Recording of dairy cow behaviour with wireless accelerometers

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Abstract

The daily behaviour of dairy cows reflects the health and well-being status. The behaviour can be monitored with accelerometers (used as a tilt sensor to measure the angle) in a wireless sensor network. The angle of a leg reflects the lying or standing behaviour, the angle of the head might reflect the eating behaviour. An experiment was carried out at an experimental farm during 50 days. Six cows were equipped with two 2D accelerometers, one attached to the neck and one attached to the right hind leg. The accelerometers were attached to wireless sensor nodes. The acceleration of the neck and leg was recorded every halve minute (average of seven measurements with 1 Hz measuring frequency). Based on calibration measurements, the acceleration of the leg and the neck were both transformed to the angle. A cow was standing when the angle of the leg was more than 45°, otherwise lying. The method to transform the acceleration to angle and behaviour appears to be appropriate, it is possible to monitor the cow's behaviour with a wireless sensor network equipped with accelerometers.

Keywords: tilt sensor, lying, standing

Introduction

The daily behaviour of dairy cows reflects the health and well-being status (Phillips, 2002). Tools that measure the cow's behaviour can help the farmer in his daily management, e.g. to detect parturition and lameness (an overview is given in Champion *et al.*, 1997). The cow's behaviour can be observed by the herdsman or, alternatively monitored with wireless accelerometers. For this application, the accelerometers were used as a tilt sensor to measure the angle (as in Müller and Schrader, 2003). The angle of a leg might reflect the lying or standing behaviour, the angle of the neck might reflect the eating behaviour. An experiment with six cows was carried out at the experimental farm ‘Nij Bosma Zathe’, in the North of the Netherlands during 50 days in May/ June 2008. The cows were equipped with two 2D accelerometers, one attached to the neck and one attached to the right hind leg. The experimental setup and results are described in this paper.

Material and methods

Data collection
Wireless accelerometers were used as a tilt sensor in an experiment to record cow behaviour. SOWNet nodes were used (www.sownet.nl) combined with 2D accelerometers with digital output (ADXL202E*, Analog Devices, www.analog.com). The experiment was carried out at the experimental farm "Nij Bosma Zathe", in the North of the Netherlands. The experiment started at May 6, 2008 (Day 0 of the experiment) and ended at June 26, 2008 (Day 51). During this period six cows (Cow 74, 428, 445, 452, 502, 507) were equipped with two nodes: one attached to the neck and one attached to the right hind leg (Figure 1). The cows were milked in a milking robot; starting times and milk yield of the milkings were available. The cows were indoors during the first 36 days

Figure 1. Two cows involved in the experiment with a view on the node attachment to outer side of the right hind leg (left) and to the upper side of the neck (right).

and had access to a pasture during the day, on the last 14 days. During these last 14 days, the cows were driven to the waiting room of the milking robot in the morning. They could only leave this waiting room by passing the milking robot. Depending on the time since the last milking, cows were milked in the milking robot or could pass the milking robot without being milked. Then they had free access to the pasture during the day. In the afternoon (between 4 and 6 p.m.) the cows in the pasture were driven to the barn were they had to stay during the night.

17 Nodes have been used as sensor nodes with accelerometers and were attached to the neck or leg of a cow during the experiment. 14 Nodes have been used as repeaters inside the barn or outside in the pasture (see also Ipema *et al.*, 2009). Every half minute, the acceleration in two axes (X and Y) was measured during 7 seconds with 1 Hz, this resulted in a sequence of 7 measurement pairs per ½ minute. These measurements were transmitted in one message per ½ minute to the gateway via the repeaters. The acceleration data were stored in text files. The signal strength, RSSI, at the first repeater was recorded every 5 minutes. The RSSI data were also stored in text files. The voltage of the battery of the sensor nodes was also measured every 5 minutes and stored in text files.

For the data analysis the data were transferred to an Access database. Each package of seven acceleration measurements was compressed to the average value, the minimum value and the maximum value. The acceleration data were stored in a table in an Access database. This table contains 1.437.696 records corresponding to the same number of measurement sequences. The acceleration sensors were calibrated and the calibration results were used to transform the average acceleration to an angle. The method used to derive the angle from the acceleration is described in the next paragraph. The calculated angle was included in the Access table for the acceleration data.

