Automated detection of lameness in dairy cows based on day-to-day variation in behaviour
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Presentation

- Material & methods
- Data analysis
  - Modelling
  - Alerts
- Results
  - 2010/2011 Data collection
  - 2012 Live test
    - Procedures
    - Results
- Discussion & conclusions
Material & Methods

Project goal:

Development of methods to monitor behaviour and health in dairy cows automatically with sensors:

1. Lameness detection with activity sensors?
2. Oestrus and mastitis detection improved with activity sensors?

Application of IceTags for behaviour recording

Data collected at Dairy Campus:
- in 2010/2011: used for model development
- January-April 2012: Live Test of developed model
M&M: available data

- **Icetags (per cow per day):**
  - number of lying bouts
  - number of standing bouts
  - lying time (part of day)
  - standing time (part of day)
  - maximal length of lying bout
  - maximal length of standing bout
  - minimal length of lying bout
  - minimal length of standing bout
  - motion index
  - number of steps

- **Milk robot data (per visit):**
  - yield (per quarter)
  - electrical conductivity per quarter
  - action: milked or refused

- **Process computer data (per day):**
  - concentrate ration, intake and remainder

- **Milk test data (per test day):**
  - fat & protein percentage

- **Cow data:**
  - calving dates, lactation number
  - cases of oestrus, insemination, diseases
  - locomotion scores, condition scores
M&M: used data (1/2)

- Icetags (per cow per day), 7 variables:
  - number of lying bouts
  - number of standing bouts = number of lying bouts ± 1
  - lying time (part of day)
  - standing time (part of day) = 1 - lying time
  - logarithm of maximal length of lying bout = normally distributed\(^1\)
  - logarithm of maximal length of standing bout = normally distributed\(^1\)
  - minimal length of lying bout =
  - minimal length of standing bout =
  - motion index = number of steps * factor\(^2\)
  - logarithm of number of steps = normally distributed\(^1\)
  - logarithm of average length of lying bout\(^3\) = normally distributed\(^1\)
  - logarithm of average length of standing bout\(^4\) = normally distributed\(^1\)

\(^1\) results from Q-Q plots
\(^2\) results from PCP & scatter plots; other variables have added value
\(^3\) number of lying bouts/lying time, \(^4\) same for standing
M&M: used data (2/2)

- Milk robot data (per visit):
  - yield (per quarter)
  - electrical conductivity per quarter
  - action: milked or refused *not yet used*

- Process computer data (per day):
  - concentrate ration, intake and remainder

- Milk test data (per test day):
  - fat & protein percentage

- Cow data:
  - calving dates, lactation number *only in titles of graphs, not in data analysis*
  - cases of oestrus, insemination, diseases *only for analysis of detection results*
  - locomotion scores = *used to define lameness cases, condition scores*
Data analysis: Modelling

Dynamic Linear Models (DLM) used to model variables:

- linear: output directly proportional to input
- dynamic: model parameters change in time

Theory & software available

DLMs used to detect:

- outliers: unexpected event is happening
- trend changes: characteristics are changing
Data analysis: Modelling

DLM for:

- lying time
- number of lying bouts
- maximal lying bout
- average lying bout
- maximal standing bout
- average standing bout
- number of steps
- daily milk yield
- concentrate remainders
- conductivity left front
- conductivity left hind
- conductivity right front
- conductivity right hind

conductivity: linear trend model, gives level & trend
other variables: quadratic trend model, gives level, trend & slope
Data analysis

example:
nine graphs for cow 612/lactation 3

horizontal axis:
day since 1/1/2010
Data analysis: Alerts

Alerts per cow & per day for:

- **Lameness**
  1. non-zero trend in one or more activity variables (or $\geq 3$ outliers in one week)
  2. non-zero trend in concentrate remainder $\geq 3$ outliers in milk in one week

