Recording and analysis of locomotion in dairy cows with 3D accelerometers

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Abstract

An automated method for lameness detection can be an alternative for detection by regular observations. Accelerometers attached to a leg of the dairy cow can be used to record the locomotion of a dairy cow. In an experiment the 3D acceleration of the right hind leg during walking of three dairy cows was measured and analysed. Nodes with a 3D accelerometer in a wireless sensor network were applied to measure with a frequency of 50 Hz. After data filtering, the data analysis was in two steps: first step detection and secondly the determination of step parameters. Variance analysis was used for step detection. For each step the parameters step length and step time were calculated. The steps and step parameters can be used in future research for gait analysis of lame and non-lame cows. The aim of this paper is to describe the collection and analysis of data in this experiment and to assess the possibilities for gait analysis. It can be concluded that the application of accelerometers in a wireless sensor network gives promising results. Step detection is possible and step parameters can be derived.

Keywords: lameness detection, steps, wireless sensor networks, gait analysis

Introduction

Lameness is a big problem in modern dairy farming. Lameness causes welfare problems and economic losses for the farmer (see Flower and Weary, 2009 for an overview). The step length is reduced during lameness and some unevenness of gait is evident (Phillips, 2002). Lameness can be detected by regular observations of the locomotion of the cows. But this method is not reliable, time consuming and more difficult in larger herds. An automated method for lameness detection can solve this problem. Flower and Weary (2009) distinguish subjective and objective methods for gait assessment. Subjective methods (rating systems) are not always reliable and require experienced observers. Objective systems like force plates can be accurate and reliable but have practical limitations when applied on farms. Accelerometers attached to a leg of the cow can be used to record the locomotion of a cow. Accelerometers have been applied for gait analysis in humans (Kavanagh and Menz, 2008 provide a review) and horses (Barrey, 1999), but not for dairy cows. Application of accelerometers is more convenient if they are implemented as parts of a wireless sensor network (WSN). Accelerometers in a WSN are being studied in the WASP project (‘Wirelessly Accessible Sensor Populations’, www.wasp-project.org), where possible applications of WSNs are investigated. One of the two chosen scenarios in the WASP project is: ‘Detection of health problems with focus on claw health and locomotion’ (De Mol *et al*., 2007). This scenario has been elaborated (Lokhorst *et al*., 2008) and will be tested.
In this paper the results are described of a small-scale experiment within the WASP project that explored the possibilities of using acceleration measurements for gait analysis of cows with accelerometers in a WSN. The 3D acceleration during walking of three dairy cows was measured and analysed to gain insight into the possibilities for the detection of steps and the derivation of

step parameters. The steps and step parameters can be used in future research for gait analysis of lame and non-lame cows. The aim of this paper is to describe the collection and analysis of data in this experiment and to assess the possibilities for gait analysis.

Material and methods

Data collection

Accelerometers attached to nodes in a WSN were used in an experiment to measure the acceleration of the cow's leg in forward, sideward and upward direction during walking. Data were collected in a passage along the milking parlour that the cows pass when they return to the lying and eating space after milking (Figure 1) at the experimental farm 'De Ossekampen' of Wageningen UR in Wageningen.

Three nodes were available for this experiment: two BSN nodes (number 4 and 5; www.doc.ic.ac.uk/vip/ubimon) and one Crossbow node (number 98; www.xbow.com), all equipped with a 3D accelerometer. These nodes were used to measure the acceleration of the left hind leg (Figure 2)

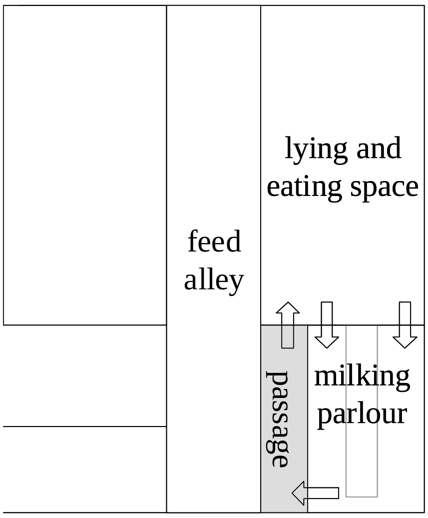

Figure 1. Schematic view of the part of the experimental farm 'De Ossekampen' of Wageningen UR in Wageningen, where the experiment was performed.