Data processing: Angle calculation

The measured acceleration and the calibration results were used to calculate the angle of the node. The method applied is described here. 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.

The neck node was attached to a collar around the neck of a cow (Figure 1). The normal position was on the top of the neck with equal distance to both ears. It could happen that the node shifted around the neck to the right side or the left side of the neck. For the calibration of the acceleration sensors attached to the neck, acceleration was measured at a standstill at known angles (varying from -90° thru 15°) and known positions of the node: top of neck, right side of neck and left side of neck. The calibration results of Node 1 are depicted in Figure 2. The acceleration in the X direction was greatly influenced by both the position of the node and the angle of the node. The acceleration in the Y direction was mostly only influenced by the angle of the node. The same holds for the other nodes. Therefore only the acceleration in the Y direction was used the transform the acceleration to the angle of the neck. This transformation was implemented by linear interpolation as can be explained by a simple example: For Node 1, the acceleration in Y direction measured at the calibration with the node in the position at the top of the neck was 126 if the angle was -15° and 130 if the angle was 0°. This implies that if the measured acceleration was 128 the transformation to an angle resulted in 7.5°.

If the measured acceleration was less than the calibration acceleration at -90°, then the calculated angle was defined as -91°. The calibration results at 0° and 15° were extrapolated to calibration results at 30°. If the measured acceleration was more then the calibration at 30°, then the calculated angle was defined as 31°.

The leg node was attached with synthetic binding to the outer side of the right hind leg of a cow (Figure 1). The normal position was to the right of the leg. It could happen that the node turned around the leg to the front side, the hind side or the left side of the leg. Also for the leg nodes calibration results were available per node and different angles (0°, 15°, ..., 90°) and position at the leg (right, left, front, hind). Both the acceleration in X direction as well as in Y direction were both influenced by the angle and the position. The transformation method from measured acceleration to calculated angle was based on both X acceleration and Y acceleration. This transformation was in three steps:

Calculation of the angle based on the X acceleration using the calibration results with the node at the right side or the left side of the leg. This was done by linear interpolation on the calibration results, similar to the interpolation for the angle calculation of the neck node.

Calculation of the angle based on the Y acceleration using the calibration results with the node at the front side or the hind side of the leg. This was also done by linear interpolation on the calibration results.

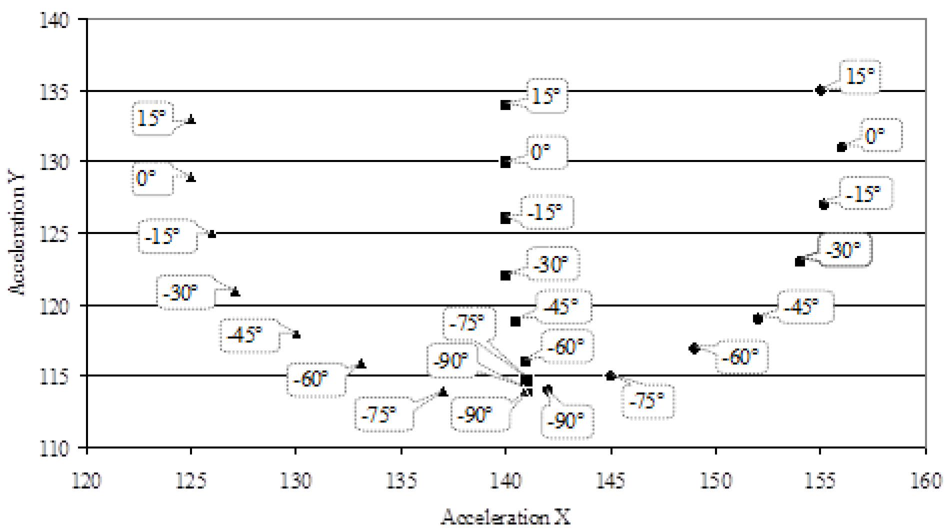

Figure 2. Calibration results for Node 1 at different angles (-90°, -75°, ..., 15°: from lower to upper) and different positions of the node: top of neck (squares), left side (triangles) and right side (bullets).

