Spatiotemporal Quadruped Gait Analysis based on Pressure Mat Data – Preliminary Results
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Abstract
Quadruped (animal) gait analysis has been a research topic for decades. Up to now however, none of these techniques has been fully adopted in commercial animal husbandry. Due to increasing lameness problems associated with intensifying cattle production, several techniques are currently being developed to detect these problems. This paper focuses on measuring spatial and temporal characteristics of the quadruped (cow) walk using a pressure sensitive mat.

In a herd of 92 cows, the gait was measured 11 times during 6 weeks in August and September 2007. The system was placed in a 1.2 m wide and 6 m long area of an alley connecting the milking parlour with the grazing area. For each walk, the location of each contact point between the cow and the pressure sensitive mat, together with the time and (relative) pressure of contact was measured.

Both the handling of the raw data and the following spatiotemporal analysis is elaborated in this paper. It will be shown that existent kinematic properties can be calculated out of measured distances between pairs of hoof imprints in XYT-space if at least one complete gait cycle is considered.

Introduction
Next to human gait analysis, quadruped (animal) gait analysis has been a research topic for decades. Up to now however, none of these techniques has been fully adopted in commercial animal husbandry. Due to increasing lameness problems associated with intensifying cattle production, several techniques are currently being developed to detect these problems. Changes in individual cow activity and stance or walking behaviour are regarded in this perspective. Tasch and Rajkondawar (2004) developed a walk-over force plate detection system and Pastell (2006) measures the weight distribution on the hind legs in a milking robot. This paper focuses on measuring spatial and temporal characteristics of the quadruped (cow) walk using a pressure sensitive mat.
Materials and methods
A commercially available sensor (CIR Systems, Inc.) was put in a waterproof sealing and mechanically protected by a rubber mat for animal use (hammered surface stable mat). The active surface area of the sensor is 4.88 m long and 0.61 m wide with 12.7 mm resolution in both ways.

As shown in figure 1, the measurement system was placed at the ILVO research farm in a 1.2 m wide and 6 m long area of an alley connecting the milking parlour with the grazing area. After the morning milking routine, roughly half of a 92 cow herd was guided over the system at 11 measurement days in summer 2007.

![Figure 1. The pressure sensitive system with protective cover. The actual pressure sensitive area is located in the middle and is 4.88 m long and 0.61 m wide.](image)

Data conditioning and analysis was done using Matlab® (Mathworks, Inc.). A first representation of the available data of one single measurement is given in figure 2a. The position (x, y) of each contact between the cow and the mat is sampled at 60 Hz and is given together with the time (t) and (relative) pressure (p) exerted. The data represented by the dots (recorded contact points) in figure 2a, is arranged as an array of (t, x, y, p)-records.

In order to calculate any hoof attribute value or kinematic variable, each (x, y, t, p)-record needs to be linked to a particular hoof imprint. The result of this can be seen in figure 2b and 2c. Figure 2c is the most easy to understand as it leaves out the temporal dimension and as such it resembles the footprints left by a cow on the floor. Records belonging to a particular hoof imprint are given a hoof imprint serial number (s) and a hoof type identification number (h). Now, for each hoof imprint, all (x, y, t, p, s, h)-records can be addressed and their average values (e.g. \( \bar{x} \), \( \bar{y} \) and \( \bar{t} \)) can be calculated.
Figure 2. Raw data of one single cow. Each hoof imprint is measured about three times. In figure 2a (left), blue dots represent lower pressures red dots mean higher pressures. The colours in figure 2b (right) and 2c (bottom) indicate the hoof type: Red: RF; black: RH; yellow: LF; green: LH. A more schematic representation is given in figure 3.

Kinematic (quadruped) gait analysis in literature focuses on measuring stride length, stride time, step time, tracking distance, etc. The large number of spatiotemporal variables measured in this research increases the need for a systematic approach. In fact, most of these measures can simply be considered as distances between two hoof imprints in XYT-space. All possible distances between sequential hooves (represented by their mean x, y and t coordinate) within a complete gait cycle were considered.

The sequence used in this research is a combination of a sequence along increasing time and one along increasing longitudinal position. In this case, a hind hoof always follows a front hoof immediately and this pattern steadily repeats for the left and the right side. This results in a sequence "...", [LF, LH, RF, RH], [LF, LH, RF, RH], [LF, LH, RF, RH], [...]. For every distance between
hooves listed in table 2, the considered first and second hoof according to this sequence is shown by the vectors in figure 3. For demonstrative purposes, each imprint is only seen twice in figure 3. As can be seen in figure 2, more imprints are available and most vectors considered in table 2 can be calculated at least twice. Average values are calculated and listed in table 2.

Figure 3. Vectors according to the used sequence starting from LH (fig. 3a, top left), LF (fig. 3b, top right), RH (fig. 3c, bottom left) or RF (fig. 3d, bottom right). The colour coding is the same as in figure 3: Red: RF; black: RH; yellow: LF; green.

**Results**

During the experiments, approximately 20 % of the cows was either running, accelerating (slowing down or speeding up), slipped or stopped during the measurement. Table 1 shows in how many cases these measurements and the subsequent automatic identification of the hoof imprint pattern was successful.

