviour classification, based on the distance between the actual value and the computed average during standing, gives good results, the similarity between observed and calculated behaviour is up to 100%. A clear distinction between lying and standing/walking can be made. When the cow is walking then moving is detected, but the other way round is not always true: moving can also be detected during standing (e.g. leg movements). Detection of moving is an effective method to initialize locomotion analysis. Bad results can occur when the sensor is defect. This method is suitable for use in practical applications of Wireless Sensor Networks as the method makes on-node processing possible as well as state-based triggering. For practical application there should be periods were the cow is known to be standing (e.g. during milking).

Acknowledgements

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