Figure 2. Attachment of a node to the left hind leg (picture taken during milking).

of three cows (number 263, 409 and 429) on three successive days after the afternoon milking (2-4 July 2008, around 16.00 hr). Cow 263 was a lame cow, according to information from the stockmen. The nodes were attached each day just before milking and removed after milking. A node was not always attached to the same cow. The acceleration was measured with a frequency of 50 Hz. The nodes were part of a WSN; the measurement data were transmitted to a gateway and stored on a laptop in the feed alley.

The measurement data were transformed in two steps to get the acceleration values in three directions: forward, sideward and upward:

1. Transform to values between -2g and +2g (the measurement range of the accelerometers, 1g = 9.8 m/s^2) by using calibration results.
2. Rearrange the directions 1, 2 and 3 to forward, sideward and upward, based on the actual positioning of the nodes.

The measurement data were collected in text files and transferred to an MS-Access database with one table per node. The transformation to acceleration in three directions was performed by queries. This resulted in one query per node and per day in the database with the acceleration in three directions. The acceleration data in the database were analysed with the objective to determine steps and step parameters. The analysis was divided into three steps: data filtering, step detection and determination of step parameters; these are elaborated in the next paragraphs. This procedure was followed for each leg sensor on each day (if sufficient data were available) for a limited interval during which the cow was walking.

Data filtering

The acceleration data appeared to be influenced by noise that was caused by effects like gravity, impacts on the node, imperfect alignment and the mass inertia of the node. The following procedure for filtering the acceleration data in forward, upward and sideward direction was implemented in GenStat (www.vsni.co.uk) to reduce the influence of the noise:

1. Acceleration values greater than +20 (≈ 2g) were cut off by +20 (to reduce the effects of incidental extreme values like 4g); acceleration values less than -20 (≈ -2g) were cut off by -20 for the same reason.
2. A median filter was applied: for each measurement the median was taken from five values: two preceding, the current and two subsequent values (also to reduce the effects of outliers).
3. A moving average filter was applied based on three median values: the current and two preceding values (to further reduce the effects of outliers).
4. The filtered acceleration data were corrected by their mean value (to reduce the effects of a non-perfect calibration).

Step detection

The filtered acceleration data were used to detect steps in the data (this paragraph) and subsequently to determine parameters for these steps (next paragraph). A modified variance analysis was applied to detect steps:

1. For each measurement the average of the squared filtered acceleration in forward, upward and sideward direction was taken over 20 values: 10 preceding, the current and 9 subsequent accelerations.
2. The average squares in forward, upward and sideward direction were summed to get a total square per measurement.
3. An arbitrary threshold was calculated by taking 7% of the maximum value of all summed squares (each over 20 values). This threshold had no theoretically basis but was found by trial and error and appeared to give satisfactory results.
4. Measurements were divided into 'move time' or 'contact time' based on a comparison of the total square and the threshold:

- total squares larger than the threshold were classified as move time;
- total squares smaller than or equal to the threshold were classified as contact time.

5. A contact time lasting less than 10 measurements (= 0.2 second) was considered as unrealistic and was reclassified as move time. This correction was added to get rid of sudden short drops in a step.

A *step* was defined as a series of consecutive measurements that were classified as move time.

Step parameters

The detected steps were the basis for the calculation of the parameters per step to characterize the cow's locomotion. Two parameters were included in the current analysis: step length and step time.

Step length: The step detection procedure resulted in a division of the time in step time and contact time. The step times were periods in which a step is taken. These could not be the exact times of the steps since they were based on averaged squares over 20 values of filtered data. Therefore this interval was adjusted based on a priori knowledge that a step can be divided into an acceleration period (start-up) and a deceleration period (completion):

- If the forward acceleration exceeded a threshold value at the start of the step period, then the start was advanced back in time till the forward acceleration was below the threshold (at most 20 measurements). This was done because the acceleration should be zero at the beginning of a step.
- If the forward acceleration was below a threshold value at the start of the step period, then the start was delayed till the forward acceleration was above the threshold (at most 20 measurements). This was done for the same reason.
- If the forward acceleration was above a threshold value at the end of the step period, then the start was advanced till the forward acceleration was below the threshold (at most 20 measurements). This was done because the acceleration is zero at the end of a step.