Both angles (based on the X and Y acceleration) were combined by taking for both the difference with an angle of 90°. These differences were summed and the combined angle was 90° minus this sum (with a minimum of 0). For example, the angle based on X acceleration was 80°, the angles based on the Y acceleration was 50°. The differences were now 10° and 40° giving a sum of 50°. The combined angle was 90° - 50° = 40°.
Both the angle of the neck node and the angle of the leg node were calculated for all sequences and were stored in the Access table with acceleration data.

Data processing: Behaviour classification
The angle of the leg of a cow tells something about the behaviour of the cow, the angle will be around 90° during standing and around 0° during lying. The behaviour was derived from the calculated angle by applying a simple heuristic rule:

- If the calculated angle is more than 45° than the cow is standing.
- If the calculated angle is at most 45° than the cow is lying.

If the derived behaviour resulted in a period of lying (or standing) of 1 minute or less, then the derived behaviour was corrected to standing (or lying) as such a short period is unlikely.
Complete observations to verify these derived behaviour results were not available. Only the milking times were available and these were used to check that the cows were standing during milking.

Results

Number of acceleration measurements
The acceleration was measured 7 times with 1 Hz twice a minute and sent to the gateway over one or more repeaters. At most 120 sequences of 7 measurements might be expected per hour. This number was lower in practice because of problems at the node or in the reception of the signals from node to repeater, between repeaters or from repeater to gateway. Overall 1.437.696 sequences were stored in the database for six cows with two nodes over 50 days, this gave on average 600 sequences per node per 6-hour period (performance rate = 83%). Theoretically, the maximum number per 6-hour period was 720 (6 hours with 120 messages). The number was lower in case of problems with the nodes. The number was higher for the neck nodes (average per cow between 681 and 708) than the leg nodes (between 630 and 677), probably because of transmission problems (e.g. when the leg was under the body during lying). The numbers were also lower when the cows had access to the pasture in Week 6 and 7. In these weeks, the average of the leg nodes in the period from 6-12 hr varied between 370 and 668 and in the period from 12 till18 hr between 375 and 541. Apparently the transmission outside the barn gave problems. The number of repeaters in the barn was lower in the last two weeks (3 instead of 6), but this did not influence the number of sequences from the neck nodes in the barn periods, the number of sequences from the leg nodes appeared to be a bit lower in the last two weeks. In general the number of received sequences was lower for the leg node compared with the neck node. This is also clear from Figure 3 where the numbers per 6-hours period for Cow 428 during the experiment are depicted. Similar results on the RSSI measurements in the same experiment can be found in Ipema *et al.* (2009).

Analysis of acceleration measurements for behaviour characterisation
Step 1: Measured acceleration: For each of the six cows, the acceleration of the neck node and the leg node were measured every ½ minute during 7 seconds with 1 Hz in two directions, X and Y. Each sequence of seven measurements was summarized by taking the average. As an example the averages of Cow 507 on the day 32 of the experiment are depicted in Figure 4. It is not possible to draw conclusions from Figure 4 as the vertical axis represents a digitalized version of the acceleration that should be transferred to an angle to make an interpretation possible.