- **Oestrous**
  1. outlier in steps
  2. outliers in other variables

- **Mastitis**
  1. outlier in (one or more) conductivity
  2. outliers in other variables
# Data analysis: Lameness alerts

<table>
<thead>
<tr>
<th>variable</th>
<th>direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>lying time</td>
<td>↑</td>
</tr>
<tr>
<td>number of lying bouts</td>
<td>↑↑↓</td>
</tr>
<tr>
<td>maximal lying bout</td>
<td>↑</td>
</tr>
<tr>
<td>average lying bout</td>
<td>↑</td>
</tr>
<tr>
<td>maximal standing bout</td>
<td>↓</td>
</tr>
<tr>
<td>average standing bout</td>
<td>↓</td>
</tr>
<tr>
<td>number of steps</td>
<td>↓</td>
</tr>
<tr>
<td>milk yield</td>
<td>↓</td>
</tr>
<tr>
<td>concentrate remainder</td>
<td>↑</td>
</tr>
<tr>
<td>conductivity</td>
<td></td>
</tr>
</tbody>
</table>

Lameness alert in case of a non-zero trend in 2 or more variables.
# Data analysis: Oestrus alerts

<table>
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<tbody>
<tr>
<td>lying time</td>
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<tr>
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<td>↓</td>
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<td>↓</td>
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<td>↑</td>
</tr>
<tr>
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<td>↓</td>
</tr>
<tr>
<td>concentrate remainder</td>
<td>↑</td>
</tr>
<tr>
<td>conductivity</td>
<td></td>
</tr>
</tbody>
</table>

**oestrus alert in case of an outlier in steps (& other variables)**
### Data analysis: Mastitis alerts

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</tr>
<tr>
<td>average lying bout</td>
<td>↓</td>
</tr>
<tr>
<td>maximal standing bout</td>
<td>↑</td>
</tr>
<tr>
<td>average standing bout</td>
<td>↑</td>
</tr>
<tr>
<td>number of steps</td>
<td>↑</td>
</tr>
<tr>
<td>milk yield</td>
<td>↓</td>
</tr>
<tr>
<td>concentrate remainder</td>
<td>↑</td>
</tr>
<tr>
<td>conductivity left front</td>
<td>↑</td>
</tr>
<tr>
<td>conductivity left hind</td>
<td>↑</td>
</tr>
<tr>
<td>conductivity right front</td>
<td>↑</td>
</tr>
<tr>
<td>conductivity right hind</td>
<td>↑</td>
</tr>
</tbody>
</table>

Mastitis alert in case of an outlier in at least one conductivity (& other variables)

Siivonen et al., 2011
Data analysis: Reference data

- Lameness:
  - locomotion score 3 or more (on a 1-5 scale) and preceding score less than 3
  - claw treatments not used
  - non-lame: locomotion score 1

- Oestrus:
  - observed & recorded cases of oestrus
  - recorded insemination cases

- Mastitis:
  - recorded clinical mastitis cases
### Data analysis: Alerts vs. reference data

#### Lameness alerts versus lameness cases

<table>
<thead>
<tr>
<th>alert \ reference</th>
<th>cow is lame</th>
<th>cow is not lame</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>alert for lameness</strong></td>
<td><strong>True Positive (TP)</strong></td>
<td><strong>False Positive (FP)</strong></td>
</tr>
<tr>
<td><strong>no alert for lameness</strong></td>
<td><strong>False Negative (FN)</strong></td>
<td><strong>True Negative (TN)</strong></td>
</tr>
</tbody>
</table>

Same for oestrus and mastitis
Data analysis: Alerts vs. reference data

any case is either TP or FN:

- lameness case is TP if one or more alerts in period since previous locomotion score (but period at least 14 days)
- oestrus case is TP if one or more alerts on oestrus day or preceding day
- mastitis case is TP if one or more alerts in week up to mastitis day

an alert outside these periods can be FP:

- lameness alert is FP if in period between two locomotion scores 1
- oestrus alert is FP if not on oestrus or preceding day
- mastitis alert is FP if not in week up to mastitis case and more than 4 days after any mastitis case
Data analysis: Alerts vs. reference data

Example Cow 938:

Reference = locomotion score (black)
Lame when 3 or more = at day 838 (=17-4-2012)
Data analysis: Alerts vs. reference data

Example Cow 938:

Reference = locomotion score (black)

Lame when 3 or more = at day 838 (2012-04-17)

Alerts = lameness alerts (red striped)

Alert level 2 or more

This lameness case is TP level = 6

number or alerts = 13

FP alerts at day 733-737

Orange dots = missing data
Data analysis: Missing cases

Evaluation of lameness/oestrus/mastitis cases

Cases with too much missing data to be classified when:

- **Lameness:**
  - < 50% of activity data available since preceding locomotion score OR
  - < 50% of activity data available in last week OR
  - < 2 days with activity data available during last 3 days

- **Oestrus:**
  - not all activity data available on oestrus day & preceding day

- **Mastitis:**
  - any missing conductivity on mastitis day or 6 preceding days OR
  - ≤ 2 conductivity data on mastitis day or preceding day OR
  - no activity data on mastitis day
Results: 2010/2011 data

survey of number of icetags

Only data from 1 Feb 2010 till 31 Dec 2011 used
Results: 2010/2011 data Lameness detection

- **85** lameness cases
- **68** determinable cases
- **17** indeterminable cases
- **59** TP cases
- **9** FN cases
- **35,187** determinable cow-days
- **31,158** TN cow-days
- **5,271** indeterminable cow-days
- **4,029** FP cow-days

- **40,458** non-lameness cow-days

- **sensitivity: 87%**
- **specificity: 88.55%**
- **average level: 3.54**
- **average number of alerts: 7.07**
Results: 2010/2011 data Lameness detection

Lameness alerts: contribution of each variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lameness</td>
<td>88</td>
<td>100</td>
</tr>
<tr>
<td>Lying time</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>Number of lying bouts</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>Maximum lying bout</td>
<td>62</td>
<td>94</td>
</tr>
<tr>
<td>Average lying bout</td>
<td>58</td>
<td>96</td>
</tr>
<tr>
<td>Maximum standing bout</td>
<td>56</td>
<td>96</td>
</tr>
<tr>
<td>Average standing bout</td>
<td>50</td>
<td>96</td>
</tr>
<tr>
<td>Number of steps</td>
<td>44</td>
<td>96</td>
</tr>
<tr>
<td>Milk yield</td>
<td>20</td>
<td>98</td>
</tr>
<tr>
<td>Concentrate remainder</td>
<td>12</td>
<td>98</td>
</tr>
</tbody>
</table>
Results: 2010/2011 data Oestrus detection

665 oestrus cases
- 521 determinable cases
- 144 indeterminable cases

61,000 non-oestrus cow-days
- 52,506 determinable cow-days
- 8,494 indeterminable cow-days

390 TP cases
131 FN cases
51,406 TN cow-days
1,100 FP cow-days

sensitivity: 75%
average level: 2.10
average number of alerts: 1.19
specificity: 97.91%
Results: 2010/2011 data Oestrous detection

Oestrous alerts: contribution of each variable

- Concentrate remainder
- Milk yield
- Number of steps
- Average standing bout
- Maximum standing bout
- Average lying bout
- Maximum lying bout
- Number of lying bouts
- Lying time
- Oestrus

Sensitivity (%):
- Oestrus: 90%
- Lying time: 50%
- Number of lying bouts: 10%
- Maximum lying bout: 10%
- Average lying bout: 10%
- Maximum standing bout: 20%
- Average standing bout: 20%
- Number of steps: 90%
- Milk yield: 90%
- Concentrate remainder: 90%

Specificity (%):
- All variables have specificity above 90%.
Results: 2010/2011 data Mastitis detection