The threshold value was taken arbitrarily as 1% of the maximum value of the summed squares in the forward acceleration. In this way an improved value of the start and end time per step was determined with the acceleration increasing from zero at the start and returning to zero at the end. A simple numerical integration procedure was used to compute first the speed based on the acceleration data and second the displacement based on the speed. The integration was performed for each step starting with zero speed at the beginning of each step and with the displacement at the end of the previous step.

Step time: The step detection procedure resulted in steps based on move and contact time. The begin and end time per step were derived for the determination of the step length. These results were also used to derive the step time per step by taking the difference of the adjusted end time and start time.

Results

Data filtering

The main elements in the data filtering procedure as described in the previous paragraph were the successive application of the median filter and the moving average filter. To illustrate the effects the data of a node are depicted in Figure 3 (before) and Figure 4 (after the median and moving average filter). The graphs in Figure 4 are clearly smoother with less outliers.

Step detection

The results of the step detection method based on a modified variance analysis method for Node 4 on 2 July 2008 are depicted in Figure 5 and 6. The time is divided into move and contact time based on the average of the total squares (Figure 5). The block structure of the step function corresponds clearly with the peaks of steps of a cow. This block graph is combined with the filtered data in

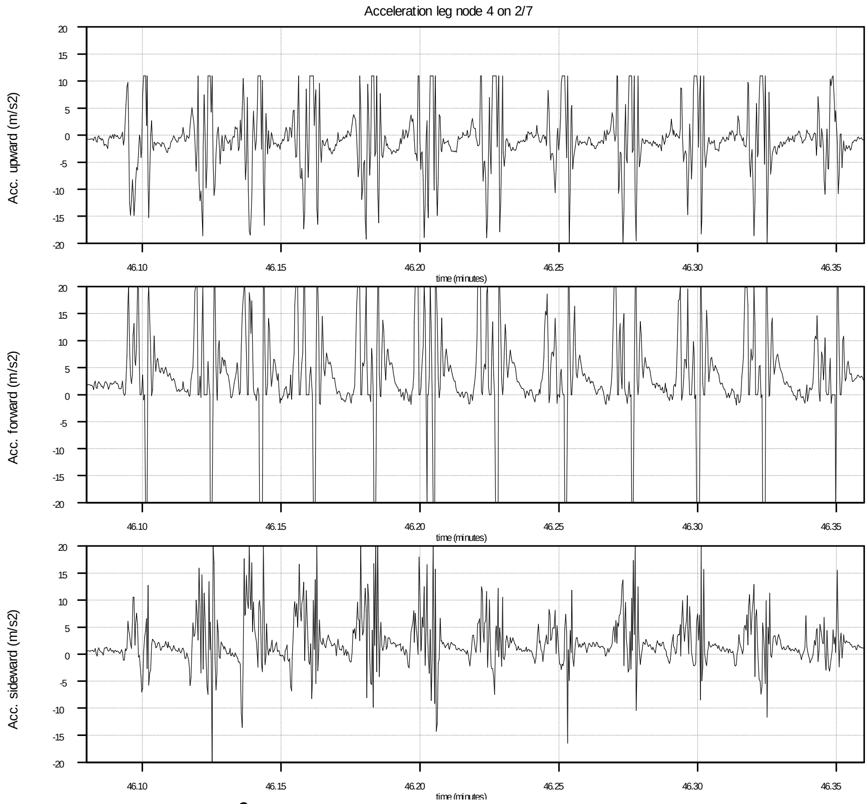

Figure 3. Acceleration data (in m/s^2) of Node 4 attached to the right hind leg of Cow 263 on 2 July 2008 during 12 steps before filtering in upward (upper graph), forward (middle) and sideward direction (lower) against time (in minutes).