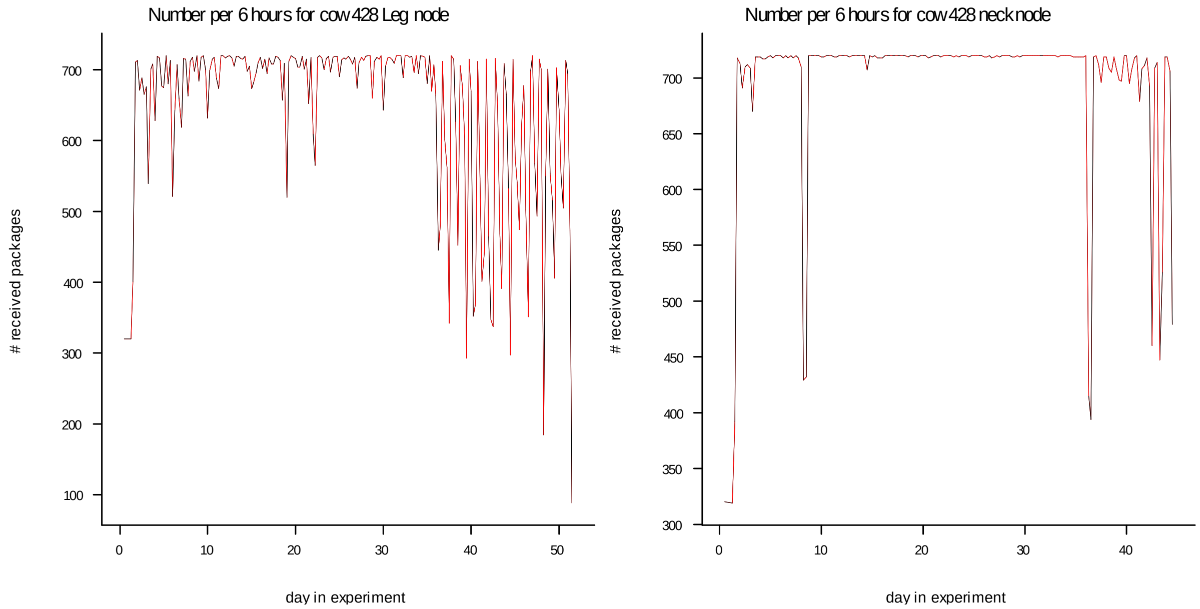

Figure 3. Number of received packages per 6 hours period from the leg node (left) and neck node (right) of Cow 428 (horizontal axis = number of day in experiment)