Bad measurements occur when two cows are on the pressure sensitive mat at the same time, when a cow is on (or already past) the pressure sensitive mat before the
measurements could start, when a cow number is missing or when any hardware malfunction occurs (e.g. short circuitry, too many accidentally triggered sensors, etc.). A bad hoof pattern identification occurred when the algorithm mentioned above failed to work properly.

Table 1. Overview of measurement success rates. Approximately 70 % of all cow passes resulted in a correct footfall identification suitable for further kinematic analysis.

<table>
<thead>
<tr>
<th>Identification</th>
<th>Cow walks (560 = 100 %)</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>good (80 %)</td>
<td>good (75 %)</td>
</tr>
<tr>
<td></td>
<td>bad (20 %)</td>
<td>bad (5 %)</td>
</tr>
<tr>
<td></td>
<td>70 %</td>
<td>1 %</td>
</tr>
<tr>
<td></td>
<td>5 %</td>
<td>4 %</td>
</tr>
<tr>
<td></td>
<td>Measurement</td>
<td>Measurement</td>
</tr>
<tr>
<td></td>
<td>good (72 %)</td>
<td>good (10 %)</td>
</tr>
<tr>
<td></td>
<td>bad (28 %)</td>
<td>bad (10 %)</td>
</tr>
<tr>
<td></td>
<td>1 %</td>
<td>0 %</td>
</tr>
<tr>
<td></td>
<td>9 %</td>
<td>10 %</td>
</tr>
</tbody>
</table>

A typical result of a between-hoof analysis can be seen in table 2. All between-hoof distances in XYT-space (as shown in figure 3) are shown for one cow walk. Among others, stride time (or cadence⁻¹) and length (*), step time and length (°), tracking distance (**) and step abduction (°°) can be seen. Other features as lateral time and diagonal time can be seen (^) or calculated from the table (^^) respectively.

Table 2. Different distances in x [m], y [m] and t [s] within a gait cycle for one typical cow walk. The vector names are in the 4th (bottom right) section and in figure 3.

<table>
<thead>
<tr>
<th>( \tilde{x}_2 - \tilde{x}_1 )</th>
<th>to 2nd hoof type...</th>
<th>( \tilde{y}_2 - \tilde{y}_1 )</th>
<th>to 2nd hoof type...</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH</td>
<td>0.02</td>
<td>LH</td>
<td>1.63*</td>
</tr>
<tr>
<td>LF</td>
<td>0.05°°</td>
<td>LF</td>
<td>1.47*</td>
</tr>
<tr>
<td>RH</td>
<td>-0.21</td>
<td>RH</td>
<td>0.80°</td>
</tr>
<tr>
<td>RF</td>
<td>-0.14</td>
<td>RH</td>
<td>0.84</td>
</tr>
</tbody>
</table>

With figure 3a-d, one can see that each vector can be calculated as the sum of two or more other vectors. Basically, as long as they are connected, only four vectors (e.g. a, b, c and d) are needed to calculate any between-hoof distance in XYT-space. A graphical representation of the between-hoof distances for all measured cow walks is shown in figure 4.
The between-hoof distances in XYT-space for all measured cow walks. The plot is similar to the drawing in figure 3a. The centre of the LH imprint is at the origin and distances to a successive LH, LF, RH and RF are given together with their 95% confidence ellipsoid.

The stance time is seen as a within-hoof temporal kinematic variable and is calculated as \( t_{\text{max}} - t_{\text{min}} \) within all records belonging to a single hoof. It can be seen as the “height” of a hoof imprint in XYT-space. Other within-hoof variables (e.g. mean pressure, mean contact area, etc.) are calculated but are left out in this spatiotemporal analysis. Other conventional temporal variables (e.g. the triple and double support time and the duty cycle) can be calculated using stance time and the aforementioned between-hoof temporal variables.
Discussion and Future Work
These techniques are being developed for cattle lameness monitoring, so further automation of the measurement procedure is needed to measure each cow on a daily basis. Both cow behaviour (during measurement) and hardware performance could be improved and together with an improvement of the hoof-identification software, an overall success rate of 90 % is within reach.

Several techniques for time series analysis can be applied to the data. Including the measured pressures beneath each hoof could enhance selectivity and/or specificity, but is left out in this discussion. If sufficient, the measurement of spatial and temporal variables only could be accomplished with a sensor mat of a more robust, simplified and cheaper design (Middleton et al., 2005).

The arithmetic mean of the coordinates of all records belonging to each hoof imprint in XYT-space is used to calculate between-hoof relations. Other research uses a distinguishable part of the hoof imprint as a “landmark” for spatial relations (Telezhenko and Bergsten, 2005) or the “hoof strike” (or “hoof-off”) event for temporal relations (Flower et al., 2005).

It is shown that each measured cow walk can be stored in 12 between-hoof variables (4 vectors in XYT-space) and 4 within-hoof variables (stance time for each hoof), eliminating the redundancy in conventional spatiotemporal terminology. The vector representation of XYT-walkway patterns enables to join the spatial and temporal information content of hoof placement during quadruped walking gait. Its possibilities to represent other gaits (e.g. assymetrical gaits, biped/hexapod gaits, etc.) is still to be explored.

References