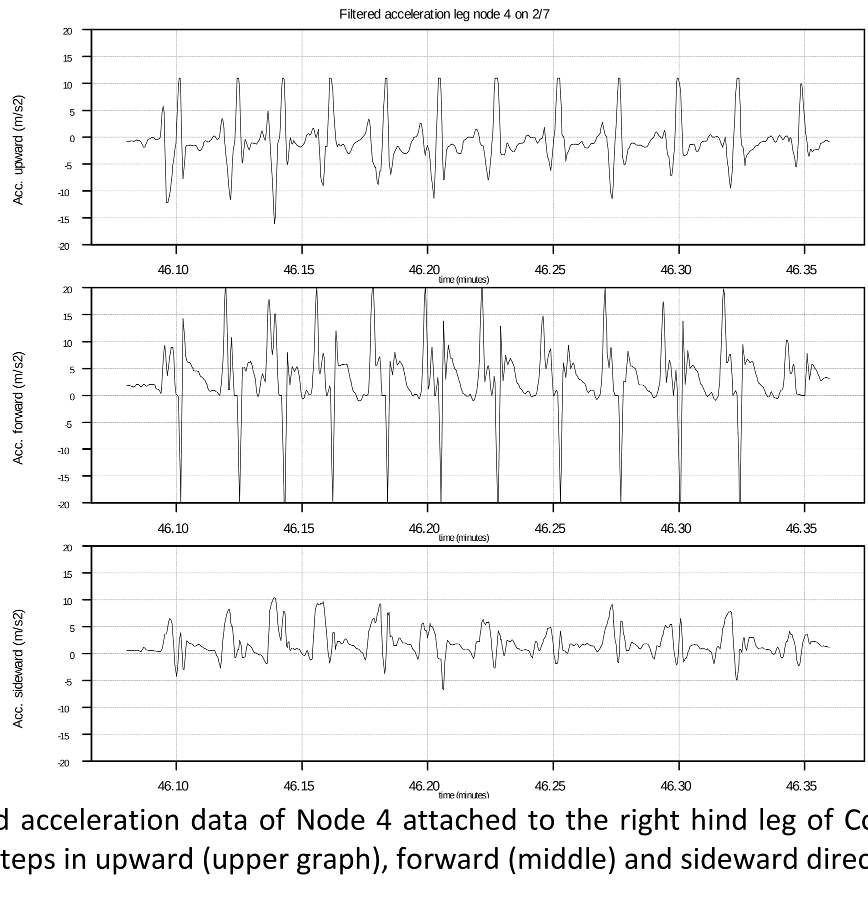

Figure 4. Filtered acceleration data of Node 4 attached to the right hind leg of Cow 263 on 2 July 2008 during 12 steps in upward (upper graph), forward (middle) and sideward direction (lower).