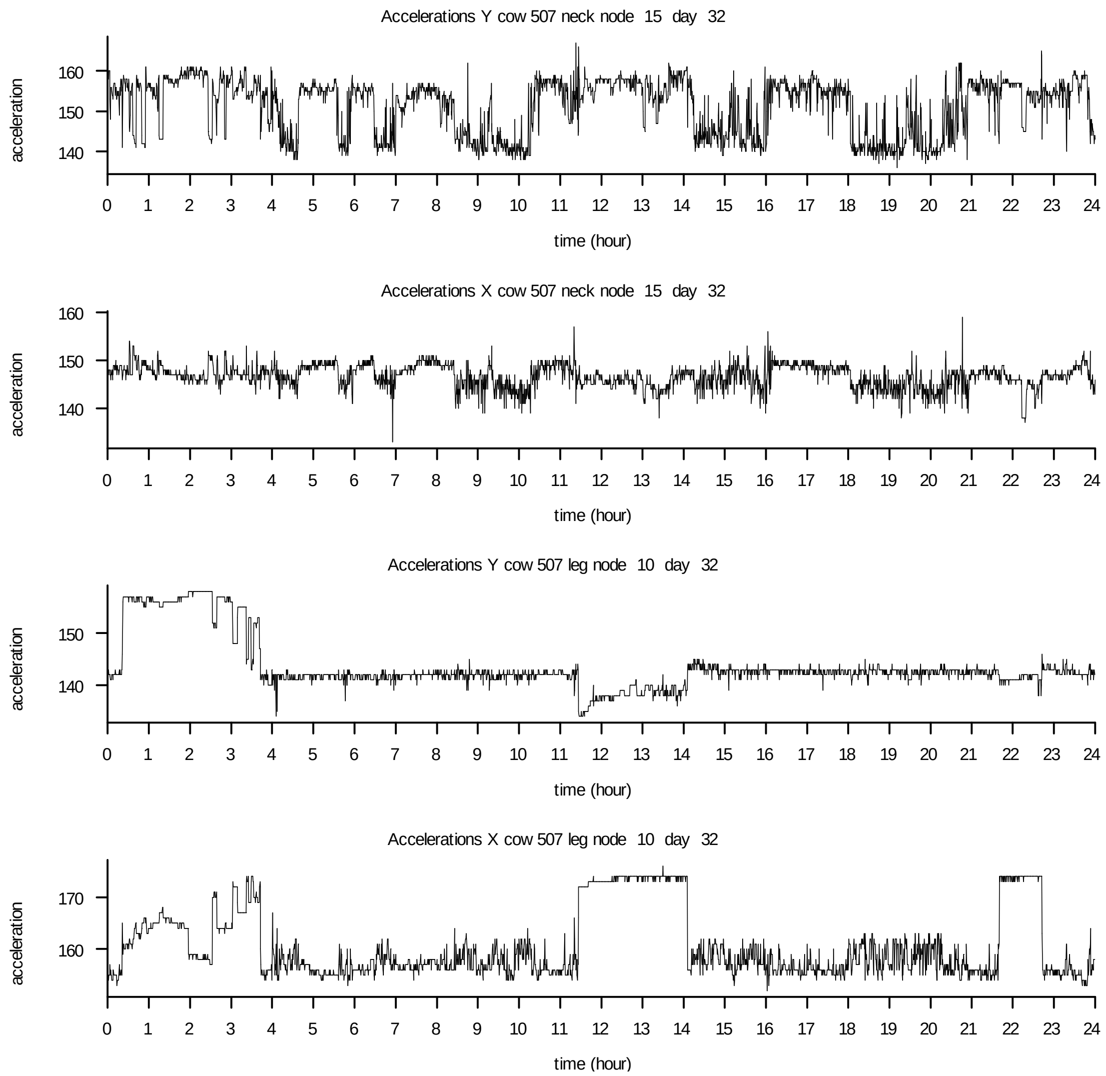

Figure 4. Measured acceleration for Cow 507 on Day 32 of neck node (two upper graphs) and leg node (two lower graphs), both in X-direction and Y-direction (average per ½ minute).

Step 2: Calculated angle: As described in the materials and methods the measured acceleration was transferred to an angle using the calibration results. The results for Cow 507 on the 32d day of the experiment are depicted in Figure 5, were in the upper part the calculated angle of the neck is depicted and in the lower part the calculated angle of the leg (based on X acceleration dashed, on Y acceleration dotted and combined as a solid line). In both parts, the milking times are included by vertical peaks of the bottom line.

Step 3: Calculated behaviour: The calculated angle of the leg was used to derive the cow's behaviour: lying or standing (see materials and methods). The calculated behaviour is depicted in the lower part of Figure 5 by the solid two-level line (lower level = lying, higher level = standing). On this day, Cow 507 is standing (or walking) most of the time alternated wither shorter lying periods. As expected the milkings fall within the standing periods.

It was possible to calculate the percentage of the time that a cow was standing based on the calculated behaviour. An example is given in Figure 6 where the percentage of time standing is given per day for Cow 428. It is known that the behaviour of this cow might be influenced by a recorded case of oestrus on Day 13 and the access to pasture starting at Day 37.