72 mastitis cases
54 determinable cases
18 indeterminable cases

48 TP cases
6 FN cases

62,021 non-mastitis cow-days
61,564 determinable cow-days
457 indeterminable cow-days

59,817 TN cow-days
1,747 FP cow-days

sensitivity: 89%
average level: 2.73
average number of alerts: 2.38
specificity: 97.16%
Results: 2010/2011 data Mastitis detection

Mastitis alerts: contribution of each variable

sensitivity (%)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>mastitis</td>
<td></td>
</tr>
<tr>
<td>lying time</td>
<td></td>
</tr>
<tr>
<td>number of lying bouts</td>
<td></td>
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<tr>
<td>maximum lying bout</td>
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</table>

specificity (%)
Results Live test: procedures

Live test to check the alerts as if they were available daily

- **Every Tuesday in January-April 2012:**
  - make data available for software
  - run DLM models
  - generate alert list
  - send alert list to farm

- **Every Wednesday:**
  - check alerts at the farm:
    - lameness: new locomotion scores for alerted cows
    - oestrus: cow status, last known oestrus case
    - mastitis: check cow

- **Every Thursday:**
  - return annotated alert list
Results Live test: example alert list

Per cow and per day alerts for:

- lameness
- mastitis (with quarter)
- oestrus
Results Live test: example annotated alert list
every alert: TP or FP with remarks from herdsman
Results Live test: practical problems

- Storage of parameter values of DLM models in database for next-week run
- Model calculations for short intervals
- Missing data on last available day
- Run-time errors in case of incomplete data
- Udder with three teats
- Different data not available for same period
- Errors in cow-tag bookkeeping
- ...
Results: Live test 2012 Lameness detection

- **15** lameness cases
- **0** indeterminable cases
- **8,162** non-lameness cow-days
- **7,986** determinable cow-days
- **176** indeterminable cow-days
- **12** TP cases
- **3** FN cases
- **7,173** TN cow-days
- **813** FP cow-days

- Sensitivity: 80%
- Specificity: 89.82%
- Average level: 3.50
- Average number of alerts: 5.67

2010/2011: 87%/3.54/7.07
2010/2011: 88.55%
Results: Live test 2012 Oestrus detection

117 oestrus cases
- 115 determinable cases
- 2 indeterminable cases

93 TP cases
22 FN cases

10,453 non-oestrus cow-days
- 10,242 determinable cow-days
- 211 indeterminable cow-days

10,017 TN cow-days
225 FP cow-days

Sensitivity: 81%
Specificity: 97.80%
Average level: 2.19
Average number of alerts: 1.25

2010/2011: 75%/2.10/1.19
2010/2011: 97.91%
Results: Live test 2012 Mastitis detection

- **13** mastitis cases
- **0** indeterminable cases
- **10,547** non-mastitis cow-days
- **10,447** determinable cow-days
- **100** indeterminable cow-days
- **13** TP cases
- **0** FN cases
- **10,217** TN cow-days
- **230** FP cow-days

Sensitivity: 100%
Specificity: 97.80%
Average level: 2.15
Average number of alerts: 1.92

2010/2011: 89%/2.73/2.38
2010/2011: 97.16%
Discussion

- Golden standard?
  - lameness: locomotion score or claw treatment
  - oestrus: sometimes incomplete, unrealistic
  - mastitis: treatment with udder balm = mastitis?

- Availability and performance of sensors?!

- Effects of missing data on performance?

- Setting of thresholds in DLM model?

- Presentation of alerts: 0/1 or alert level?

- Timeliness of alerts

...
Conclusions

- Performance in Live test similar to performance in 2010/2011
- Activity data can be used to detect changes in behaviour, therefore useful for lameness detection
- Activity data can be used to detect peaks in number of steps and other variables, therefore useful for oestrus detection
- Activity data can be used to detect additional changes in case of lameness, therefore useful for mastitis detection
- But only if sensor performance is okay
Questions?