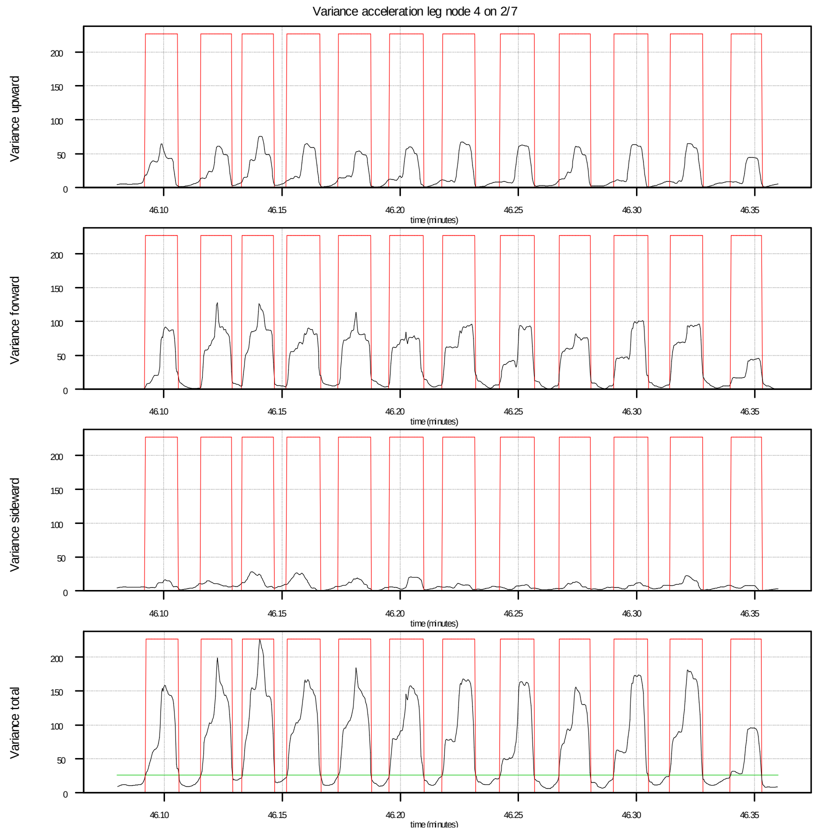

Figure 5. Results of the step detection method based on a variant of the variance analysis for Node 4 attached to the right hind leg of Cow 263 on 2 July 2008 during 12 steps with average squares (upper = upward, second = forward, third = sideward, lowest = total), move/contact time (block diagram) based on threshold level in lowest graph.

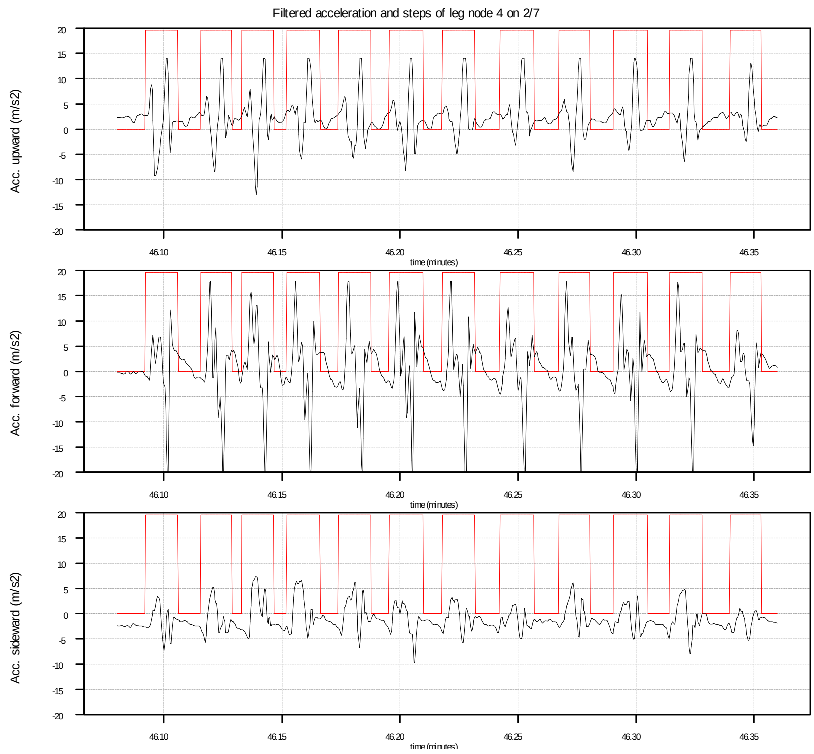

Figure 6. Filtered acceleration data of Node 4 attached to the right hind leg of Cow 263 on 2 July 2008 during 12 steps as in Figure 4 in upward (upper graph), forward (middle) and sideward direction (lower) with block diagrams representing the derived steps.

Figure 4, resulting in Figure 6, which shows that the block structure also corresponds to the peaks and dips in the forward acceleration.

Step parameters

Per node and per day the number of steps were determined, as well as the step length and the step time. A survey of the results in given in Table 1.

In Table 1 results are given per cow and day by taking the average over all steps:

- Length: determined step length based on acceleration and derived speed.
- Maximum speed: maximum of the derived speed during a step.
- Speed at end of step: derived speed at the end of the step (should be zero with perfect measurements).
- Time: time needed for the step.

Table 1 also contains total results:

- Average speed: sum of lengths of all steps divided by time difference between beginning of first step and last step.

No valid measurements were available from Node 98 at 3/7, so no step parameters were available then. Parameter values from Node 98 on the other days were available but appeared to be deviating (especially at 2/7, e.g. average speed).