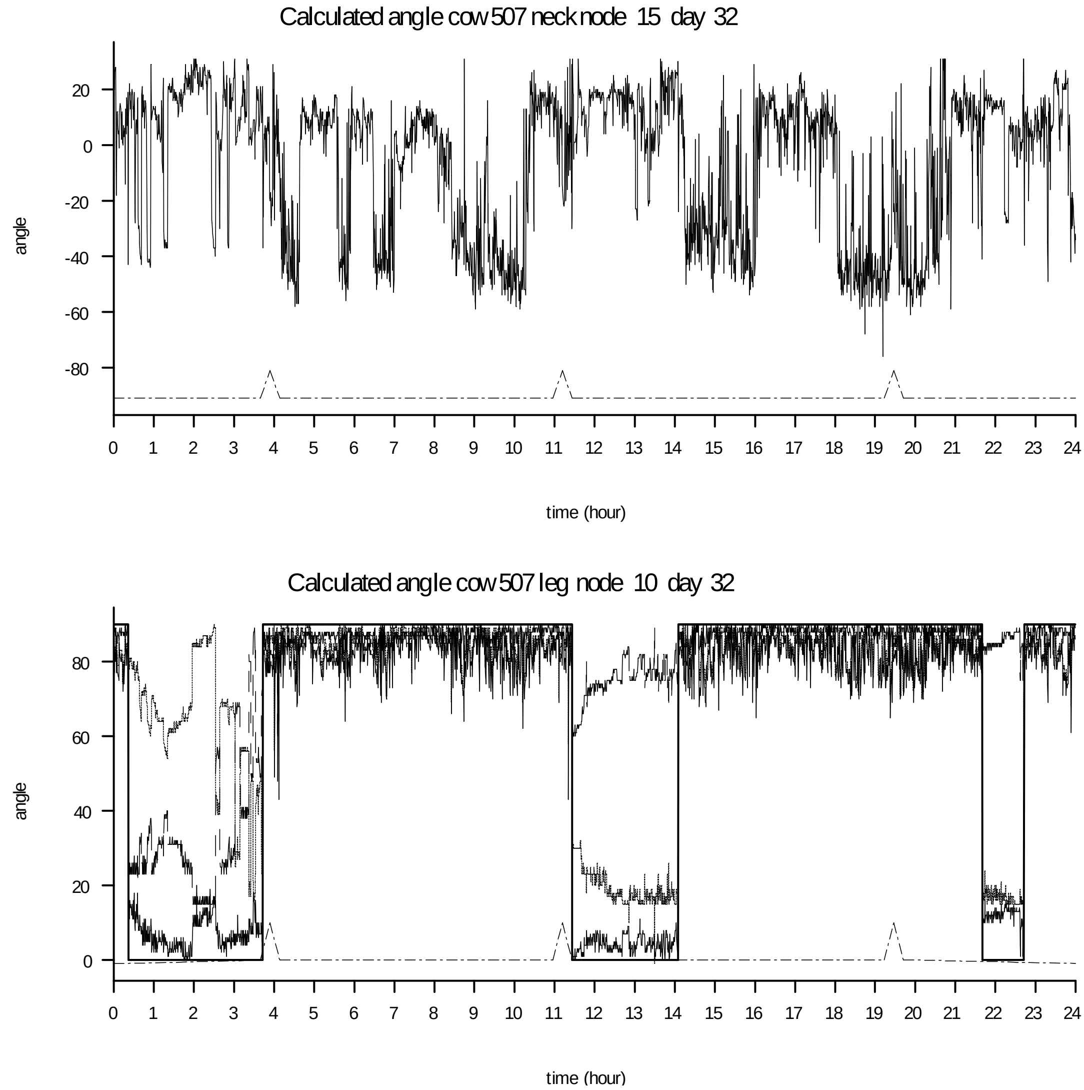

Figure 5. Calculated angle for Cow 507 on Day 32 of neck node (upper) based on acceleration in Y-direction, and leg node (lower) based on acceleration in X direction (dashed), Y direction (dotted) and combined (solid) with derived behaviour based on the combined angle in included by a solid two-level line (low value = lying, high value = standing). The milkings are denoted in both graphs by a dash-dotted line at the bottom with peaks at each milking