Discussion and conclusions

The first step of the data analysis was the step detection. Some remarks can be given on the step detection method described in materials and methods paragraph:

The sum of 20 values of the squared accelerations was used in the first step. This number was based on a comparison of the frequency of measuring and walking: 20 measurements with a frequency of 50 Hz imply a period of 0.4 second, which should be enough to distinguish steps, given the knowledge that a cow takes 0.6 steps per second (Phillips and Morris, 2000).

Table 1. Determined step parameters per day and totals per leg node (grouped per cow, see text for explanation).

Cow	Day	Node	Number of steps	Average over all steps				Total results
				Length (m)	Maximum speed (m/s)	Speed at end of step (m/s)	Time (s)	Average speed (m/s)
263	2-7	*4*	12	0.64	1.95	0.26	0.60	0.49
	3-7	*4*	12	0.58	1.99	-0.03	0.53	0.49
	4-7	*5*	10	0.54	1.67	-0.20	0.58	0.41
409	2-7	*5*	10	0.49	1.74	-0.20	0.56	0.39
	3-7	*98**	n/a	n/a	n/a	n/a	n/a	n/a
	4-7	*98*	9	0.60	1.80	-0.18	0.63	0.41
429	2-7	*98*	7	0.42	1.25	0.28	0.67	0.19
	3-7	*5*	17	0.56	1.74	0.05	0.56	0.43
	4-7	*4*	8	0.54	1.91	-0.34	0.56	0.36

* No measurement data available due to malfunctioning of the node

The squares in all directions have been used for the step detection and not only the squares in forward direction to detect a forward step to take into account a possible displacement of the leg node. If the node is twisted around the leg, the expected relations with forward, upward and sideward direction may be faulty.

Variance analysis was used here for step detection, other methods like Fast Fourier Transform (FFT) might also be used and could provide an alternative method.

The second step was the calculation of step parameters, results were given for step time and step length. It is recommended to evaluate more parameters, e.g. the contact time (see material and methods) or new parameters like symmetry and regularity index (Barrey, 1999).

There were no apparent differences between the results per cow in Table 1; deviating results might be expected for Cow 263 because of lameness. Other methods might be more useful to generate more discriminating results based on the characteristics of the acceleration curves (like in Barrey, 1999).

The resulting step parameters in Table 1 have not yet been compared with the videos of the experiment. A comparison of the results can give an indication of the quality of the resulting parameters if time synchronization of the measurements and the video is possible.

The derived step length and average speed Table 1 were lower than expected, e.g. in Song *et al.* (2008) the step length was somewhere between 1 and 2 m and it was between 1.35 and 1.66 m (depending on floor type) in Phillips and Morris (2000). The derived step time did conform to values from literature.

Acceleration was not only measured with the leg nodes but also with nodes attached underneath the mouth. The results of these head nodes were not used in the analysis since a clear relation with the steps of the cow was not visible in the graphs (like Figure 3). A thorough analysis of the head nodes data might result in a relation.

The analysis of the acceleration was restricted to relatively short walking intervals. It should be checked whether an analysis over the whole recorded interval gives similar results.

The results of the step detection procedure and the step parameters derivations depend on the chosen thresholds (see point 3 of step detection and step parameters in material and methods). Both parameters were chosen arbitrarily and depend on the maximum squares per node. More tests are needed to verify that these thresholds are generally applicable. If the first threshold is too low, the successive steps are not distinguished. If the threshold is too high, then steps might be missed.

Acceleration was measured only for the right hind leg of cows, further research is needed to find out whether one leg is sufficient for lameness detection and to choose the most appropriate leg.

It can be concluded that measuring locomotion with accelerometers in a wireless sensor network gives promising results. Step detection is possible and step parameters can be derived. Further research is needed to validate the methods, to improve the step parameters and to determine differences between lame and non-lame cows.

Acknowledgements

A large part of the data analysis methods was developed by Rudie Lammers during his Master's thesis for the Farm Technology Group of Wageningen University. The applicability of the median filter and the moving average filter as described in the data filtering (material and methods) was assessed by him. The step detection method described here is a variant of the method in the Master's thesis where the variance was used instead of the average square.

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