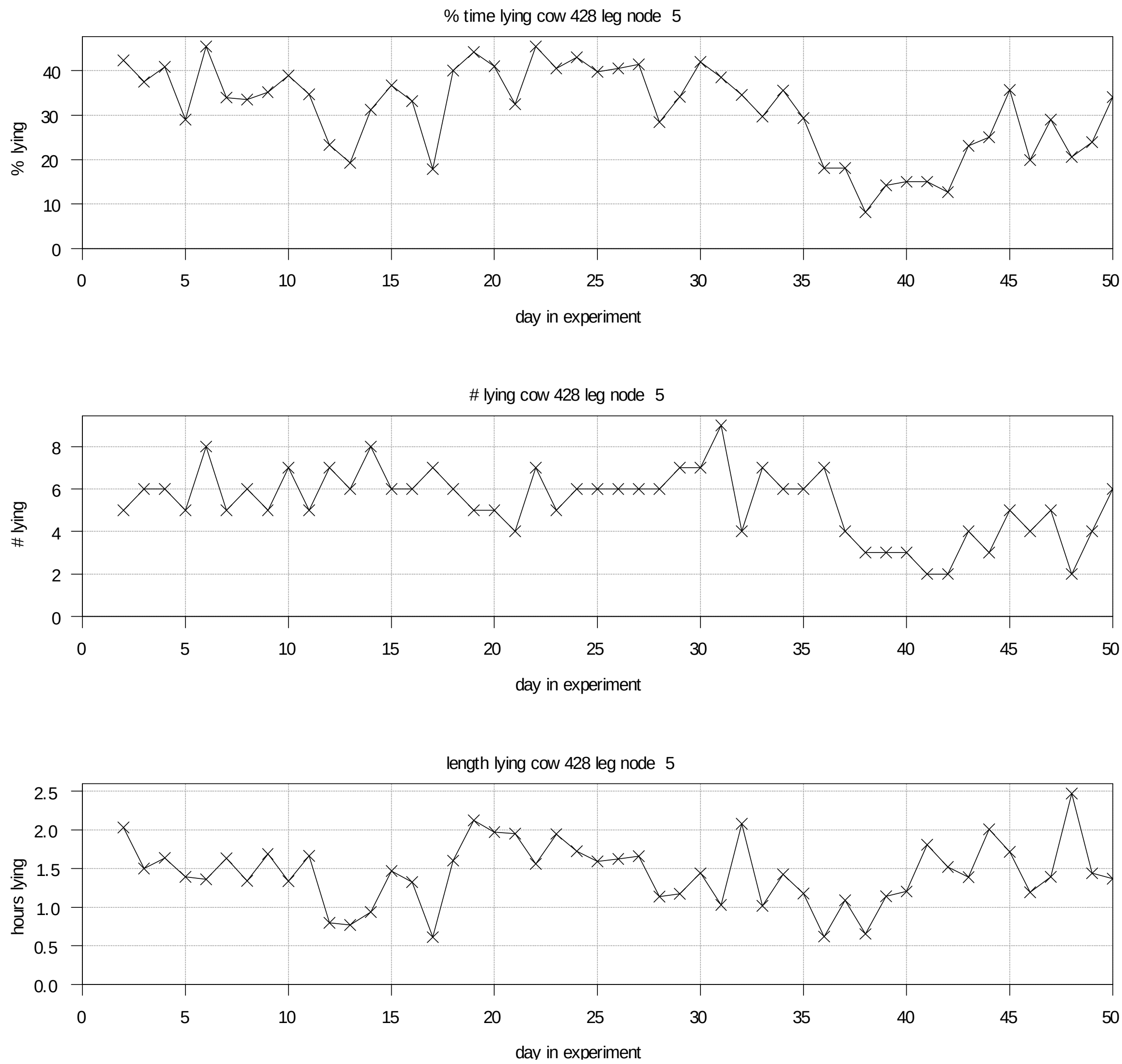

Figure 6. Calculated behaviour for Cow 428 during the experimental period: percentage of time lying (upper), number of lying intervals (middle) and average length of lying intervals (lower).

Discussion and conclusions

In this research accelerometers were used as a tilt sensor. The results can be compared with research on cattle behaviour with tilt sensors as in Champion *et al.* (1997).

The equipment used to measure the behaviour should be small and light-weighted, as stated by Müller and Schrader (2003), otherwise the animal's behaviour will be influenced. Accelerometers attached to nodes and deployed in a wireless sensor network can fulfil this requirement. This development is part of the WASP project where animal behaviour recording is one of the explored applications of wireless sensor networks (www.wasp-project.org).

Measurement of the acceleration (and thus behaviour) with nodes in a wireless sensor network made on-line measurement possible. Data are stored till read-out (up to 700 days) in the activity monitoring system described in Müller and Schrader (2003) and stored up to 16,000 readings in the datalogger system of O'Driscoll *et al.* (2008). A time interval between recording and data processing is a drawback if the behaviour data are needed for cattle management, e.g. in case of detection of parturition and lameness.

The behaviour classification (standing or lying) was based on the calculated angle and the threshold used (45°). This threshold is common in this research field (e.g. Champion *et al.*, 1997, O'Driscoll *et al.*, 2008).

The number of received packages was lower when the cows were in pasture (Figure 3). This might be caused by transmission problems when the cow was lying. The percentage of time lying was based on the length of lying intervals, but intervals without any message during half an hour or more were excluded from this analysis. This might imply an underestimation of the lying intervals if there were no data transmitted for more than half an hour during lying.

The conclusions from this experiment were:

- Accelerometers applied in wireless sensor network can be used as on-line tilt sensors.
- Measured acceleration can be transformed to angle of the node (although verification by other measurement methods is advised).
- The calculated angle of the neck nodes are not straightforward useful for behaviour analysis.
- The calculated angle of the leg nodes appears to be useful to derive the standing and lying behaviour of cows (but verification is advised).

References

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